Aluminium foam filled steel tubes as composite shock absorbers

R. Gradinger
Leichtmetall-Kompetenzzentrum Ranshofen (LKR), Austrian Research Centers Seibersdorf,
A-5282 Ranshofen, Austria
M. Seitzberger, F.G. Rammerstorfer
Vienna University of Technology, Institute of Lightweight Structures and Aerospace
Engineering, Gußhausstraße 27-29, A-1040 Vienna, Austria
H.P. Degischer
Vienna University of Technology, Institute of Material Science and Testing,
Karlsplatz 13, A-1040 Vienna, Austria
M. Blaimschein, Ch. Walch
VOEST-ALPINE STAHL Linz GmbH, VOEST-ALPINE Straße 3, A-4031 Linz, Austria

Abstract

The quasi-static axial crushing behaviour of shock absorbers composed of aluminium foam and steel tubes is investigated experimentally. Different designs are compared against each other – with special emphasis put on bitubal arrangements, which are shown to offer a particularly high potential with respect to the mass related energy absorption capacity.

1. Introduction

The uniaxial compression behaviour of aluminium foam comes close to that of an ideal shock absorber and makes this lightweight material suitable for energy absorption [Gibson and Ashby, 1997].

This investigation deals with the collapse behaviour of axially compressed thin-walled tubes (the latter currently being one of the practically used kinetic energy dissipating structures) combined with the advantageous characteristics of aluminium foam. The improvements with respect to the mean force levels and energy absorption capacity per unit mass are shown.

Experimental studies were carried out to analyse the potential of a new design version: the bitubal arrangement with one slender tube inside a wider one and the intervening space filled with aluminium foam. Various arrangements were investigated including square, hexagonal and octagonal steel tubes. For reference purposes unfilled bitubal and empty or filled monotubal samples were crushed, too.

J. Banhart, M.F. Ashby, N.A. Fleck: *Metal Foams and Porous Metal Structures.* © MIT Verlag (1999)

2. Specimen's preparation

Three different designs were investigated: empty steel tubes, monotubal samples (i.e. tubular members filled with aluminium foam) and bitubal sandwich specimens (empty as well as foam filled in the anulus between the inner and the outer tubes). These bitubal crush elements are a new kind of composition, consisting of two concentrically oriented profiles of different size having the same cross sectional shapes with foam in between. Regarding the materials and the geometry, the specimens can be divided into three groups:

Series I:	ZStE340 steel of length 100 mm and of square, hexagonal and octagonal cross sections, mean side lengths 28.5 mm, 20 mm and 15 mm, respectively, wall thickness 1.5 mm; empty and foam filled (average foam density ρ_f between 0.38 and 1.00 g/cm³); monotubal;
Series Z:	ZStE340 steel of length 250 mm and of square, hexagonal and octagonal cross sections, mean side lengths 64.5 mm, 40 mm and 30 mm, respectively, wall thickness 1.5 mm; empty and foam filled (ρ_f between 0.47 and 0.81 g/cm³); monotubal and bitubal arrangements (where for the inner profiles tubular members of test series I, having a length of 250 mm, are used);
Series S:	St37.2 steel of length 250 mm and of square cross section, side length 40 mm, wall thickness 1.5 mm; empty and foam filled (ρ_f between 0.37 and 0.68 g/cm³); monotubal and bitubal (with the inner profiles consisting of the same material, but having a side length of 20 mm).

The steel tubes of series S and I were filled with ALULIGHT™ aluminium foam precursor material and inserted into a foaming furnace. No special surface treatment was applied – neither to inhibit nor to advance metallurgical bonding between aluminium foam and steel tube. For comparison purposes some of the empty samples of series I and S were subjected to the same heat treatment as it happened to the filled tubes during the foaming process [Mepura, 1996]. The foam cores of the specimens of series Z were produced separately in a suitable die. For the bitubal square members some gluing was used to fix the foam cores and the steel profiles prior testing.

3. Testing

A universal testing machine was employed for carrying out the compression tests. The loading velocity was fixed at 1 mm/s. Except for the empty bitubal arrangements no clamping of the ends of the samples was provided.

3.1 Observations

Within test series I only the square tubes deformed in a progressive manner. The hexagonal and octagonal samples of this group mostly showed local buckling and – in case of foam filling – extensional folding with all lobes moving outwards.

The specimens of test series S deformed in a progressive manner. Only the empty monotubal samples, however, buckled inextensionally, the others changed from an extensional to an inextensional buckling mode during the deformation process.

The deformation behaviour of series Z was partly influenced by breaking of the welding seams. Whereas some empty square and hexagonal samples exhibited typical progressive buckling, all foam filled specimens of this test series, but also the empty octagonal ones formed local, but irregular folds.

All empty bitubal samples failed globally, which may be traced back to global buckling of the slender inner profile.

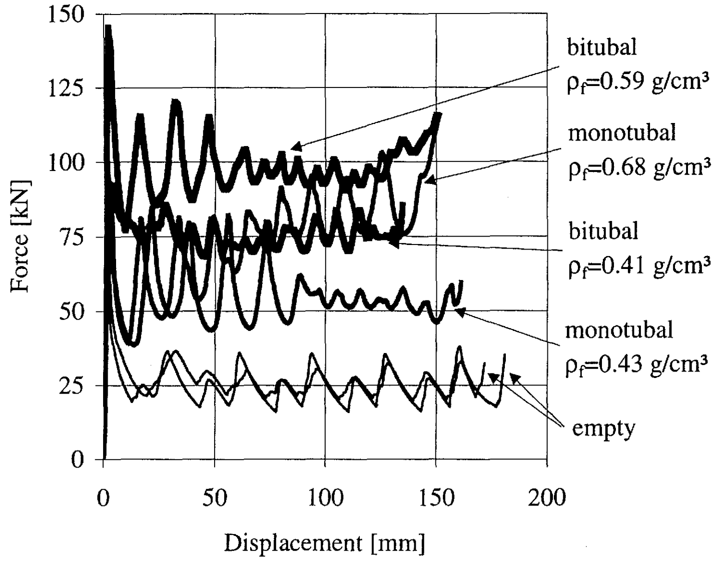

Figure 1: Compressive load vs. displacement curves of empty, monotubal and bitubal foam filled specimens of test series S.

4. Discussion of results

In accordance to theoretical predictions [Santosa and Wierzbicki, 1998] the test results reveal that foam filling leads to a marked increase of the crushing force levels, going beyond a simple addition of the axial force compression characteristics of the individual members. This is mainly caused by the activation of interaction effects, i.e. changes of the buckling modes of the tubes and multiaxial (instead of uniaxial) compression of the foam cores. These advantageous interaction effects can be even reinforced by bitubal arrangements. The presence of foam leads to increases of the plastic dissipation (owing to changed buckling modes) in both outer and inner profile, and even the foam core is subjected to much higher multiaxial compression, as compared to a monotubal filled member. These effects also become obvious from the sectioned samples shown in Figure 2.

Within a moderate range of apparent mass density aluminium foam as a filler material acts beneficially with respect to mass specific energy absorption of the whole crash element. However, too high foam densities may lead to unfavourable situations such as global buckling or extensional folding patterns, the latter being accompanied by increased force fluctuations.

Compared to the empty tubes maximum increases of the mean force efficiencies of more than 80% could be measured for the monotubal filled samples, if compared to the empty ones. These results were even topped by the bitubal specimens, verifying the suitability of the bitubal concept [Seitzberger et al., 1999]. Although the stroke efficiencies are reduced with foam filling, marked increases of the specific energy absorption capacity are also observed for the different test series, where maximum values of up to 60% could be measured for square test arrangements.

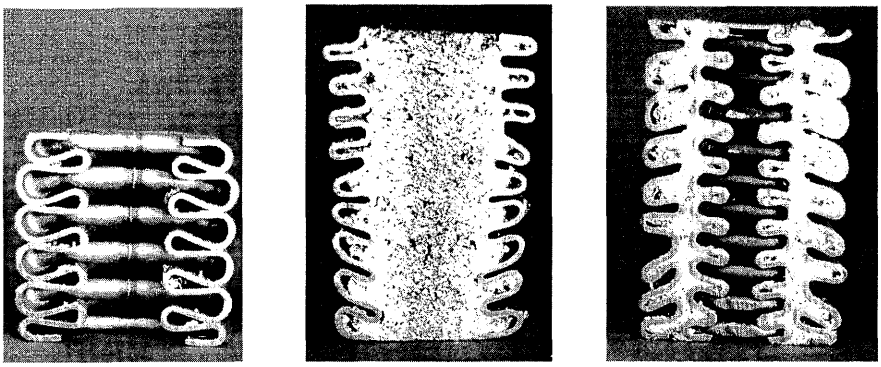

Figure 2: Axially cut, deformed specimens of test series S. From left to right: empty, monotubal (ρ_f = 0.43 g/cm^3) and bitubal (ρ_f = 0.45 g/cm^3) sample.

5. Summary

Compared to an independent parallel compression of foam core and steel tube the increase of the energy absorption capacity of foam-filled crush elements is essentially effected by two mechanisms. On the one hand the buckling lengths of the individual folds are shortened by the intrusion resistance of the foam core, causing a higher frequency of progressive buckling and leading to an increase in the energy dissipation due to increased plastic deformations. On the other hand the deformation capacity of the foam core is exploited not only by axial compression but also in lateral direction by locally intruding folds, leading to a multiaxial state of compression (and accordingly, higher energy dissipation) in the filler material.

The test results reveal that simple foam filling may considerably improve the mass specific energy absorption, if compared with empty monotubal members, where increases of up to 60% were measured. Even further increases can be observed for both the mean force efficiency and the specific energy absorption by applying bitubal shock absorbers. However, because the inner profiles should not exceed some critical slenderness, these bitubal composite shock absorbers seem to be advantageous mainly for applications, where higher mean force levels are to be used.

References

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