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Oblique Loading Effect for Automobile Bumpers

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Abstract: This paper introduces the multiple-objectives optimization of the double circular tube made of aluminium foam under oblique load for numerous parameters of load angle and geometry. Thin-walled metallic tubes are used for the absorption of impact energy in vehicle systems, for example in bumper beams. In this paper, the aluminium alloy'AA6063 T6' foam filled tube that was clamped at both ends, at the bottom as boundary condition and at the top, the tube is applied with quasi-static load angle force ranging from 0 degree to 30 degree with respect to longitudinal direction of tubes.The finite element analysis using'ABAQUS code' was validated based on the applicable experimental data, and the tubes deformation modes were analysed. Using the Particle Swarm optimization algorithm (PSO), multiple-objective optimization design of crush parameters such as minimum peak crushing force and maximum specific energy absorption was performed.Different optimum designs were detected for different loading angles and double circular tube geometries.

Keywords: Aluminium foam, bumper, beam, double circular tube, oblique loading/impact, PSO (Particle Swarm Optimization).

INTRODUCTION

The automotive industry now aims to increase the ability of systems to crash worthiness and to minimize vehicle weight for fuel protection. Simulation is chosen in this paper because physical testing is costly. Alexander *et al.* initially studied the behavior of tubes under axial load.This research was then continued by other scholars such as Reid *et al.*, who studied tube inversion and bending; and Jones et al., who concentrated on the variations between circular and square tubes that were subject to impact axial loading. Alghamdi *et al.* compared various collapsible energy absorbers, such as circular and square tubes, in different cross-sections.Several researchers filled thin-walled tubes with cellular material such as foams, in order to further increase energy absorption[1]. Pioneers in the study of empty and lined aluminum tubes were Seitzberger et al. Guo et al. studied axial and three-point bending of the experimental and numerical solutions of tubes. Subjected to oblique impact testing, Reyes *et al.* studied thin-walled aluminum [2]. Several researchers investigated thin-walled aluminum foam tubes for bumper beam, for example Li *et al.* This work utilized the numerical solution to analyze the crash-worthiness behavior of different loading angles subjected to a double pipeline.Instead, using particle swarm optimization (PSO), the result of finite element simulation was optimized [3].

Material and Methodology

Crash-worthiness: Requirements of Double Tube Subjected to Oblique impact

Some crash worthiness criteria for evaluating structure efficiency energy absorption include energy absorption (EA), specific energy absorption (SEA), mean crushing force (MCF), and peak crushing force (PCF). EA is defined as the total stress energy that was absorbed from the crushing force-deflection curve during deformation. EA is set out in equation 1.

$$\mathrm{EA(d)} = \int_0^d F(x)\,\mathrm{d}x \ldots (1)$$

Where d is the effective duration of the stroke and F(x) is the instantaneous crushing rate. SEA is defined as the energy absorbed ratio (EA) to the mass of the structure (Mt) and is given by the formula in equation 2.

$$\mathrm{SEA} = \mathrm{EA} / \mathrm{Mt} \qquad \ldots(2)$$

Finite Element Models of a Cylindrical Double Tube upon Subjection to Oblique loading:

Models of the cylindrical double tube are illustrated in figure 1.

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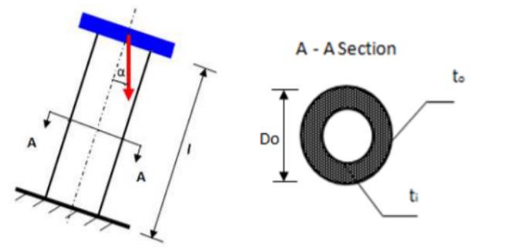

Fig. 1: Dimensions, boundary, and loading condition of aluminum-foam-filled double tube

Test length of double tube (Length= 210 mm), inner thickness' ti' and inner diameter ' Di' are 1.5 mm and 26 mm sequentially for modeling energy absorbing structures such as a passenger vehicle's bumper brace. Pipe ends were set at both ends. The bottom was the boundary condition, and oblique loading was imposed on the top of the drain. We found four loading angles in this model (θ1= 0 degree, θ2= 10 degrees, θ3= 20 degrees and θ4= 30 degrees). In the simulation the explicit finite element code 'ABAQUS' has been implemented [4].The circular tubes were modeled in Figure 2, with four Belytschko–Tsay node shell elements. For aluminum alloy, an elastic-plastic model was adopted while the closed-cell aluminum foam used the crush-able foam, which Deshpande and Fleck had developed.AA 6063 T4 aluminum alloy was modeled using a shell element, and solid elements were used to develop the foam. Two surfaces were added to the double cylinder pipeline. A constant velocity of 1 m / s was applied to oblique charge.

Material of Aluminum-Foam-Filled Cylindrical Double Tube

For the double circular loop, the AA6063 T6 was applied with the following material properties: density π=2700 kg / m3, Young's module E=68.2 Gpa, Poisson ratio v=0.3, initial yield stress πy=162 Mpa, and Ultimate stress πu=192 Mpa. By comparison, the properties of the foam are: density ÿ0= 2700 kg/m3 Cpow= 526 and m= 2,17.

Multiple-Objective optimization

This research aims to optimize double tube aluminum foam for optimum crash-worthiness efficiency i.e. maximum SEA and minimum PCF under axial and angular impact charge as illustrated in figure 2.

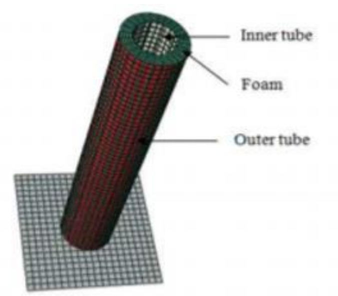

Fig. 2: Finite element model of cylindrical double tube

Multi-Objective Particle Swarm Optimization (MOPSO)

PSO's history is a population based optimization algorithm focused on flocking bird behavior. Among these algorithms was created the multiple objective Particle Swarm Optimization (MOPSO).The' MOPSO' algorithm requires low computational cost and rapid convergence, and it is able to get the best set of Pareto solutions close to the true Pareto form [5]. MATLAB implemented the MOPSO algorithm to produce the Pareto front of two opposing EA and PCF in separate multi-objective parameter optimization problems.

Results and Discussion

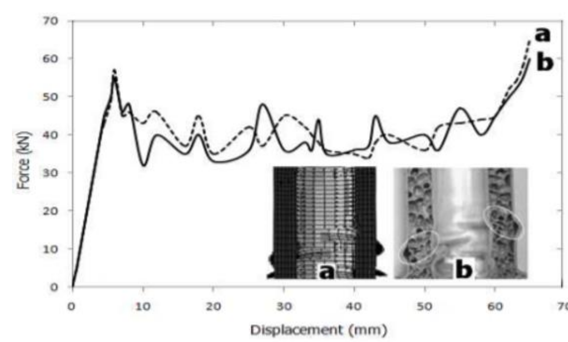

Fig. 3: Simulation Comparison of (a) and experiment results (b)

Validation is required to make sure that the results of the experiment match the derived data from the developed model. Li et al. used experimental results to present energy absorption of single, double, and empty tubes filled with aluminum-foam illustrated in figure 3.Figure 4 demonstrates the axial and angular loading crushing behavior(0 degree and 30 degrees). Absorption of energy

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affects the structure's pattern of deformation. Tubes under axial load caused behavior of deformation, such as collapse and crushing whereas on the other side of the tube, oblique impact is switched from mode of deformation to mode of bending [6].Through considering the parameters, the equations of multi-objective optimization of aluminum foam dual tube were obtained [7]. The maximum specific energy absorption energy (SAE) and minimum peak crushing force (PCF) were expected to be determined in the results. Two parameters are presented in this paper: outer thickness of wall tubes (to), and outer diameter of wall material (Do).

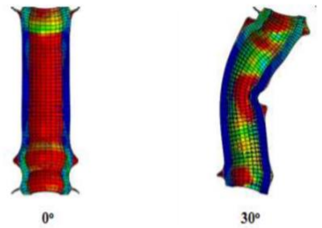

Fig. 4: Crash Behavior of Aluminum foam tube subjected to axial and angular impact

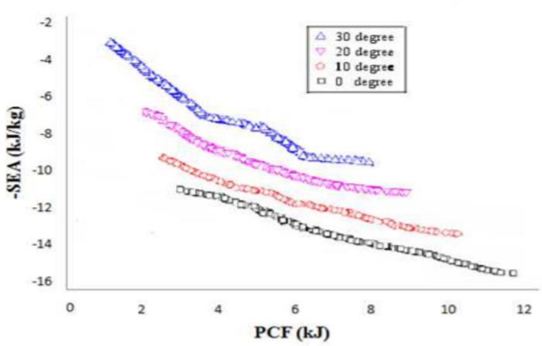

Fig. 5: Parento front for the PCF versus SEA

Table 1 and Figure 5 show the impact of the load angle on the performance of the crash-worthiness optimization for the double tube aluminum foam [8]. The maximum value of SEA on the axial impact on the other hand is the minimum PCF value on the oblique effect at 30° degrees. Increasing effects of load angle to decrease the load angle effects of SEA and PCF.

Table 1: Ideal optimums of the objective function for aluminum foam double tube subjected to Oblique loading

Impact angle [deg]	Objective function	t_o[mm]	D_o[mm]	SEA[kJ/kg]	PCF[kN]
0	Max SEA	2.65	42.43	15.65	11.96
	Min PCF	2.64	40.67	11.51	3.08
10	Max SEA	2.65	42.43	13.84	10.86
	Min PCF	2.71	40.59	9.84	2.87
20	Max SEA	2.29	42.43	11.06	9.13
	Min PCF	2.49	40.28	7.03	2.51
30	Max SEA	2.75	42.46	9.25	8.54
	Min PCF	2.19	40.15	2.97	1.04

CONCLUSION

This paper addressed the optimum conditions of cylindrical double tubes with aluminum foam subjected to oblique effect by taking into account different loading angles. To evaluate the maximum SEA and minimum PFC with varying thickness and diameter of the outer tube walls, the multi-objective optimization equation was formulated. PSO algorithm used the Pareto front has achieved optimum results. This thesis studied the optimization of double tube aluminum foam subjected to angular loading variation.With the increasing angle of impact it causes effects on the SEA and PCF which decrease the value. These results can be the basis for designers to implement this structure especially for the bumper beam of automobiles.

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