Optimization foam filled thin-walled structures for the crashworthiness capability: Review

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Abstract

In automotive industry, foam-filled structures have aroused increasing interest because of lightweight and capacity of energy absorption. Two types of foam filled thin walled structures such as the uniform foam filled (UF) and the functionally graded foam (FGF). To improve crashworthiness performance, FGF are used to fill structures, unlike existing uniform foam materials. In addition, by seeking for an optimal design systematically, some computational optimization signifies a more effective tool to find the best crashworthiness design of structures,. This paper will an exhaustive review of the previous studies of simulation-based optimization such as metamodels, objective functions, design variables, design of experiments, optimization techniques of crashworthiness of tubes.

Keywords: *Foam filled, Optimization, Crashworthiness, Thin walled structures, Uniform structure*

1. Introduction

The structure of modern vehicles are expected to absorb more energy and at the same time minimizing mass. To achieve this design, foam material has shown outstanding ability in absorbing energy because of large deformations in loading nearly constant [1]. To improve the stability of collosion and deformation modes of the structure thereby enhancing the overall crashworthiness, so foam filler material are used. The experiment of thin-walled tubes were investigated, it was found that the foam deformation mode with different of foam density [2]. Zhang et al [3] has been exploring of the structural designs of thin-walled room filled with aluminum foam. For the reason reducing not too much weight and increasing the crashworthiness capability, alumnium foam is the best criteria of material for automotive structures.

Conventional optimization requires a large number of iterations for an optimum form of limited practical value may, for example simulations of crash structure requires high computational cost. To address this problem, one of the most effective ways is to create a metamodel method based on finite element analysis [4]. Metamodel method can be derive the relationship objective function as output data from design variable as input data. It also expressions easier for optimization. Untill now, there are some kind of metamodel that have been developed in practical engineering. Different metamodel can provide the accuracy and the response is different [5].

Based on the brief introduction, this paper aims to review papers from reputable papers that study design optimization of crashworthiness for structures that filled by foam. Because of the capability in absorption energy, crashworthiness optimization design for Functionally Graded Foam (FGF) needs to more improve in future for in-stance its double structure under axial and oblique impact. The knowledge from review can be used to improve of the performance and utilization of structural materials using significant optimization in crashworthiness structures.

2. 2. Crashworthiness of Foam Filled Structures

3. 2.1 Uniform Foam (UF)

For collusion and crash analysis, some crashworthiness structures study and compare to find the superior structures (Figure 1). Thus, the basic concept of this theory have been studied extensively before developing a system of energy absorption. Structures under axial impact were studied such as for foam filled square tubes, circular tubes, hat tube, rectangular tapered tube, conical tube were studied [6-10]. However, structure filled by foam under different load angle was analyzed for example the crash behavior of square, circular, conical tube [11-13] containing foam under oblique loading. The combination of tubes and foam filler that play a role by changing the mode on the mode of failure is more effective for double tube [14-16].

2.2 Functionally Graded Foam (FGF)

In the previous study, the energy absorption performances of thin-walled structures having uniform thickness (UT) are extensively investigated. However, the UT tubes may not provide the best energy absorption capabilities. Indeed, the FGT enables to obtain variable stiffness along the structure [17]. As the new material, Functionally graded foam (FGF) depends on its density for its mechanical property. FGF proposes to absorb more energy and it is developed by density variation. However, in terms of design FGF more complex than UT. FGF has produced in laboratory by Kie-back et al. [18]. The crash capacity and characteristics of FGF was investigated [19] and it was concluded that the FGF can be perform more excellent than UT for the crashworthiness criteria. FGF filled tapered [20] as new type of foam was studied. It is limited published works discuss of FGF tube expecially behavior using experimental and simu-lation solution under oblique impact [21].

3. Optimization of Crashworthiness Issues

Generally, engineering design involves many disciplines and one of them is multi-objective optimization associated with many types of disciplines. Problems of design commonly known as the optimization problem multiple objectives and need for simultaneous consideration of all the objective function to optimize a system. Many solutions and existing methodology for optimization expecially optimization in component for the case related crashworthiness.

3.1 Crashworthiness Optimization for Bitubal Tube

It is increasing attention from the researchers, the advantage of bitubal tubes under oblique impact. To compared the energy absorption capacity of bi-tubular and tri-tubular configurations filled by tube of circular and square tubes by using simulation methode [22]. Using experimental and numerical solution testing, the bitubal tubes under bending conditions was investigated and it was indicated the superiority of the ability absorbing the energy [23]. In addition, with different arrangements under quasi- static axial compression loading using experimental and finite element analyses, Kashani [24] studied bitubular square thin-walled tubes. Li et al. [25] investigated the energy absorption of single and bitubal tube filled by foam under oblique loading. The crash capacity of foam-filled bitubular tubes is better than that of the empty and the single tubes.

Computer optimizations are used to attain the best and the more effective performance of crashworthiness of structures. The optimum of squared bitubal tube was studied by Zhang [26]. They depeloped the design of the crashworthiness optimization. it can be concluded that bitubal structure has a better crashworthiness than the foam-filled monotubal. The structure of foam filled double tube has a better crashworthiness than a single structure for automotive applications are studied by multi objective optimization design. Fang [27] performs the multiobjective robust design optimization (MORDO) method to explore the design of bitubal structures filled by foam. Futhermore, the optimization of the tubes under axial [28] and oblique [29] load and this bitubular structures can be implemented for the automobile bumper system.

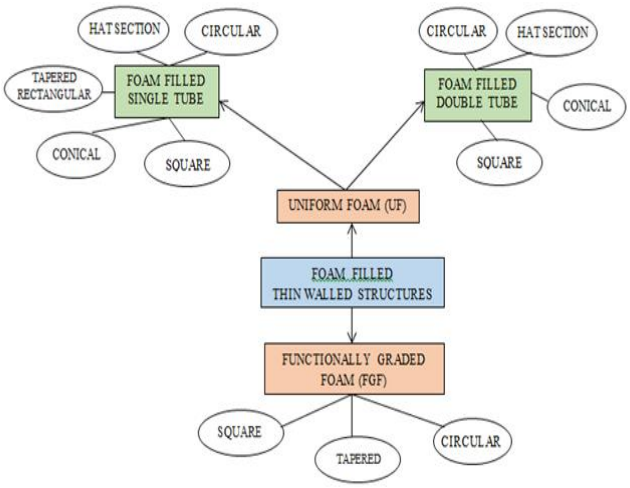

Fig1. Comparing of the UF and FGF structures

Table 1. The type of structures, materials, loading conditions and methods of crashworthiness tubes

Researchers	Structures	Materials	Loading Conditions	Design of Experiment	Meta model	Optimization Method
[38]	Square tubes	UF	Axial/Dynamic	D-optimal	Response surface method	Response surface method
[39]	squared columns	UF	Axial/Dynamic			Weighted arithmetical average method Geometrical average method
[40]	Hexagonal columns	UF	Axial/Dynamic	polynomial functions	Response surface method	
[41]	Tapered circular tubes	UF	Axial/Dynamic	Factorial design Latin Hypercube Sampling	Response surface method	Particle swarm optimization
[42]	Tapered square tubes	UF	Oblique/Dynamic	Full factorial design	Response surface method	Particle swarm optimization
[26]	Double square column	UF	Axial/Dynamic	D-optimal	Kriging	Genetic algorithm
[37]	Square columns	UF	Oblique/Dynamic	D-optimal	Kriging	Non-dominated Sorting Genetic Algorithm II Particle swarm optimization
[43]	Square columns	FGF	Lateral/Dynamic	Full factorial design	polynomial functions	multiobjective particle swarm optimization
[44]	tapered tube	UF and FGF	Axial/Dynamic	Latin hypercube design	polynomial response surface	multiobjective particle swarm optimization
[46]	Square columns	FGF	Oblique/Dynamic	Full factorial design	radial basis function	Non-dominated Sorting Genetic Algorithm II
[36]	conical tube	UF	Oblique/Dynamic	D-optimal	Kriging model	multiobjective particle swarm optimization
[47]	Square columns	UF	Lateral/Dynamic	Latin Hypercube Sampling	Kriging model	Non-dominated Sorting Genetic Algorithm II
[48]	Square tube	UF	Axial/Dynamic	full factorial design	Response Surface Method	Sequential quadratic programming
[49]	Double circular tube	UF	Axial and Oblique/Dynamic	D-optimal	radial basis function	Non-dominated Sorting Genetic Algorithm II
[50]	Double ellipse tube	UF	Axial and Oblique/Dynamic	D-optimal	Kriging	multiobjective particle swarm optimization
[51]	ellipse tubes	UF	Oblique/Dynamic	D-optimal	Quartic polynomial functions	Non-dominated Sorting Genetic Algorithm II

Table 2 The type of optimization, objective functions and design variables of crashworthiness tubes

[47]		√	specific energy absorption initial peak force	thickness gradient thickness ranges
[48]	√	√	specific energy absorption mean crushing forces	Poisson's ratios
[49]		√	specific energy absorption peak crushing force	wall thickness diameter of tube foam density wall material yi eld stress
[50]		√	specific energy absorption peak crushing force	variables of radial rate wall thickness foam density
[51]		√	specific energy absorption peak crushing force	variables of radial rate wall thickness foam density

2 Crashworthiness Optimization of Tube under Oblique impact

The vehicle collosion happens in a combination of oblique (or off-axis) impacting direction in real world not only axial or transverse loads. The deformation mode of the tubes have been analyzed and some novel structures are proposed under the oblique loading has been analyzed and some novel structures. The Structure deformation as studied [30] It was found that a critical load angle in the transition place from the axial to the bending collapse mode. The foam-filled structures under different angle of load conditions. There was decreasing of the energy absorption as increasing loading angle [31-33]. Also the other structures such as tapered thin-walled rectangular tubes [34-35] and found it is better stability than the straight tube under oblique impact. In addition, foam-filled conical tubes as energy absorbers under oblique loads was analyzed [36]. The optimal foam-filled tube may have better crashworthiness under pure axial loading compare to the empty tube, but the optimal empty tube has more space to enhance the crashworthiness under oblique loading [37].

The optimization design expecially the type of methods can be in table 1 and it continues to main finding in table 2 for crashworthiness optimization issue on thin-walled structures.

3. Conclusions

The recent research trend concerning to the use of optimization of structures were provided an overview in this paper. The number of research papers that use optimization methods to solve impact and crashworthiness problems has increased dramatically in recent years and some researchers have solved multi-objective problems related to crashworthiness using some metamodel and optimization techniques for uniform functionally graded thickness foam filled structures expecially for double structures under axial and oblique impact. Finally the crashworthiness design optimization of FGF filled double structure under axial and oblique impact will be explored in future work.

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