Composite Structures 141 (2016) 39–49

Contents lists available at ScienceDirect

Composite Structures

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

Design and experimental verification of composite impact attenuator for racing vehicles

Jianfeng Wang [a], Na Yang [a,*], Jinghui Zhao [a,b], Dafang Wang [a], Yongtai Wang [a], Kun Li [a], Zhongqing He [b], Baoming Wang [a,c]

[a] School of Automotive Engineering, Harbin Institute of Technology, Weihai, Shandong 264209, PR China
[b] Pan Asia Technical Automotive Center Co., Ltd., Shanghai 201201, PR China
[c] Weihai Guangwei Group Co., Ltd., Weihai, Shandong 264200, PR China

ARTICLE INFO

Article history:
Available online 12 January 2016

Keywords:
Composites impact attenuator
Crashworthiness
Quasi-static test
Drop-weight impact test
Finite element simulation
Light weight

ABSTRACT

Implementing measures to enhance collision energy absorption of a racing vehicle is essential to protect the vehicle and its driver and maximize the driving performance. In this study, based on the energy absorption characteristics of composites, the requirements of competition rules, and the overall vehicle arrangement, a preliminary design of an impact attenuator is performed. This paper will design the basic model with rules requirement in second section, and refer existing composite material-corrugated beam energy absolved structure, and write in half-corrugated beam energy absolved structure, so the model structure can be parameterize. Based on commercial nonlinear finite element analysis software LS-DYNA, established the numerical model. Subsequently, the optimization is divided into structural and lay-up optimizations. Using the LS-OPT software, and based on the response surface analysis method, the structure is optimized to obtain a composite impact attenuator model with the highest possible specific energy absorption. The lay-up of the model is optimized to attain a final lay-up with the minimum weight. Quasi-static axial compression and dynamic drop-weight impact tests are conducted to verify the optimization design. Finally, the composite impact attenuator of the racing car with high energy absorption efficiency, high specific energy absorption, and light weight is achieved.

1. Introduction

It is particularly important to ensure the safety of a racing driver given the danger and specificity of the extreme sport of motor racing. High speeds give rise to huge impact energies and threaten the safety of the driver if a collision accident occurs with a car, especially in the case of frontal crashes. Therefore, the rules of the racing formula demand that a racing car be installed with an impact attenuator capable of ensuring that the front of the cockpit can absorb a certain amount of impact energy to improve the structural crashworthiness of the vehicle [1]. The impact energy should be consumed quickly and steadily if and when a collision occurs so as to realize buffering protection for the driver and the vehicle.

Crashworthiness refers to the buffering capacity and the vehicle's ability to absorb the collision energy if a collision occurs. The energy-absorbing components rely on structural fractures, buckling, and material damage to absorb the impact energy [2,3]. Good crashworthiness of the racing vehicle is required to ensure the safety of the vehicle and driver in the event rules of the FSAE (Formula Society of Automotive Engineering) which is a formula racing competition. One requirement of those in the rules is that all the participating racing vehicles must be installed with front impact attenuator to absorb impact energy. In the 2015 FSAE competition rules, the impact attenuator must satisfy the following requirements [1]:

(a) Installed forward of the front bulkhead.
(b) At least 200 mm (7.8 in) long, with its length oriented along the fore/aft axis of the frame.
(c) At least 100 mm (3.9 in) high and 200 mm (7.8 in) wide for a minimum distance of 200 mm (7.8 in) forward of the front bulkhead.
(d) Be designed such that it cannot penetrate the front bulkhead in the event of an impact.
(e) Be attached securely and directly to the front bulkhead and not by being part of non-structural bodywork.

* Corresponding author. Tel.: +86 631 5677530.
E-mail address: ynhelen@163.com (N. Yang).

http://dx.doi.org/10.1016/j.compstruct.2016.01.013
0263-8223/

In addition to those requirements, the impact attenuator, when mounted on the front of a vehicle with a total mass of 300 kg (661 lbs) and run into a solid, non-yielding impact barrier at a velocity of 7.0 m/s (23.0 ft/s), would result in an average deceleration of the vehicle not exceeding 20 g, with a peak deceleration less than or equal to 40 g. The total energy absorbed must be equal to or exceed 7350 J. The event organizing committee just provides an optional, PET foam standard impact attenuator to the teams. But there are no mandatory materials requirements made in the rules. In addition, aluminum honeycomb is a popular material of impact attenuator which is selected by most FSAE racing teams, as shown in Fig. 1.

Recently as the progress of the FSAE competition and the development of the material application industry, carbon fiber composites with superior crashworthiness are widely used in energy absorption components in international racing as well as in the automotive industry as a whole [4]. During the buffering process, a metal buffering structure mainly relies on plastic deformation to absorb the impact energy. In the case of a composite structure, however, unlike a metal structure, energy is absorbed through the brittle fracture or other microscopic damage, making the capacity and efficiency of the energy-absorption much higher [5–7]. A controllable failure mode, stable compression load, and high energy absorption efficiency for a composite buffering structure can be obtained through reasonable design and a good knowledge of the failure process [8–10]. Therefore, ujithe application of fiber reinforced composite material in impact attenuator of the FSAE car has been carried out widely to absorb impact energy.

Savage et al. [11] and Quaresimin et al. [12] found that the composite hollow cone structure can meet the requirements of the rules of the competition, and achieve progressive compression failure which is more effective and stable and can avoid the large area buckling failure. In this paper, to achieve large specific energy absorption, different thickness, size of wall section and half angle would be selected.

Jovan Obradovic et al. [13] studied a composite shell structure with taper and cross section shape. In this paper, first simple composite carbon fiber cylindrical tubes were conducted with quasi-static compression and dynamic drop tests to get the material properties first. At the same time, LS-DYNA finite element simulations were conducted according to the experimental results. In this research, the composite thin shell is divided into three regions, and each region is laminated with different layers. The best value is determined by numerical LS-DYNA analysis of quasi static compression and dynamic impact tests.

Although the above research have achieved some results, the research methods are limited to the level where the structure and the layer parameters were first modified, and then the numerical analysis method or experimental method is used to verify the reliability. In this way, the final buffer structure is only to meet the performance requirements, not taking into account the light weight and other events.

LS-OPT is a finite element optimization analysis software produced by Livermore Software Technology Corporation, which has good compatibility with LS-DYNA. It is an extension of parametric applications in finite element simulation techniques. Based on the experiment design method and tests, certain data can be obtained through the Response Surface Methodology (RSM). The functional relationship between the factors and the response values can be fitted by using the multiple two regression equations. Through the analysis of the regression equation, the optimal process parameters could be found to solve the problem with multiple variables.

Differing from the method of modifying parameters with multiple simulations to meet the design requirements, this study uses ls-dyna to establish finite element analysis model and then use multi-objective optimization design software LS-OPT, binary quadratic regression orthogonal combination experiment and response surface method. Both the overall structure of the composite impact attenuator and layers are optimized respectively with the optimization goal of lightweight and constraint of requirement of rules. Finally through the quasi static compression test and dynamic impact experiment, the design reliability of composite impact attenuator was verified.

This paper will design the basic model with rules requirement in second section, and refer existing composite material-corrugated beam energy absolved structure, and write in half-corrugated beam energy absolved structure, so the model structure can be parameterize; in third section the establishment of model, which based on commercial nonlinear finite element analysis software LS-DYNA is expounded; In the fourth LS-OPT is used to optimize the mass ratio energy absolved, experiment method of dyadic and square regression orthogonality is used, by method of response curve design it optimize the basic structure of impact attenuator energy absolved structure; The fifth section is based on optimized result in the fourth section, constrain the max acceleration, average acceleration and absolved energy with rules requirement, and get the lamination project, which with constraint condition min mass, by response curve design method. In sixth and seventh section respectively used quasi static compression experiment and drop hammer dynamic experiment to verify the result. At last it get a lightweight composite impact attenuator with high efficiency and high specific energy absorption.

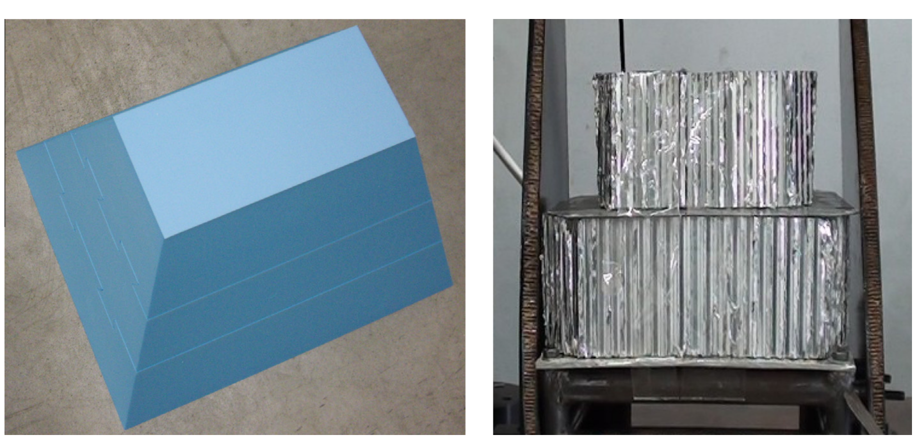

Fig. 1. Some materials of impact attenuator.