Turkish Journal of Engineering

Turkish Journal of Engineering (TUJE)
Vol. 2, Issue 1, pp. 17-21, January 2018
ISSN 2587-1366, Turkey
DOI: 10.31127/tuje.330658
Research Article

LIGHTWEIGHT FOAM IMPACT ATTENUATOR DESIGN FOR FORMULA SAE CAR

Emre İsa Albak *[1], Erol Solmaz [2], Necmettin Kaya [3] and Ferruh Öztürk [4]

[1] Uludağ University, Engineering Faculty, Automotive Engineering Department, Bursa, Turkey
ORCID ID 0000-0001-9215-0775
emrealbak@uludag.edu.tr

[2] Uludağ University, Engineering Faculty, Automotive Engineering Department, Bursa, Turkey
ORCID ID 0000-0001-9369-3552
esolmaz@uludag.edu.tr

[3] Uludağ University, Engineering Faculty, Mechanical Engineering Department, Bursa, Turkey
ORCID ID 0000-0002-8297-0777
necmi@uludag.edu.tr

[4] Uludağ University, Engineering Faculty, Automotive Engineering Department, Bursa, Turkey
ORCID ID 0000-0001-5767-8312
ferruh@uludag.edu.tr

* Corresponding Author
Received: 24/07/2017 Accepted: 22/09/2017

ABSTRACT
The impact attenuator is a safety component which is used to reduce the effects of frontal crash on driver, which can cause injuries. This article describes the design process of the impact attenuator with lightweight materials to satisfy the required weight reduction targets for Formula SAE racing car. This study is carried out as part of weight reduction studies on Formula SAE racing car. As a first step, the impact-absorbing structures and technical features were compared. In this step, it was decided to use EPP foam material with a density of 100 g/l as basic material to design a lightweight impact attenuator. Also, the design outlines of shape and analysis techniques for impact attenuator was defined in this step. Then, validation process was carried out for virtual model of 100 g/l EPP foam material. Foam material model was validated using reference study in literature. After model validation, a new impact attenuator was designed according to Formula SAE rules. It is 10% lighter than the standard model. The results show that selected EPP foam material can be used to design a lightweight impact attenuator for formula SAE race car to satisfy weight reduction requirements successfully.

Keywords: *Impact Attenuator, EPP, Foam, Formula SAE, Formula Student*

1. INTRODUCTION

The Formula SAE competitions are one of the most important engineering competitions held in over 13 countries around the world and participated by over 500 college teams. In these competitions, racing car designs are evaluated in different categories for all the design stages. There are many categories such as cost analysis, engineering design and performance. The weight reduction studies for Formula SAE car are taken considerable attention recent years due to green design concepts in car design. This article describes the design process of the impact attenuator with lightweight materials to satisfy the required weight reduction targets for Formula SAE racing car. The impact attenuator is a safety component which is used to reduce the effects of frontal crash on driver, which can cause injuries.

Although there are several research papers in literature regarding weight reduction and frontal crash structures of car body, there are only a few works regarding design of Formula SAE racing car impact attenuator. Benchmarking study was also carried out to examine the design outline and specifications of other Formula SAE racing cars and their safety components. One of the most important safety criteria during the design of a racing car is the characteristic behavior of the vehicle in the event of a crash (Boria, 2014). Safety in the event of an accident is important not only in Formula 1 vehicles but also in Formula SAE vehicles (Belingardi *et al.*, 2010). In high-speed accidents, special structures are designed to absorb kinetic energy that will affect the human body (Obradovich *et al.*, 2012). The energy damping structures which are used in Formula SAE racing cars are impact attenuators. Impact attenuators should be lightweight for better performance such as better acceleration, better steering, and easier maintenance for the vehicle's handling dynamics (Enomoto *et al.*, 2007). For this reason, impact attenuator materials must be made from lightweight materials to ensure high performance criteria (Munusamy *et al.*, 2010). Materials such as aluminum, honeycomb, carbon, foam are usually used for impact attenuators.

Foams are used in different areas in many sectors due to their low density and high energy damping properties. They are widely used in passive safety systems in modern vehicles in the automotive sector (Slik *et al.*, 2006). Many types of foam materials are used in the automotive industry. One of them is expanded polypropylene (EPP). The energy absorption capacity and lightness properties of the EPP material are key features that enable it to be used as an energy absorbing pad in the automotive industry (Yıldızhan *et al.*, 2016). EPP foams are used as sandwich material in crush boxes in automotive industry due to low weight and high energy damping, and as impact protectors in side door panels (Bouix *et al.*, 2009).

The Uludağ Racing team has used a standard impact attenuator made from Impaxx 700 foam (Impaxx) and the weight is 700 gr. This study describes the design process of the new lightweight impact attenuator which was designed according to Formula SAE rules. EPP foam material with a density of 100 g/l as basic material was selected to design a lightweight impact attenuator. Also, the design outlines of shape and analysis techniques were defined in the first design step. Then, validation process was carried out for finite element model of 100 g/l EPP foam material. The results of the physical drop test at the initial speed of 2.2 m/s to the 50 mm cubic sample were taken as reference points to validate the material model. After model validation, a lightweight impact attenuator was designed according to Formula SAE rules. The results show that selected EPP foam material can be used successfully to design a lightweight impact attenuator for formula SAE race car to satisfy weight reduction requirements.

The following sections describe the design of a foam impact attenuator to satisfy weight reduction requirements for the Formula SAE racing car.

2. ULUDAĞ RACING TEAM AND IMPACT ATTENUATOR

Uludağ Racing Team (URT) was established in 2011 to produce cars for Formula SAE competitions under the Uludağ University Automotive Community. URT have produced four racing cars. The last one was produced in year of 2017. First participation of URT to Formula SAE Racing Car Competition was in 2011 in UK. Second and third participations took place in the following years competitions which were organized in Italy and Russia. URT won two rewards from these competitions.

2.1. Impact Attenuator

The impact attenuator is one of the most important parts in terms of safety in Formula SAE vehicles. The specific requirements of impact attenuator are outlined in FSAE rules which are given as follows:

- At least 200 mm (7.8 in) long, with its length oriented along the fore/aft axis of the Frame;
- 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 (2017-18 Formula SAE® Rules, 2016).

The desired dynamic test conditions for interrogating the impact attenuator stiffness are given below:

Test data that proves that the Impact Attenuator Assembly, when mounted on the front of a vehicle with a total mass of 300 kg (661 lbs.) and impacting a solid, non-yielding impact barrier with a velocity of impact of 7.0 meters/second (23.0 ft./sec), decelerates the vehicle at a rate not exceeding 20 g's average and 40 g's peak. The energy absorbed in this event must meet or exceed 7350 Joules (2017-18 Formula SAE® Rules, 2016).

3. IMPACT ATTENUATOR DESIGN AND SIMULATIONS

Finite element simulations are important to check how well the required properties are achieved in the design process. Two different simulation studies were conducted in this study. The first study is the validation of the material model of EPP. The second study is dynamic finite element simulation according to Formula SAE rules. Hyperworks Student 2017 Edition software was used for finite element modeling and analysis. The finite element model of the structure was developed by means of the software code Hypermesh. Finally, the crash event simulation has been developed by means of the Radioss code.

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3.1. Validation of EPP 100 g/l Material Model

EPP material with 100 g/l density was selected for impact attenuator. In order to validate the material model, finite element simulations were carried out. The stress-strain curves to define the material model for the EPP are given in Fig. 1. These curves were taken from a 50-mm cubic specimen of 90 kg of mass at the initial speed of 2.2 m/s followed by a drop test conducted by Untaroiu *et al.* (2010).

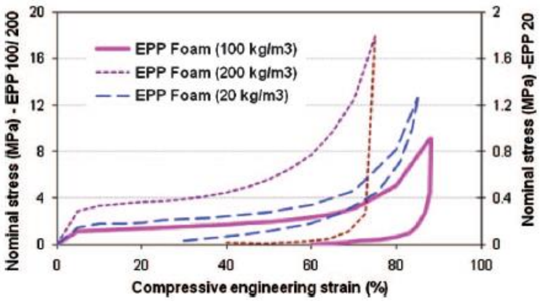

Fig. 1. EPP 100 g/l foam material Strain-Stress Curves (Untaroiu *et al.*, 2010)

To define the EPP foam material model, LAW70 material card and P14_solid property card were used. Stress-strain curve was defining in Radioss solver code (Altair University). Material card and the property card information are given in Table 1. The values used for the property are the values recommended for the foam element in the Radioss Manuals.

Cubic specimen of 50 mm dimensions was modeled with first order hexahedral elements. Rigid wall was defined as 90 kg mass and the drop velocity is 2.2 m/s. In order to achieve the same test conditions, six degrees of freedom of the underside of the specimen was also constrained (see Fig. 2).

Table 1. Material card and property card specifications for foam material

Material Cards	(MAT70)
Rho_Initial	1.0e-10 (Mg/mm^3)
E0 (Initial Young's Modulus)	230.0 MPa
Failure Plastic Strain	0.9
Property Card	(P14_SOLID)
ISOLID	24
Ismstr	11
I_strain	1

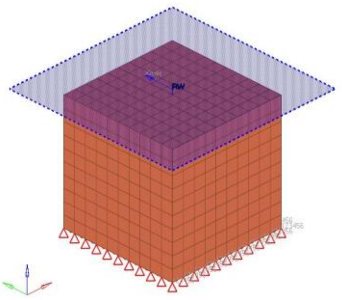

Fig. 2. Validation model of EPP foam material

The comparison of finite element drop analysis and Untaroiu *et al.* (2010)'s test results is given in Fig. 3. It is seen that the strain-stress results are in very good correlation (Fig. 3). According to this result, the selected material card for the foam material and the property card can be used in the analysis of the dynamic finite element analysis.

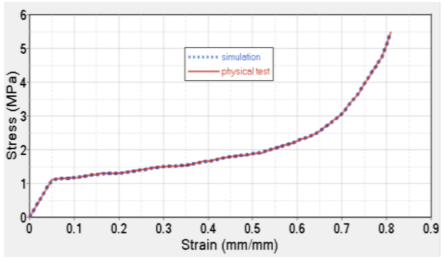

Fig. 3. Correlation results of simulation and physical test

3.2. Impact Attenuator Dynamic Simulation

A dynamic finite element analysis was conducted for the suitability of the designed impact attenuator to the Formula SAE rules. The requirements for the dynamic model according to the rules are that the vehicle with a mass of 300 kg is hit with a rigid wall at the initial velocity of 7m/s. It is required that the energy of the 7350 J energy is absorbed and the deceleration is 20 g average and 40 g maximum.

The dynamic model consists of the chassis, anti-intrusion plate, impact attenuator, mass, the rigid wall and rigid elements. The finite element model is shown in Fig. 4.

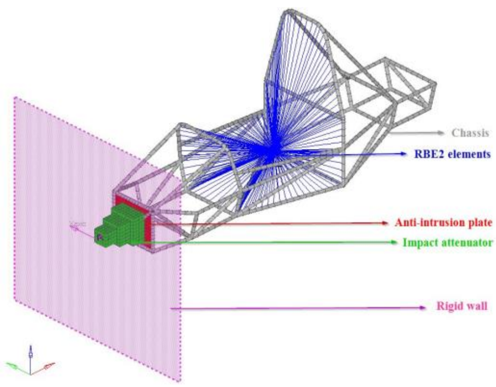

Fig. 4. Simulation model of Formula SAE Car

The chassis was modeled with beam elements with 50 mm element size. Anti-intrusion plate thickness is 2mm. It allows the foam material to be fixed to the chassis, was modeled with 25 mm first order 2D quad elements. The impact attenuator was modeled with first order hexahedral elements with 25 mm element dimensions (Fig. 5 on the right). The connections were made with rigid elements of RBE2.

Fig. 5 represents the model of current impact attenuator and new impact attenuator. Current impact attenuator weight is 700 gr and new impact attenuator is 632 gr. Impact attenuator's mass was decreased about 10%.

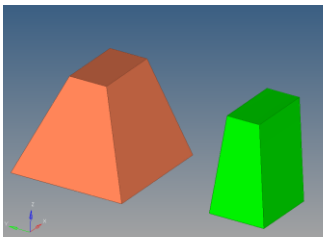

Fig. 5. Impact attenuators (current model on the left, new model on the right)

The finite element analysis results are shown in Fig. 6 and Fig. 7. In Fig. 6, the dots represent the initial position of the chassis and it is seen that the impact attenuator reduces the speed of the vehicle to zero. Fig. 7 shows the shape of the impact attenuator depending on the time.

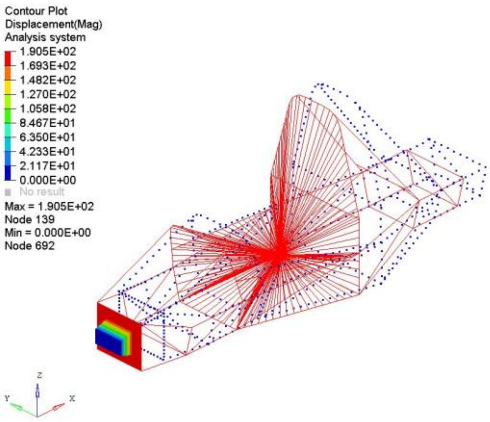

Fig. 6. Finite element crash simulation results

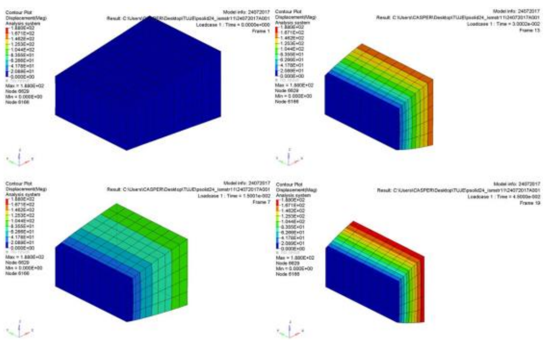

Fig. 7. Displacement results after crash

Fig. 8 shows the deceleration of the vehicle versus time. Deceleration increases as the foam compresses, and about the velocity is 0 m/s, it takes its maximum values and falls rapidly afterwards. Deceleration value of the vehicle reaches a maximum of 30 g and the average deceleration value is less than 20 g. All deceleration results are in accordance with the rules.

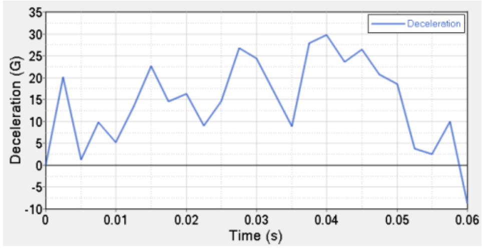

Fig. 8. Deceleration results of crash simulation of Formula SAE Car

As shown in Fig. 9, the amount of energy absorbed increases as expected and there is a backward movement when the vehicle speed is zero. The maximum amount of absorbed energy is 7420 J, which is above the minimum required by the Formula SAE rules. Therefore, it has been shown that using a foam as a crash absorbing material which is lighter but provides the desired conditions can be used for such Formula SAE vehicles.

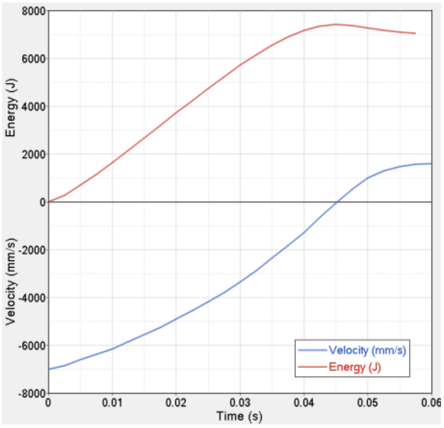

Fig. 9. Energy and velocity results of dynamic simulation

4. CONCLUSION

In this study, 10% lighter impact attenuator compared to the standard model was designed to satisfy weight reduction requirements for the Formula SAE racing car. It was found that the foam impact attenuator can be used successfully to satisfy the required Formula SAE racing car specifications regarding the deceleration and energy absorbing criteria. This study was carried out as part of weight reduction studies on Formula SAE racing car.

In future work, further weight reduction and new structural design will be enhanced by creating an optimization model for the foam impact attenuator. In addition, designs with different materials and structural topology will be tried for new impact attenuator which can also be used for other vehicles, not just for Formula SAE racing cars.

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