DESIGN AND PHYSICAL TESTING OF IMPACT ATTENUATOR FOR FORMULA SAE RACECAR

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Abstract— **Structures which could absorb enormous quantity of impact energy during collision are a challenge for automobile industry these days. This requirement is to design and produce advance crash safety systems to protect the driver from fatal injuries. The impact attenuator is such safety structure installed on car that could absorbs energy during frontal collision by progressive deformation debilitating effect of force and deceleration transmitted to passengers. This plastic deformation is a major part of impact energy. Aim of this paper is to provide lightweight, cost-effective Impact Attenuator made up of Rohacell 110IG Foam for FSAE cars. Quasi-static testing of the same qualifies functional requirements of average & peak deceleration and energy absorption mentioned in FSAE design rulebook.**

Index Terms—
Impact Attenuator, Formula SAE, Quasi-static Testing, Energy absorbing Foam, Crash safety system.

I. INTRODUCTION

As Automobile industry progressed through different phases, another branch of it evolved in 1950's. Since then Motorsports, Auto racing have been most followed sports in the world. Plenty human beings get attracted towards this dangerous sport. Many have lost their lives in fatal crashes. Racecars roll over the track and with parts airborne in all ways as the vehicle is simply shattered, is a clichéd image at car race accidents. Therefore, it is inevitable for engineers to design impact attenuators to protect the driver from serious wounds. Impact attenuators have to achieve 2 safety goals: To diminish the initial force of the impact and they redistribute the force before it reaches the vehicle's passengers. For design and manufacturing of impact attenuators in race cars, structural weight saving is one of the major considerations.

The prime intension is to present a design of impact attenuator which can be used in Formula SAE racecars. This is mounted on front bulkhead of racecar as most intensive load develops in head on collision. According to FSAE rulebook, attenuator should have specified minimum dimensions and mounting constraints. Generally, Aluminium Honeycomb structure or carbon fiber monocoque structure is used as impact attenuator. Another option of using foam gives lightweight and effective crash system. The testing can be carried out by 2 ways:

1. Dynamic load Testing
2. Quasi- Static Load Testing (Gradual Loading).

Quasi-static Testing is preferred over Dynamic Testing due to its availability and cost of testing. This paper presents testing by gradual loading.

II. DESCRIPTION OF PROBLEM

As per rules, mentioned in FSAE rulebook for impact attenuator.

"The Impact Attenuator must be:

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. Such that it cannot penetrate the Front Bulkhead in the event of an impact.

The attachment of the Impact Attenuator must be constructed to provide an adequate load path for transverse and vertical loads in the event of off-center and off-axis impacts.

On all cars, a 1.5 mm (0.060 in) solid steel or 4.0 mm (0.157 in) solid aluminum "anti-intrusion plate" must be integrated into the Impact Attenuator. If the IA plate is bolted to the Front Bulkhead, it must be the same size as the outside dimensions of the Front Bulkhead. If it is welded to the Front Bulkhead, it must extend at least to the centerline of the Front Bulkhead tubing.

The Impact Attenuator Data Requirement:

Test data must show that their 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 with a velocity of impact of 7.0 meters/second (23.0 ft. /sec), would give an average deceleration of the vehicle not to exceed 20 g's, with a peak deceleration less than or equal to 40 g's. Total energy absorbed must meet or exceed 7350 Joules.

No part of the anti-intrusion plate may permanently deflect more than 25.4 mm (1 inch) beyond the position of the anti-intrusion plate before the test".

III. DESIGN METHODOLOGY

A. Material Selection:

1) For Impact Attenuator

The factors can be considered for material selection are cost, weight, reliability and availability. Weight is an important measure of the whole car design as the overall design is meant to keep the car lightweight to not take away from its speed. Monocoque structure, Aluminium Honeycomb and Foam are

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the options in sight. Monocoque structure is too expensive to buy as Formula SAE budgets are constrained. Further, Aluminium Honeycomb, though it's reliable, foam outclass the honeycomb if cost, weight and availability these factors are concerned. Rohacell 110IG foam is easily available if compared to DOW IMPAXX or other foam s.

Property	Rohacell 110IG
Density	110 kg/m^3
Compressive Strength	3.0 MPa
Tensile Strength	3.5 MPa
Shear Strength	2.4 MPa
Elastic Modulus	160 MPa
Shear Modulus	50 MPa

Table 1: ROHACELL 110IG PROPERTIES

2) For Anti-Intrusion Plate
Rules suggest that Impact attenuator must be attached to Anti-Intrusion Plate which could be either 1.5 mm thick Steel or 4 mm thick Aluminium material. As we know commercial Mild Steel and Aluminium have following densities
Density (Mild Steel): 7850 kg/m^3.
Density (aluminium): 2700 kg/m^3.
For 280*280 (mm*mm) anti-intrusion plate, 4 mm thick aluminium material saves approximately 150 grams weight if compared to 1.5 mm Steel plate.

Mechanical Property	Al 6063 T6
Density	2700 kg/m^3
Elasticity Modulus	68.9 GPa
Poisson's Ratio	0.33
Ultimate Strength	241 MPa
Yield Strength	214 MPa
Elongation at Break	12%

Table 2: ALUMINIUM MATERIAL PROPERTIES

3) Attachment of Impact attenuator to anti-intrusion plate
Impact attenuator is glued to plate with ARALDITE (Standard Epoxy Resin) & M-SEAL (Epoxy Compound for sealing and fixing.)
4) Integration of whole structure to Chassis
The whole structure could be mounted on front bulkhead by welding or bolting. Due to working space requirements and impasse condition of aluminium and steel welding together, bolting is favored over welding.
Bolts used:
Four (4) 15 mm length Grade 8.8 (5/16 inch Grade 5) bolts.

B. Design & Manufacturing of Impact Attenuator:
Fig. (1) depicts the CAD model of the Impact Attenuator designed using SOLIDWORKS software. Overall dimensions of the attenuator taken were 210 x 210 x 100 mm3. The sheet thickness eventually used was 4 mm. This impact attenuator is manufactured using materials mentioned before.

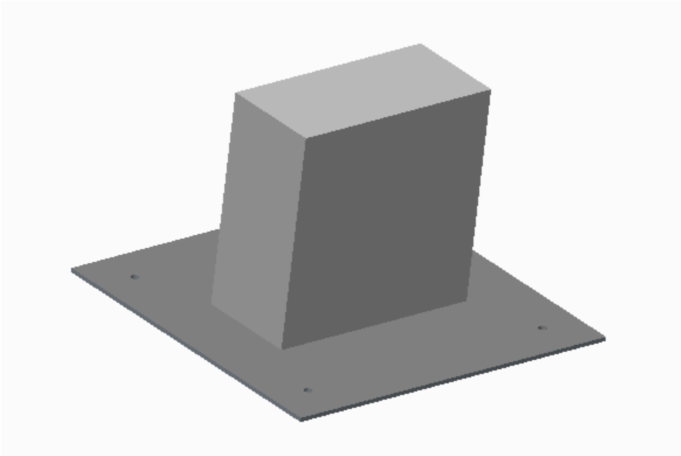
Figure 1: CAD MODEL OF IMPACT ATTENUATOR

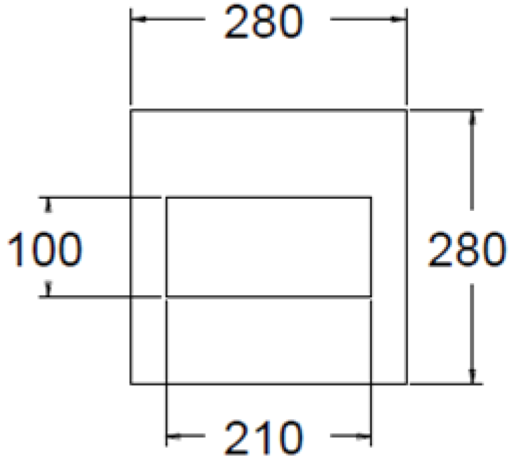

Figure 2 : TOP VIEW OF IMPACT ATTENUATOR.

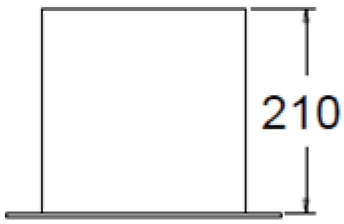

Figure 3 : FRONT VIEW OF IMPACT ATTENUATOR.

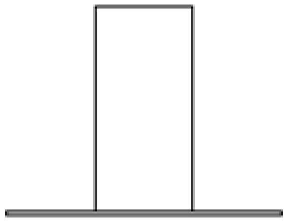
Figure 4 : SIDE VIEW OF IMPACT ATTENUATOR.

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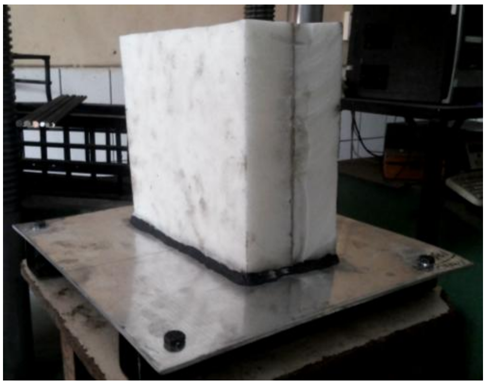

Figure 5 : ACTUAL IMPACT ATTENUATOR AS CONSTRUCTED.

Figure 6 : ACTUAL IMPACT ATTENUATOR MOUNTING.

IV. TESTING

After fabrication of Impact Attenuator can be tested physically for its reliability on UNIVERSAL TESTING MACHINE, which have minimum load applying capacity 200KN. Impact attenuator could be tested under gradual load apply (quasi-static) condition. This universal testing must give computer generated LOAD Vs DISPLACEMENT graph. (It is suggested that to use well calibrated, government affiliated Testing Machine to get accurate results.) Figure 7 shows the fixture made for testing of Impact Attenuator. Small Mild steel plates are welded to square channel and holes are drilled for bolting Anti-Intrusion Plate and square channel through plates. Observe carefully, Bolts are not resting on the testing machine's lower surface. Height of Impact foam taken as 210 mm, further it is compressed under gradual loading by 140-150 mm. While compressing, computer integrated with Universal Testing Machine gives corresponding displacement graph. Simultaneously noted down load for each 5mm rise in reading on digital board in order to plot TOTAL ENERGY Vs DISPLACEMENT graph. At the end of testing, Impact attenuator's crushed displacement, post crush displacement (demonstrating any return), deflection in anti-intrusion plate were observed.

Figure 7: FIXTURE FOR IMPACT ATTENUATOR TESTING

Figure 8: IMPACT ATTENUATOR DURING TESTING

Figure 9: IMPACT ATTENUATOR AFTER TESTING

V. OBSERVATIONS AND CALCULATIONS

Graph 1 show LOAD Vs DISPLACEMENT curve of the tested specimen of Impact Attenuator. This graph is important for calculating peak deceleration and average deceleration. Given that:

Mass of the vehicle= 300 kg,

Formula:

Force= mass*acceleration.

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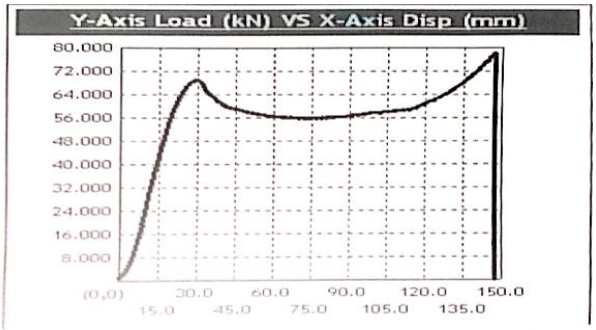
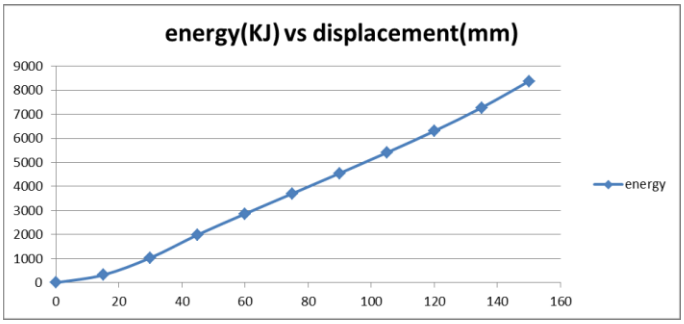


Graph 1: LOAD vs. DISPLACEMENT CURVE

Peak Deceleration:
Here, Load= *load_peak*
load_peak = 78.3 KN
Load = mass*acceleration
Acceleration = Load / mass
= 78.301 (KN) / 300 kg
= 78301 (N) / 300kg
= 261.003 /9.81
= 26.606 g's.

Average Deceleration:
Here, Load= *load_average*
load_average = 55.063 KN (calculated)
Load= mass*acceleration
Accleration = Load / mass
= 55.063 (KN) / 300 kg
= 55063 (N) / 300 kg
= 183.5451 /9.81
= 18.71 g's.



Graph 2: ENERGY vs. DISPLACEMENT CURVE

As shown in the graph 2, energy at displacements is calculated by finding out area under the CURVE shown in graph 1. Adding all cumulative energy values gives total energy absorption as 8377.65 J (viz. >= 7350J).

Other Observations:

1. Anti-Intrusion Plate Deformation (mm) = 14 mm
2. IA Post Crush Displacement - (mm): = 31.2 mm.

VI. CONCLUSION

The behavior of an Impact Attenuator for Formula SAE racecar has been described with detailed material selection, design methodology and physical testing procedure.

Based on the calculated results, it is found that Impact Attenuator made up of ROHACELL 110IG foam satisfies all functional requirements and design rules set up by Formula SAE. This attenuator provides better energy dissipation.

Miscellaneous advantages of the same Impact Attenuator are reduced weight, less volume occupied and flexibility in nose design of car.

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