Optimization of foam filled door sill for Pure Electric Vehicle

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Abstract—In this work, the optimization values for several double circular tubes filled with foam under dynamic bending loading are compared. The thin-walled tube is frequently used in vehicle construction, especially on the door sill, to reduce impact. Double circular tubes made of the aluminum alloy AA6063 T6 were filled with foam for this numerical study. Structures are modeled and analyzed using the ABAQUS algorithm. Optimization of tubes determined using Non-Dominated Sorting Genetic Algorithm version II (NSGA II). Excellent agreement between the results of the simulation and the empirically validated FE model has been attained. Also, It was found that a double circular tube filled with foam absorbs more energy than one that is empty of foam. Hence, it can be recommended that this structure be used as an energy-absorbing part, such as a door sill, for pure electric vehicles (PEV).

Keywords—PEV, foam, sill door, NSGA II

I. Introduction

With the growing number of cars on the road, energy scarcity and pollution have become serious issues that must be addressed. In this environment, as a new energy vehicle. Sadly, limited mileage has consistently been a major obstacle to PEV growth. A solid strategy to boost PEV mileage while reducing energy usage is a lightweight design. However in the process of designing lightweight vehicles, assuring structural crashworthiness is a challenging technological job. The advancement of the automobile industry has benefited from the extensive research that has been done to achieve lightweight design without sacrificing vehicle safety performance, [1], [2], [3], [4], [5]. Accidents can happen in a variety of ways, affecting any aspect of the vehicle as well as the occupants. Because frontal impact is the most prevalent style of collision, it has already received a lot of attention. It should be emphasized that protecting occupants from side impact incidents is more challenging because to absorb impact energy, there is less room for the vehicle structure to flex and collapse. Researchers have been studying the capabilities of automobiles to safeguard occupant safety during an accident for several years. To do this, a car prototype was placed through real-world crash testing, and the vehicle characteristics collected throughout the trial were used to model the vehicle accident in computer software.

[6], investigate a thorough model of a battery pack under a side pole testing into a stiff pole at a speed of 29 km/h. Furthermore, their crashworthiness experiments revealed that hexagonal packs outperform trapezoidal and rectangular packs in terms of occupancy rate and energy absorption. [7], used the frontal crash test using the FEM model to examine the lightweight construction and crashworthiness of PEVs. The numerical simulations by [8], showed the benefits of using composite materials in energy-absorption components. To protect the battery pack floor from damage after a side pole collision, [9], examined the door sill construction using a multi-level optimization technique. The redesigned door structure provided better energy absorption, which increased the battery pack's security. The work in [10], refined the battery pack's flexible structure to improve the crashworthiness of PEVs in head-on collisions. The results revealed a significant decrease in passenger compartment acceleration when battery packs were utilized as energy-absorption components. To test the effectiveness of energy-absorbing materials in protecting the battery pack from a 32 km/h oblique side pole collision, [11], employed a finite element model. The battery pack was deformed by 9.4 mm when the aluminum foam was utilized as a filler for the door sill construction, which was less than the 15.3 mm maximum. Energy-absorbing capabilities and adequate stiffness are critical in passive safety systems in automobiles. Crash boxes and bumper mounts are examples of thin-walled structures with diverse shapes that are good at absorbing impact energy. Cellular materials can further enhance these structures, [12], [13], [14], [15], [16].

Covering thin-walled structures with cellular materials (such as foam, [17], and honeycomb, [18]. [19], observed that the filled cellular materials increased the bending strength and prevented them from collapsing in parts. [20], used numerical analysis to study the bending characteristics of square columns filled with foam. They found that the energy absorbed by foam-filled columns may be significantly affected by changing the foam density. To better understand how tubes packed with foam would crush during compression testing. Researchers, [21], [22], [23], found that foam-filled tubes have great crash performance because of the interaction between the tube and the filler element. Similar to this, [24], discovered that sophisticated deformation under oblique load happens when the tube and foam contact. Because of this, using foam-filled building components requires careful consideration of the filling procedure. The characteristics of the fundamental components and the filling process have a significant impact on how the filled element and the frame behave, [25], [26], [27], [28], [29].

Engineers and scientists can use optimization techniques like the genetic algorithm (GA) and particle swarm optimization (PSO) to create foam-filled thin-walled structures with optimum crashworthiness properties, [30], [31]. [32], recommended employing metamodel techniques. To determine the various design goals for optimization of thin-walled tube-filled foam. Rectangular tubes filled with foam that had been constructed to have a crushing strength peak and absorb a specific amount of energy, [33]. Using a square foam-filled square, a distinct investigation was carried out by [34]. A foam-filled double structure outperformed a foam-filled single tube structure in terms of protective effect, according to the MOO approach design. As a consequence, the optimal solution is determined by combining many mathematical programming techniques, including the GA and Non-Dominated Sorting Genetic Algorithm version II [35], [36], [37], [38], [39], [40], [41], [42].

This work employed ABAQUS, a finite element software program for crash analysis, and NSGA II for optimization. A variety of design strategies were looked into to reduce or completely avoid battery deformation and, consequently, the risk of fire. To maximize the available space, the idea is to employ a range of alternative impact absorbers to occupy the door sill area rather than the door or the roofline (Figure 1).

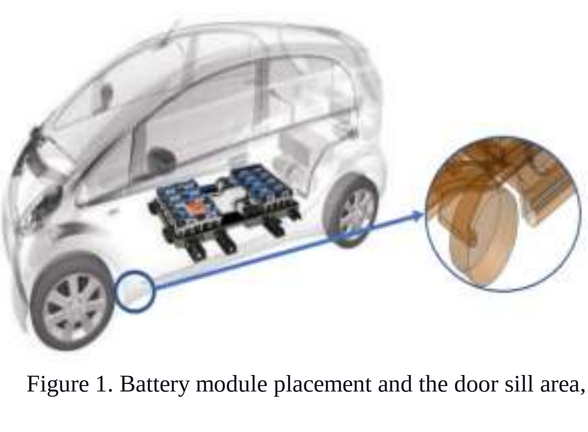


Figure 1. Battery module placement and the door sill area, [11]

II. Material and Method

The aluminum alloy A6063 T6, [43], was used to create the material properties in Table 1. Moreover, Table 2 describes the foam material properties.

Table 1. Aluminum alloy 6063 T6: Mechanical properties, [43]

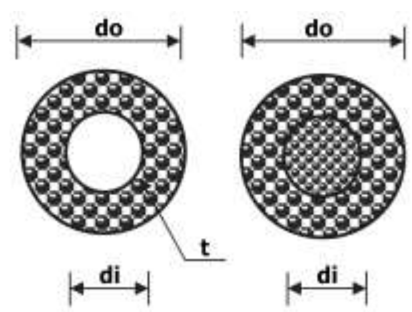
Parameters	Values
Density (ρ)	2700 kg/m3
Young Modulus (E)	60.2 GPa
Poisson ratio (v)	0.3
Yield stress (σ_y)	184.4 MPa
Maximum stress (σ_y)	215.5 MPa

Table 2. Mechanical Properties Of Closed Cell Foam, [44]

Parameters	Values
Density foam (ρ_f)	534 kg/m^3
Young Modulus (E)	0.625 GPa
Poisson ratio (v)	0.1

The aluminum foam-filled tubular tube models were constructed using the finite element approach to predict the behavior of thin-walled structures hit by a free-falling impinging mass. Each tube has a 90 mm outer diameter and a 45 mm inner diameter. Nonetheless, the double tube walls' outer and inner walls were both 1.8 mm thick. Numerical simulations were performed to study the deformation behavior of foam-filled double tubes when subjected to a bending force. Tensile testing, [27], was conducted to get the material properties employed in the simulation. The tested tubes are supported by two 10 mm diameter cylindrical supports.
Three layers of the tube such as the inner tube wall, the outer tube wall, and the foam are chosen to simulate the double circular tube filled with foam (Figure 2). 3D Deformable Shell Extrusion is used to build the tube wall layer whereas 3D Deformable Solid Extrusion is used to model the foam. The ABAQUS package's Crushable Foam and Crush Foam Hardening functions are used to characterize foam plastic. Based on mesh convergence investigations, the element mesh size of 2 mm for void elements and foam models has been determined. For the deformation process to produce correct results, mesh convergence is crucial, [25].

As shown in Figure 2 and Figure 3, several arrangements of the tubes' span length, L_o, and outer diameter, D, are employed. When L_o/D is 7, L is chosen to be 280 mm. The impact mass of 24.23 kg throughout the experiment was sufficient to begin crumpling the tubes, [20].



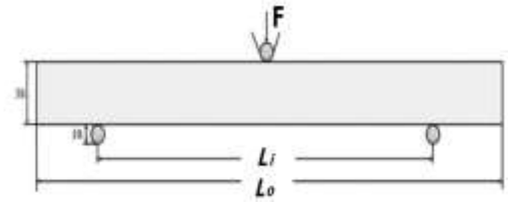


Figure 2. Cross section of FET, and FFT

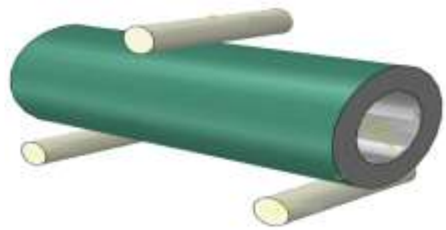


Figure 3. The FE model geometry for a double tube filled with foam

Radial basis functions (RBF) are used as a surrogate and NSGA II and Pareto front as optimization design (Figure 4) for crashworthiness performances, [45], [46].

To handle optimization design challenges such as geometric and material variables are also used as objective functions. Using the typical dimensions of a passenger automobile reported in the literature, the upper and lower bounds for all design variables were defined, [47]. In addition, this method examines if the optimization strategy is statistically sufficient and whether the optimal value choice capacity is satisfactory. Furthermore, earlier researchers validated the accurate simulation model, [48].

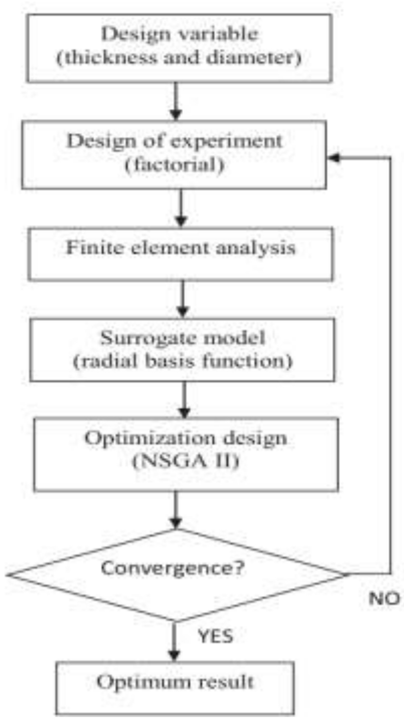


Figure 4. The multi-objective optimization design flowchart

Using Weibull distribution, validation from finite elements is contrasted and evaluated against experimental data. The validation method applies probability analysis for the optimization design, which is a new method for the validation of crashworthiness performance. The probability analysis was validated using the Weibull distribution, which is consistent, [49].

$$f(x) = \frac{\beta_c}{\eta}\left(\frac{x}{\eta}\right)^{\beta_c - 1} e^{\left(\frac{x}{\eta}\right)^{\beta_c}} \tag{1}$$

where is the design variable, c is the shape parameter, and x is the scale parameter.

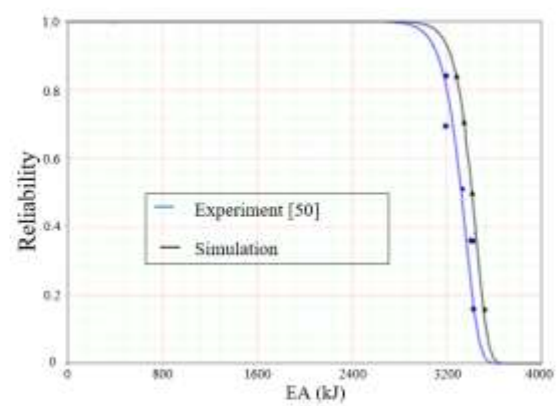
III. RESULTS AND DISCUSSION

As demonstrated in Table 3, which is comparable to the references, [25], [26], [27], [28], [29], there has been a good agreement between simulation and experimental data, [50]. These findings suggest that FE models have been designed well for design optimization research.

Table 3. Differences In Experimental and Simulation Results

Parameters	Experiment	Simulation	Error (%)
Crushing force	5.63	5.71	1.42
Energy absorption	2143	2140.8	0.11

The Weibull distribution for validation is shown in Figure 5. The likelihood of verified simulations and experiments, [50], is shown by the plot shown in the graphs and it is found that 95 percent confidence level correlation line.



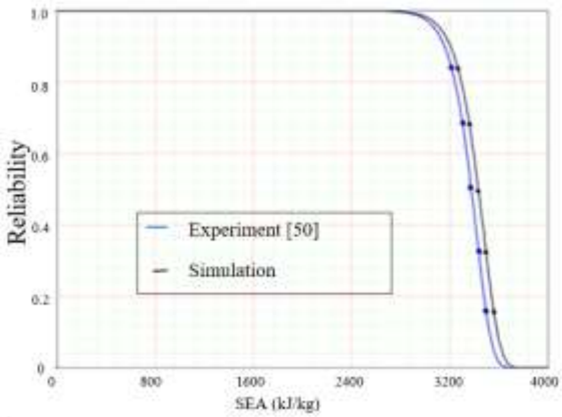


Figure 5. The Weibull distribution

Figure 6 shows the findings of a correlation study using statistical methods. Also, the correlation value, or R2, between the findings of the FEA and the RBF simulations is better than 0.9109 for SEA and PCF.

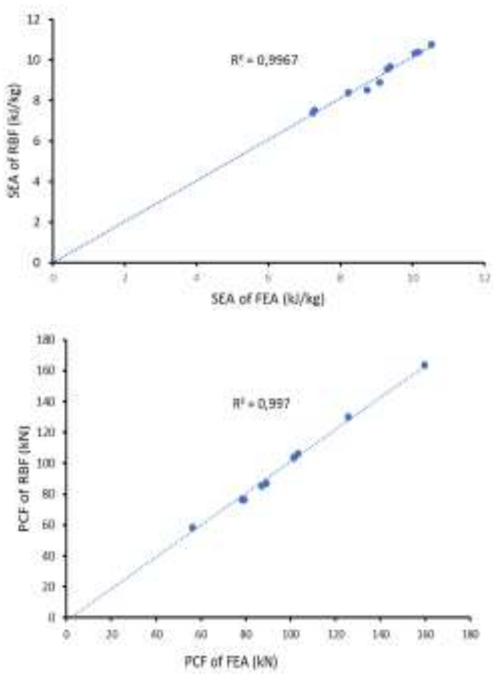


Figure 6. Correlation of SEA and PCF

Figure 7 shows the deformation caused by dynamic bending force on the foam tube filled with foam in the model. As shown in Figure 8, tubes filled with aluminum foam (FFT) have a higher SEA value than foam-empty double circular tubes (FET) due to friction interactions between foam fillers and inner/outer tubes. The double tube optimization equation is created using the thickness and diameter parameters. The results are aimed to identify the optimal SEA and PCF simultaneously

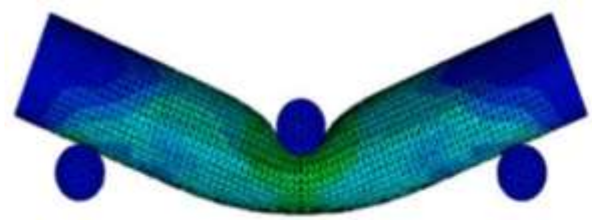


Figure 7. Structural deformation under bending load

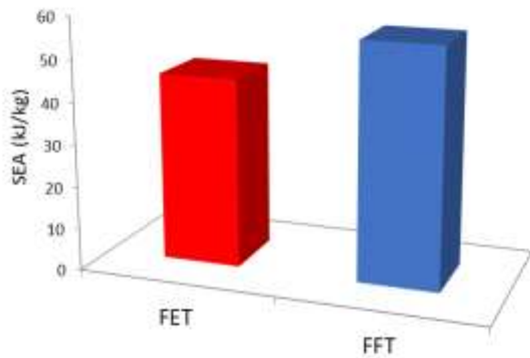
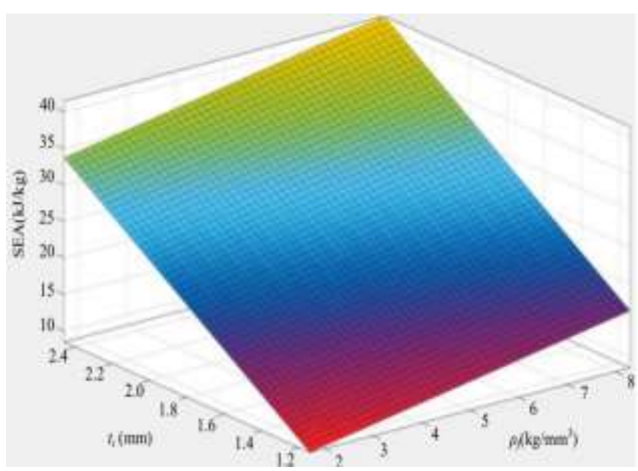
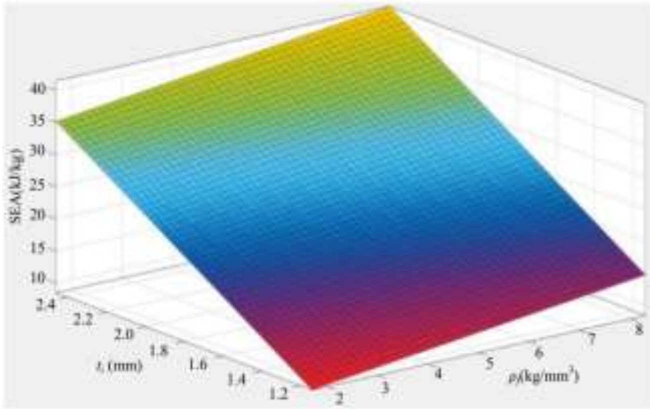


Figure 8. SEA of FET and FFT

The objective function parameters for protecting the foam-empty double circular (FET) and filled foam-foam (FFT) functions are the maximum SEA value and the lowest PCF value. For optimization purposes, inner wall thickness (t_i) and inner diameter (d_i) are used as objective functions since both of these modifications appear to characterize the crashworthiness of the structure.



(a)



(b)

Figure 9. RBF metamodel design of (a) FET and (b) FFT

To estimate the crashworthiness, the FE and RBF models are used; specifically, the SEA and PCF are selected points of 1.4 mm ≤ ti ≤ 3.0 mm, and the diameter of the diameter is 21 mm ≤ di ≤ 27 mm. The Pareto solution, represented by the circular point optimization results in Figure 9, describes the trade-off between SEA and PCF. These findings suggest that the structure of foam has the potential as an effective energy absorber since the SEA and PCF are optimized concurrently, as in the reference, [26]. Lastly, the Pareto fronts for the double cylindrical tubes are presented in Figure 10.

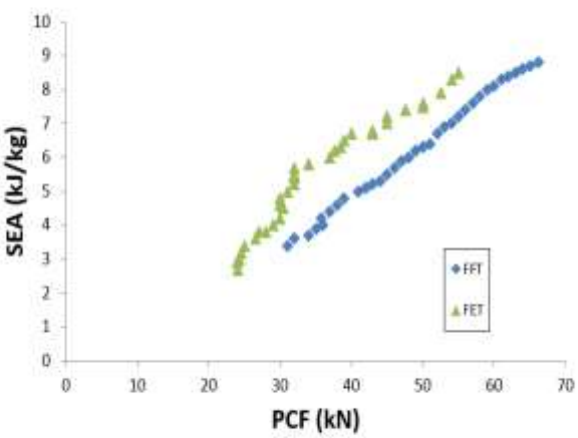


Figure 10. Pareto fronts for the double cylindrical tubes

IV CONCLUSIONS

To find the ideal design, this study examined the foam-filled structures in a variety of combinations. Peak Crushing Force (PCF) and Specific Energy Absorption (SEA), crashworthiness indices, were loaded to determine the optimal door sill design. In this study, multi-objective problems based on Radial Basis Functions (RBF) were created using Finite Element Analysis (FEA).

The Non-dominated Sorting Genetic Technique II (NSGA-2) method for multi-objective optimization is used to optimize the PCF and SEA of foam-filled circular double tubes together with other parameters. It can be determined that the maximum SEA of FFT is 9.87 kJ/kg and the PCF of FFT is 64.87 kN. To design the ideal door sill for various structural designs, the NSGA-II is employed. Lastly, FFT provides the best dynamic bending load crashworthiness performance.

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