Numerical analysis of the influence of mechanical stress on the battery pack's housing of an electric vehicle

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Abstract. In this paper is presented a crash simulation analysis of the battery pack in order to increase the stiffness when the electric vehicle is involved in traffic accidents. In the first part is presented the state of the art, highlighting the advantages of using electric vehicles. The second part of the study presents the steps required to create the crash analysis of the battery pack. The CAD design of the assembly model is generated using advanced modelling techniques for two simulations battery pack models: the first model has a basic shape geometry and the second model has a shock absorber mounted on the external faces to reduce the crash impact. The crash analysis of the battery pack is determined for three velocity cases: 7 m/s, 14 m/s and 21 m/s. The final part of the paper presents the simulation results and different advantages of the battery pack geometry with the shock absorber.

1. Introduction

The current market for electric vehicles (EV) is no longer a question of speculation and analysis predictions. The introduction in the market in 2017 of the Chevy Bolt and Tesla Model 3 models (with an average range of over 250 km on a single charging of energy source) was the event that marked a new era for the automotive industry. The latest trends from the Scandinavian countries (Sweden, Norway and Denmark) is concerning the ban on the sale of vehicles equipped with internal combustion engines, underlining once again the use of EVs as a future sustainable means of transport.

Generally, if the battery (pack) is damaged during a road accident, it has the potential to cause a fire and/or explosion hazard. This immediate danger is amplified by the increasing capacity of energy storage for lithium-ion cells used in the construction of the battery pack of an EV, and thus the stored large energy can be released suddenly during a vehicle accident (as a thermal effect). Together, automotive manufacturers, battery/energetic sources producers, regulatory agencies and the car insurance domain should be prepared to cope with this growing problem resulting from the increased number of EVs in circulation. This implies the necessity of carrying out studies and researches aimed at identifying the constructive solutions (both at the micro-level of the electrochemical cell and at the macro level of the battery pack in its entirety) that provide the protection required for the battery pack (the energy source) in the case of impact or road accident. Experiments that were done included mechanical and structural stresses on the cell through penetration with a rigid rod, hemispherical head penetration, three-point bending and axial and lateral compression, to determine the moment of the onset of the short circuit (detected by tracking cell voltage and temperature). The results of the tests showed that in the case of three-point bending the cell initially presented a linear elastic response (three distinct local peaks on the load-displacement curve were identified). The behavior of large NCO type Li-ion cylindrical cells (SOC = 0 %) was studied in quasi-static mode under three different loading scenarios: compression between two flat plates (lateral crushing), lateral penetration and three-point bending [1]. Observations on the cells after the three-point bending strength test case indicated that the short circuit was caused by a macroscopic fracture occurring in the cell's core due to mechanical stress. From the point of view of research on the effect of structural loads on the battery pack housing at the macro level, fewer studies were published because their geometric shape depends to a large extent on the geometric constraints given by the type of vehicle on which the battery pack will be mounted. A comprehensive analysis of the damage to a battery pack integrated into the vehicle body structure was done in order to develop a general methodology for impact situation [2]. The research results have shown that the right integration of the battery pack in vehicle structure is a key factor in controlling the damage severity of an electric car subjected to a ground impact. The car structural elements such as chassis, bottom protective plates and floor panel provide various levels of protection (function of design and materials used), but they can also endanger the safety level of the battery pack due to deformations caused by mechanical stress.

Full-vehicle crash analyses via finite element simulations were done for several battery pack configurations [3]. The research compared the multifunctional battery system to battery packs with batteries alone, battery packs and battery packs within housing where cellular solids are used as energy absorbers. The general conclusion stated the necessity to use a multifunctional battery system for EVs (damage tolerant and impact energy storage capable). It should be mentioned that there is a major restriction in the construction of the battery packs for EVs, namely a reference parameter in the EV design and use - the battery specific power (250…350 W/kg [4]) - a parameter that directly influences the autonomy of the electric vehicle (due to the total weight of EV). For this reason, materials used for the construction of the housing must provide a high degree of mechanical resistance in the case of structural loads for a minimum weight.

In the article, numerical simulation methods were used to present the effects of structural mechanical stresses (which can occur in the event of an electric vehicle accident) on the battery housing. Several scenarios / cases have been considered regarding the properties of the walls that form the battery housing by modifying the structure, material, and wall thickness.

2. Method

An important aspect of this study is to determine the optimal geometry of the battery pack in order to minimize the damage of the battery cells. In this paragraph are presented all the design and analysis processes used for the crash test of the battery module used for electric vehicles. The start point of the crash analysis is CAD design of the base battery module. The assembly model is loaded into Hypermesh software where applying an advanced technique it is meshed into finite elements. After the preprocessing is done the battery model is simulated using Radioss solver. The CAD model geometry was designed by using SolidWorks modelling technique. The base battery module assembly consists of eight parts for the base model and ten parts for the second model. In figure 1 the overall dimensions and the internal components of the battery's module are presented. The model of the battery assembly is composed from a component that ensures a proper function. For a better and safer assembly between the rows of the battery cell, the box module and the radiator, spacers are made of ABS material.

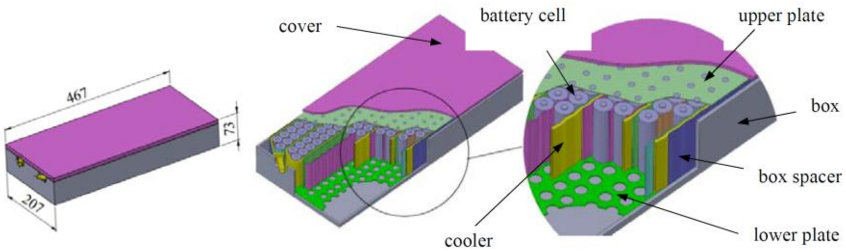


Figure 1. CAD model of battery pack

An important aspect of the electric battery module is for it to fit into a lower volume space and that it must have a lower weight. In the details of figure 1 it can be observed the fixing of the cell battery for a better distribution in the box space. The battery cell is modeled according to the dimensions of the real cell model 18650 type.

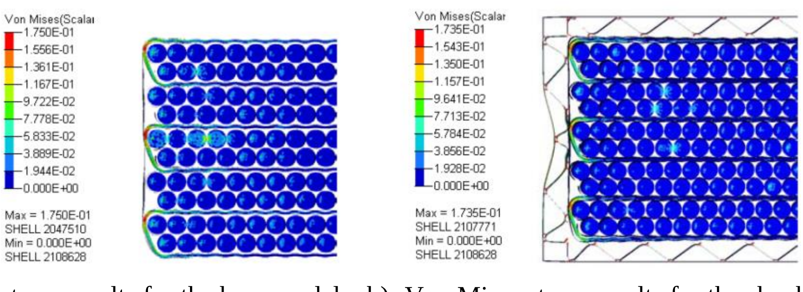
3. Finite element simulations

In this section are presented the steps that make possible the finite element simulation of the battery pack in order to view its behaviour in the crash events. Elaboration of a crash study requires three steps: in first step the CAD geometry is imported for cleanup and prepared to mesh into Hypermesh software, the second step consists of assignations of materials and creation of the load case, and in the last step the finite elements model is ran in Radioss solver and the results can be viewed in HyperView.

An important point of this research are the materials model of the battery pack and its components. The material type M2_PLAS_JOHNS_ZERIL is assigned to the components. In LAW 2 this material type is an isotropic elastic-plastic material, expressing the flow stress in a material as a function of strain, strain rate and temperature. For the spacer parts between batteries the isotropic elastic-plastic material type M36_PLAS_TAB is assigned. The stress-strain material curve is given by the value of the strain included in the range 0-16 and the value of the stress included in the range 1-17. After the cleanup geometry process the battery module assembly model has meshed into 374710 shell elements. During the crash and buckling simulation process a general contact interface type 7 is chosen. The shock absorber plate, the impact plate and the box are interconnected by rigid elements RBE2. The crash simulation scenarios for both batteries pack models were done. The initial velocity of the battery's module is set to 7 m/s in the first simulation case, 14 m/s in the second case and 21 m/s in the third case. For a better view of the results, the time of the simulations is set to 15 ms. During this time the battery pack assembly is crashed into a rigid pole and is rejected by the pole. Both simulation assemblies, the base model and the model with shock absorber, are impacted into a rigid pole haing a 100 mm diameter.

4. Simulations and results

In this section are presented the analysis results for all velocity cases considered.

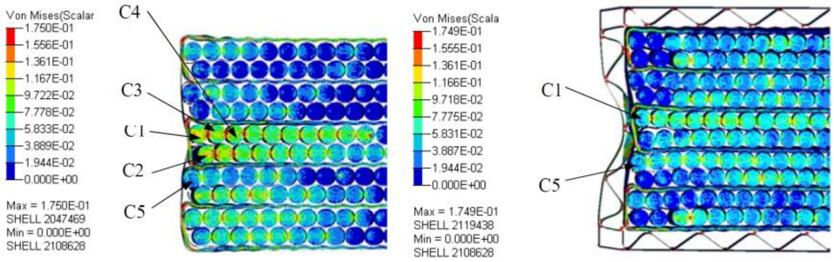


a) Von Mises stress results for the base model b) Von Mises stress results for the shock absorber model

Figure 2. Crash simulation of the first case (impact speed 7 m/s)

Distribution of the von Mises stress for the first simulation case are presented in figure 2, where it can be observed that the cell battery of the base model is not affected during the crash simulation. In figure 2b the shock absorber picks up the crash impact resulting into a lower value of the von Mises stress.

The second simulation case of the base model is presented in figure 3a. In this case the shape of the radiator is deformed due to the crash impact and the four cell batteries are affected. The displacement of the wall affected the cells batteries as it can be observed in figure 3, and the value of displacement for each indicated cell is: C1= 0.924 mm, C2= 1.797 mm, C3= 14.493 mm, C4= 1.697 mm and C5= 2.462 mm.



a) Von Mises stress results for the base model b) Von Mises stress results for the shock absorber model

Figure 3. Crash simulation of the second case (impact speed 14 m/s)

In the second case of simulation the impact energy is absorbed by the shock absorber mounted on the impact area of the battery pack. It can be observed that in the simulation of the model with the shock absorber the damage is lower, only two battery cells being affected. The value of the displacement of the wall affected battery is: for the first cell 6.775 mm and for the fifth cell 0.301. Due to the impact the cooler, contact plate and the shock absorber are bent, as it can be seen in figure 3b. In the third case the battery cells of the base model are the most affected as compared to the first two cases. The maximum displacement is located in the middle of the battery pack in the crash area. Displacement of the cell battery wall measured after crash impact is: C1=4.390 mm, C2=2.745 mm, C3= 4.094 mm, C4=2.56 mm, C5=4.588 mm, C6= 2.018 mm, C7= 1.808 mm, C8= 1.651 mm, C9=5.400 mm, C10=1.347 mm, C11=5.545 mm and C12=0.957 mm. The result of the simulation crash with the shock absorber can be observed in figure 4b. Due to the battery pack's shock absorber, the battery cells are less affected. The displacement values of the affected battery cells are (in mm): C1=5.859, C2=2.573, C3=1.966, C5=1.691, C8=0.92, C9=7.449 and C11=1.103.

a) Deformation of the base battery pack at 21 m/s b) Deformation of the base battery pack at 21 m/s with shock absorber

Figure 4. Results of the battery pack model simulation

In figure 4a are presented the deformation of the base battery pack model at the velocity of 21m/s. The kinetic energy curve starts from the initial value of 1410 joules, it remains constant for the first 0.55

milliseconds, after which the battery pack gets in contact with the rigid pole. The kinetic energy drops continuously until 2.7 milliseconds, being close to zero. The battery pack deformation stops when the kinetic energy of the model is absorbed in plastic deformation.

In the case study of the battery pack with shock absorber the crash results are presented in figure 4b, where the maxim deformation of the battery pack with shock absorber at the velocity 21m/s can be observed. The kinetic energy curve starts at 1607 joules, it remains constant for the first 0.55 milliseconds, after which the battery pack gets in contact with the rigid pole. After impact the kinetic energy drops continuously until 3.8 milliseconds, being close to zero. Deformation stops when the kinetic energy of the model is absorbed in plastic deformation, and it gets converted into internal energy.

5. Conclusions

An important advantage of using finite analysis in the design of the automotive industry is the possibility of using the models at many load cases and crash scenarios, without using the physical models. This way the material and human resources are reduced, and the final product satisfies the safety and comfort required conditions. According to the simulation results, it can be observed that the use of shock absorber in the construction of the battery pack improves the safety of the battery cells. In the first simulation case at a velocity of 7 m/s of the battery pack the battery cells are not affected by the crash impact in both simulations. In the second (14 m/s) and third (21 m/s) simulation cases the battery cells are affected by the crash impact but using a shock absorber the battery cells deformation is smaller compared to the simulation of the base model battery packs.

Acknowledgments

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References

[1] Greve, L.; Fehrenbach, C. Mechanical testing and macro-mechanical finite element simulation of the deformation, fracture, and short circuit initiation of cylindrical Lithium-ion battery cells. *J. Power Sources* 2012, *214*, 377–385.

[2] Y. Xia,T. Wierzbicki, E. Sahraei, X. Zhang. Damage of cells and battery packs due to ground impact. Journal of Power Sources, 267, 2014, 78-97.

[3] J. Kukreja, T. Nguyen, T. Siegmund, W. Chen,W. Tsutsui, K. Balakrishnan, H. Liao, N. Parab. Crash analysis of a conceptual electric vehicle with a damage tolerant battery pack. Extreme Mechanics Letters, 9(3), 2016, 371-378.

[4] Hannan, M.A.; Lipu, M.S.H.; Hussain, A.; Mohamed, A. A review of lithium-ion battery state of charge estimation and management system in electric vehicles applications: Challenges and recommendations. Renew Sust Energ Rev, 2017, 78, 834-854.