Structural Lightweight Research of Module in EV Lithium-ion Battery Pack

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Abstract. As the lightest metal material in engineering application, magnesium alloy has widely prospect. In this paper, magnesium alloy is considered to design structural parts of EV lithium ion module in order to improve energy density and enhance mileage. Finite Element Models of modules in EV pack are established separately with aluminium alloy general used in EV pack and magnesium alloy AZ31B. The procedure of impact and random vibration in ABAQUS are analysed according to GB/T31647.3-2015. Compared results show that, single module decrease 0.82Kg and the energy density increase 13.4% with the performance of impact resistance and random vibration resistance better. The feasibility and lightweight effect using magnesium alloy in EV modules industry are proven. It can provide research direction for structural lightweight, energy density increasing and mileage enhancing.

1. Introduction
With the development of EV industry, the issue of safety in new energy vehicle has received considerable attention. Accompanied by the restraint of energy density and endurance mileage, EV pack is the directly targeted. Enhancing energy density in EV battery under the premise of ensuring safety and balancing the relationship between the two become hot point of industrial development.

At present, a large number of innovative researches focus on thermal runaway and spread of battery pack [1-4]. The materials and components of electrode, separator and electrolyte in battery cell level are investigated in literate [5]. Rare studies are carried on mechanical abuse, Binghe Liu [6] research the mechanical integrity of 18650 cylinder cell and Fengchong Lan [7,8] study the structural basics in pack level. There are few studies in module structure, which is critical factor to thermal runaway and spread.

As the direct sub-system of pack, the module plays a role of runaway and spread resistance. The module structure is also critical to energy density and endurance mileage. The standard of EV pack and equipments are set in GB/T 31467.3-2015, such as in China, and the product EV battery performance must meet or exceed this standard. In order to improve product competitiveness, the application prospect of the lightest metal material-magnesium alloy in battery pack module is studied in this paper.
2. Theoretical basis and material properties

2.1. Theoretical basics

2.1.1. Impact theoretical basics. As we all know, impact resistance is the basic performance for structure, especially for vehicle, a special structure always in motion. According to newton’s laws, for an impact input, the response of spring-mass system can be expressed,

\[ G_r(t) = 2\pi f_n \int_0^\infty G_i(\tau) \sin[2\pi f_n(t - \tau)]d\tau \]  

(1)

Where, \( G_i(\tau) \) is the input impact pulse in acceleration, \( G_r(t) \) is the response impact pulse, \( 2\pi f_n \) is the nature circle frequencies, \( t \) is the impact contact time.

If the impact pulse style is half-sine function, \( t \) is at level of millisecond, then \( \tau \) tends to 0, formula (1) can be written to,

\[ G_r(t) = 2\pi f_n \sin(2\pi f_n t) \int_0^\infty G_i(\tau)d\tau \]  

(2)

Structural acceleration response pulse can be calculated with above formula.

2.1.2. Random vibration theoretical basics. Power spectral density (PSD) is an expression form of random vibration. Random vibration can be expressed by random vibration signal \( x_i(t) \) at specific time \( t \). Acceleration PSD(\( f \)) is the root-mean-square of random signal passing narrow-band filter with centroid frequency \( f \) and bandwidth \( B \). When \( B \) tends to 0, average time \( T \) tends to \( \infty \), the value of acceleration PSD(\( f \)) is as follow,

\[ PSD_x(f) = \lim_{T \to \infty} \lim_{B \to 0} \frac{1}{BT} \int_0^T x^2(f, t, B)dt \]  

(3)

\[ A_{RMS} = \left( \int_{f_1}^{f_2} PSD(f)df \right)^{1/2} \]  

(4)

2.2. Impact and random vibration standard

Take Chinese national standards as example, in module impact analysis, 50g_6ms half-sine acceleration pulse is always the experience impact load. In module random vibration analysis, PSD below 1000Hz is adopted. The curve is shown in Fig.1.

![Figure 1. Impact load and PSD curve.](image)
2.3. Magnesium alloy and aluminium alloy properties

The materials test is performed on microcomputer control electron universal testing machine of MTS in Mechanics Experiment Centre of South China University of Technology under room temperature.

In order to eliminate accidental error, 6 group tests are carried out for the same tensile specimens. The average test strain rate is $7 \times 10^{-4}$ s$^{-1}$. The average true stress versus strain results of quasi-static tensile tests are illustrated in Fig.2.

![Figure 2. Results of quasi-static tensile test](image)

3. Simulation

Finite Element Models are established in Abaqus. Structural material properties are defined as curve illustrated in Fig.2. The weight in magnesium alloy models decrease 0.82Kg in single module. Simulation comparisons are carried out.

3.1. Impact and random vibration results

The impact results of structure with aluminum alloy and magnesium alloy are illustrated in Fig.3 and Fig.4, separately. Plastic strain and stress are adopted to evaluate that the materials are satisfied the structural demands or not. Plastic strain and stress nephogram are shown in Fig.3 and Fig.4. Impact results in X direction are illustrated due to space limitations in the article. The concrete results are illustrated in Tab.1.

![Figure 3. Plastic strain and stress nephogram of module structure with aluminum alloy.](image)
The random vibration results of structure with aluminum alloy and magnesium alloy are illustrated in Fig. 5. RMS are adopted to evaluate that the materials are satisfied the structural demands or not. RMS nephogram are shown in Fig. 5. Only RMS results in X direction are illustrated due to space limitations in the article. The concrete results are illustrated in Tab. 2.

3.2. Comparisons

Other directions results are concreted illustrated in Table 1 and 2. From the table, we can see that, magnesium alloy is satisfy for module impact and random vibration with lightweight.

In three directions impact analysis, the maximum response stress in magnesium alloy structure is 92.1MPa, and the maximum strain is 1.6%, when the value in aluminum alloy structure is 128.5MPa and 2.4%, the impact resistance performance is advanced. In three directions random vibration analysis, the maximum response stress in magnesium alloy structure is 11.3MPa when the value in aluminum alloy structure is 14.2MPa, the random vibration resistance performance is advanced.

| Materials       | X-direction strain (MPa) | Y-direction strain (MPa) | Z-direction strain (MPa) |
|-----------------|--------------------------|--------------------------|--------------------------|
| Aluminium Alloy | 2.4%                     | 0.1%                     | 0                        | 1.9                      |
| Magnesium Alloy | 1.6%                     | 0.1%                     | 0                        | 9.9                      |

| Materials       | X-direction       | Y-direction       | Z-direction       |
|-----------------|------------------|------------------|------------------|
| Aluminium Alloy | 14.2             | 8.6              | 2.7              |
| Magnesium Alloy | 11.3             | 7.5              | 2.6              |
4. Conclusion
The lightest engineering metallic material magnesium alloy is attempted to use in module structure. From the perspectives of structural analysis, it is fully consistent the demands, such as impact and random vibration resistance performance in this study. The investigate performance is advanced and the lightweight effect is obvious- 0.82Kg decrease and energy density increase 13.4%.

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