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RESEARCH ON SAFETY CHARACTERISTICS OF LIGHT WEIGHT FRAME COLLISION

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Abstract: Compared with traditional cars, electric vehicles carry heavier battery pack weights. Therefore, in the design process of electric vehicles, more stringent requirements are imposed on the safety and light weight of the entire vehicle. As the most important load-bearing component of electric vehicles, the frame has become a key issue in the design while pursuing the lightweight and meeting the safety requirements. Taking the electric vehicle frame as an example, the lightweight frame material Magnesium alloy metal was used and the dynamic large deformation nonlinear finite element simulation technology was applied to study the process of the frame frontal collision. Firstly, the dynamic impact finite element model of the electric vehicle frame is established, and the corresponding load and boundary conditions are applied according to the electric vehicle occupant, the load arrangement and the actual load condition of the frame. The dynamic impact test method of the electric vehicle frame pendulum is designed to verify the accuracy of the frame finite element model. On the basis of ensuring the accuracy of the model, the dynamic impact characteristics of the electric vehicle frame are analyzed, and the lightweight material, the variation of the performance parameters of the Mg alloy during the dynamic impact of the electric vehicle are analyzed, and the Mg frame is analyzed with the characteristics of the Mg alloy material. The superiority of the safety of electric vehicles lays a theoretical foundation for the wide application of Mg alloy materials on the frame of electric vehicles.

Keywords: Electric vehicles, Frame, Lightweight, Collision, Magnesium alloy.

1. Introduction

Safety, energy saving and environmental protection are the research hotspots of the 21st world automotive engineering field, and the passive safety of automobiles is an important research in automotive safety research. In car traffic accidents, the highest probability of occurrence is car collisions, with frontal collisions being the most common. For vehicles with

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non-loaded body structure, the frame is the most important energy absorbing component in car collision, and more than 50% of the impact energy is absorbed by the frame. Therefore, it is important to study the collision characteristics of the frame.

Material's role is of paramount importance to crashworthiness. Lighter materials are being developed to reduce automobile's weight for cost and emission reduction. At the same time these lighter materials should maintain the safety of the automobile according to regulations. The research in this area can be classified according to the type of material into two categories:

(1) Steel sheets have been used in vehicle structures for more than one century. Its low production costs, consistent properties and the huge accumulated and available knowledge about its production processes make it the material of choice for automobile manufacturers.

(2) Magnesium has recently received a great attention from the automotive industry due to its attractive low density. It is the lightest of all structural metals (78% lighter than steel and 35% lighter than aluminum). Moreover, it is also one of the most abundant structural materials in Earth's crust and in sea water [2]. Due to its excellent casting properties, it has been used in several automotive components, such as, engine block, engine cradle, transmission case, and instrument panel [3]. Also, it has been used as inner door frames and seats [4].

Early car crashworthiness research was mainly conducted in crash tests under various conditions, which required a lot of money and time. The finite element method for vehicle collision research can improve the collision safety of the vehicle at the design stage, which is beneficial to reduce the research and development cost of the vehicle and shorten the design cycle. At present, the work in this area at home and abroad is basically a finite element simulation study on the full-width collision of the wall front and the crashworthiness of the cylindrical collision.

2. The Shock dynamic theory of car impact.

In the frontal collision of the fixed barrier, the car collides with the fixed barrier at the initial speed. According to the analysis of a large number of automobile crash test data, when the collision speed of the car is high (such as 30km/h or more), the collision recovery coefficient is almost zero. The speed of the car after the collision is about zero, which means that the car's collision kinetic energy changes to other forms of energy almost instantaneously during the collision of the car. Considering that the collision time of the car is extremely short, the friction between the road surface and the friction between the car and the fixed barrier is much smaller than that of the car. The kinetic energy of the car consumed by the friction is small, so the total energy before the collision can be considered. Almost all absorbed by the deformation of the body. So there is

$$E = \frac{1}{2} m v_0^2 = \int_0^S F ds = m \int_0^S a(t) v(t) dt$$

Where: m is car mass; v is speed before the car collision; F is load during the car collision; S is deformation of the body under the force F, can be approximated as the displacement of the body center of mass relative to the fixed barrier; S is the maximum displacement of the car, T is from the beginning of contact to the impact of the collision time; a (t) is the deceleration of the body; v (t) is speed of the body centroid during the collision process.

It can be known from equation that the collision energy of the car is related to the acceleration and speed of the center of mass of the car, and the change in the velocity of the centroid is related to the acceleration. Therefore, the car collision energy E is closely related to the car's centroid acceleration a(t) and is closely related to the car's collision time T.

1) According to the above analysis, the frontal collision of the fixed barrier of the automobile body is closely related to the centroid acceleration of the center of the collision of the automobile, and the collision characteristics of the vehicle body can be evaluated by using

the relevant indicators of the centroid acceleration in the collision of the automobile. Therefore, the indicators for evaluating the collision characteristics of automobile bodies are as follows.

The average acceleration of the car body during the collision:

$$\bar{a} = \frac{1}{T}\int_0^T a(t)dt$$

The acceleration is related to the collision load, and the average acceleration a reflects the average collision force during the collision of the car. As can be seen from the above equation, the average acceleration a is related to the collision time T of the vehicle. The longer the collision time T, the lower the average acceleration a, the smaller the average collision load of the vehicle body, and the better the collision safety.

2）Root mean square acceleration of the car body during the collision:

$$\sigma_a = \sqrt{\frac{1}{T}\int_0^T (a-\bar{a})^2 dt}$$

In the formula, the degree of deviation between the acceleration a and the average acceleration $\bar{a}$ during the collision of the vehicle is characterized. The larger the value of σ_a, the larger the variation of the acceleration a of the vehicle, and the worse the collision safety.

3）Maximum acceleration of the car body during the collision The maximum acceleration of the car body during the collision is an important indicator of the maximum load the car is subjected to in the collision. The greater the maximum acceleration a, the greater the maximum load on the car, the worse the security.

The above three indicators complement each other and complement each other with the three indicators that represent the mean, root mean square and maximum values of vehicle crash acceleration, which can be used to evaluate the safety of vehicle body collision. The curve of the B-column deceleration and time is a common indicator.

3. Dynamic impact analysis of lightweight electric frame

3.1 Model establishment

The finite element model of the car frame was established after the construction of the overall complex structure CAD model of the frame. The frame is the main component that bears the load of the whole vehicle. It is assembled from multiple parts, and the overall structure is quite complicated. Therefore, it is very difficult to construct the overall frame CAE high-quality grid computing model based on the CAD geometric model, but the grid is the basis of finite element analysis, so the high-quality mesh model is accurate to the accuracy of the finite element analysis. It is important. This paper constructs a high-quality grid computing model for a non-loaded frame of a truck. The finite element model of the entire frame has a total of 14238 nodes, and the number of grid cells is 10080, as shown in Figure 1.

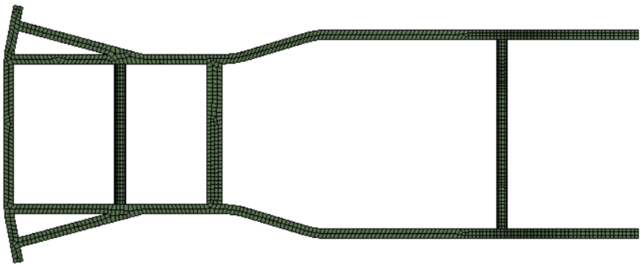


Fig 1 FEM model of Frame

3.2 Model materials

As standards for greater fuel economy tighten and automobile designs become more complex, steel simply can't deliver on higher performance expectations. Light weight magnesium requires far less energy during the entire die cast production process and designs can be far more elaborate without sacrificing strength. Tolerances are tighter and the fit and finish in the final product is vastly superior. The advantages magnesium offers over steel include:

1）75% lighter than steel；

2）Complicated thin-walled near net shape casting that would be impossible to achieve using steel；

3）Consolidation of individual components into a single die cast magnesium part, which improves rigidity while reducing welding costs and assembly time associated with steel；

4）Tooling costs are significantly reduced due to consolidation of multiple parts into a single part；

5）Lower working temperature reduces energy consumption during production and extends die life；

6）Superior dimensional stability and repeatability.

Table 1 Material properties of Steel and Magnesium alloys

	Density（Kg/m^{-3}）	**Elastic coefficient (GPa)**	**Tensile strength (MPa)**	**Yield strength (MPa)**	**Damping ratio（%）**
Steel（Spfh540）	7850	210	540	355	0.05
Magnesium（AZ91）	1830	45	230	160	3

3.3 Model boundary condition

In the international automotive crash test standard, the main forms are divided into frontal collision, offset collision (contact area 30%-70%) and side collision. Due to the limited test conditions and the verification of the correctness of the finite element model, the 260mm diameter spherical or cylindrical body was used for the crash test analysis in the test and finite element analysis. The collision speed was 32km/h in the finite element analysis.

3.4 Model verification

In order to verify the correctness of the finite element model, it is ensured that the simulation results of the steel and magnesium alloy frame are obtained separately. Dynamic impact test on a certain model frame, as shown in Figure 2, and take 8 test points, as shown in Figure 3, where 1, 2, 3, and 4 points are symmetric at 11, 12, 13, and 14 points respectively.

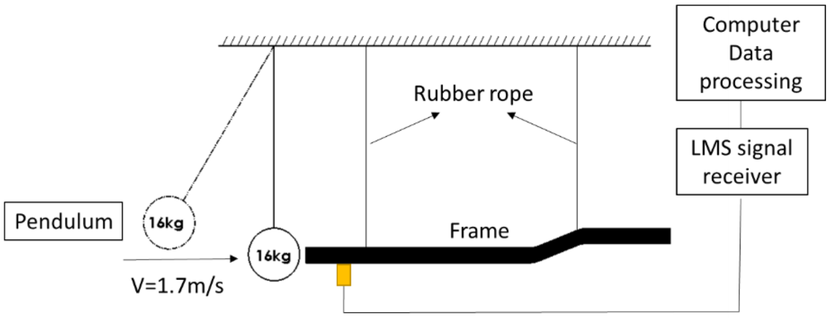


Fig 2 Impact test diagram

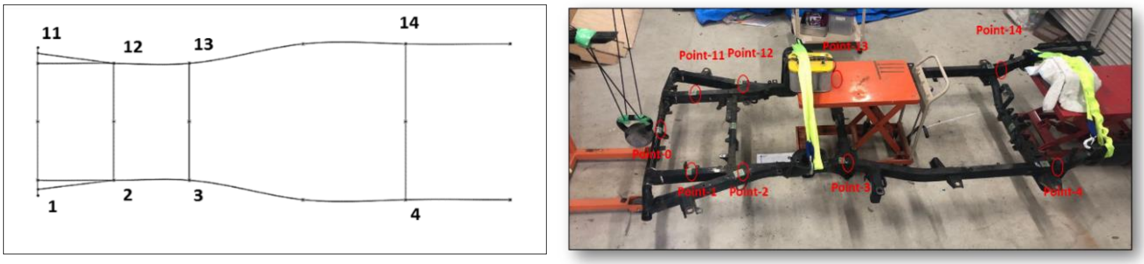
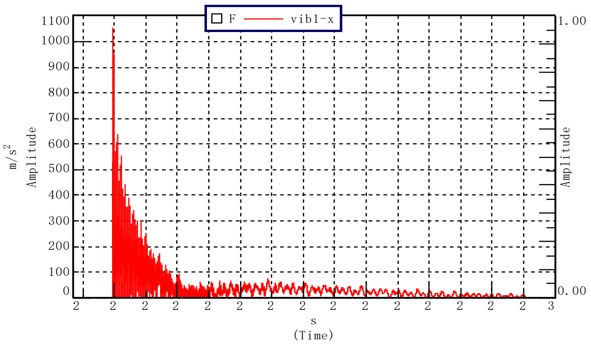
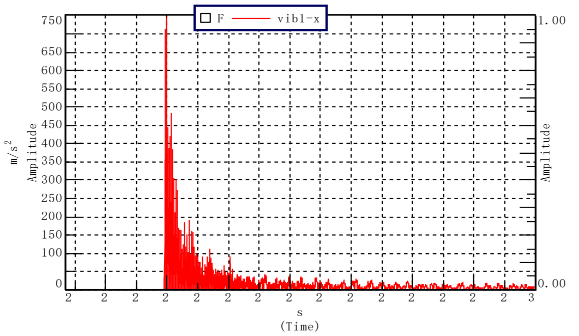


Fig 3 Test points

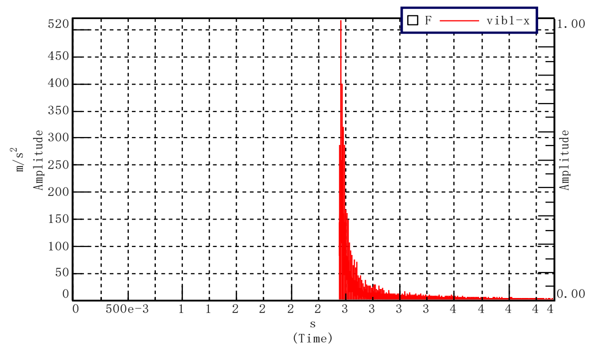
Through the impact test, the acceleration values in the X direction of 8 points can be obtained, as shown in FIG. From the test results, the acceleration peaks of 4 and 14 points far from the impact point are the smallest, and the closer the impact point is, the larger the acceleration peak is, which meets the requirements of general experimental rules.



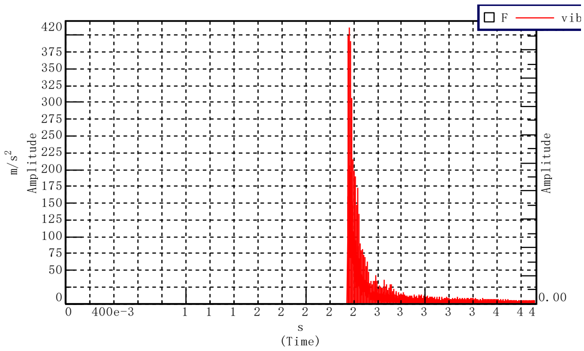
Point 1-11: Acceleration



Point 2-12: Acceleration



Point 3-13: Acceleration



Point 4-14: Acceleration

Fig 4 Acceleration of Test points

The dynamic impact simulation analysis of the frame was carried out with Ansys software, and the results were compared with the experimental results, as shown in Fig. 5. The results show that the acceleration peak and decay time of the 1 point obtained by the simulation analysis are basically consistent with the actual results, which proves that the finite element model can be used for the dynamic impact simulation analysis under different materials.

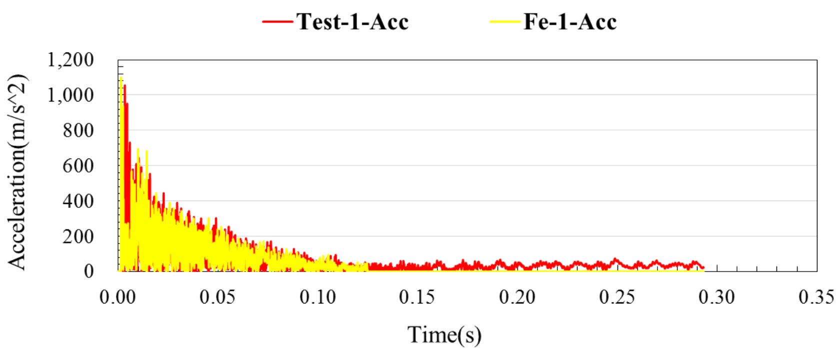
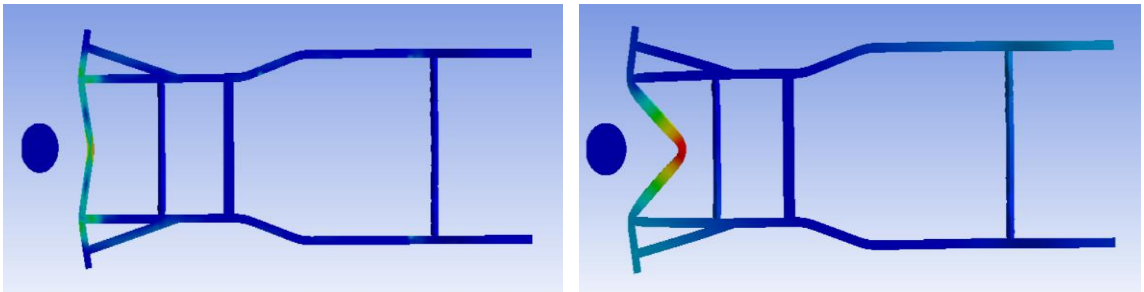


Fig 5 The comparison of 1th point acceleration

4. Comparative study of impact properties under different materials

On the basis of the above experimental verification, the impact test of the rigid frame on the steel frame and the magnesium alloy frame was carried out respectively. The numerical simulation of the rigid cylindrical deformable collision with a diameter of 260 mm was carried out at a speed of 32 km/h, and the simulation was calculated for 40 ms. The collision process, the calculation tool is the application of Ansys software Ls-Dyna module, Figure 5 is the collision simulation structure deformation results comparison chart.



a. Mg-Frame Impact b. Steel-Frame Impact

Fig 6. Mg-Frame Impact

According to the theory of judging the collision safety of the frame, the frame is not the same in density under the two materials, so the overall quality of the frame is also different. When the impact is made at the same speed, the kinetic energy is different. In this experiment, the mass of the magnesium alloy frame is 21.5kg, the kinetic energy generated by the impact is about 871J; the quality of the steel frame is 92.5kg, and the kinetic energy generated by the impact is about 3744J. The impact kinetic energy attenuation curve of the frame under the two materials is shown in Fig. 5. The results show that at the same speed, the kinetic energy generated by the steel impact is about 4.3 times that of the magnesium alloy.

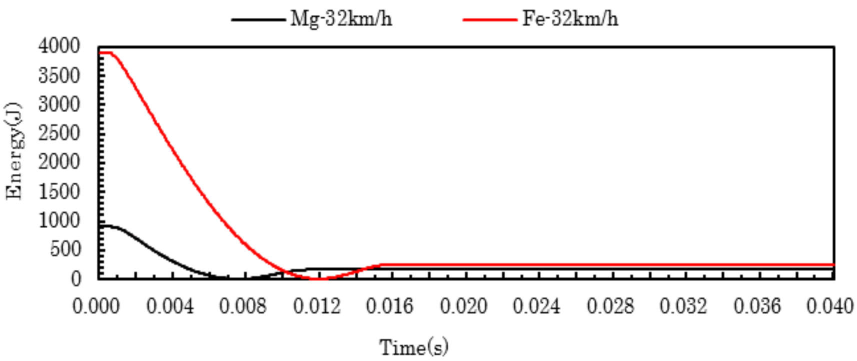


Fig 7. Impact kinetic energy attenuation under two materials

Figure 7 shows the acceleration curve of the centroid of the two materials obtained, from which the average acceleration $\bar{a}$ of the frame centroid, the acceleration root mean square σ_a, and the maximum acceleration value α_max can be obtained. Table 2 shows. According to the results obtained, under the same conditions, the impact kinetic energy of the magnesium alloy frame is not only smaller than that of the steel frame, but the three indexes related to the impact centroid acceleration of the magnesium alloy frame are smaller than the steel material, because magnesium The alloy has high damping characteristics and can achieve the purpose of rapid depletion of vibration energy, so that the average acceleration of the magnesium alloy frame is smaller than that of the steel frame, so the safety of the magnesium alloy frame is better than that of the steel frame.

Table 2. Comparison of analysis results

Materials	Mass（kg）	Knetic Energy（J）	Average acceleration $\bar{a}$（m/s^2）	Acceleration root square σ_a	Maximum acceleration α_{max}
Steel Frame	92.5	3744	1042	645	2528
Magnesium Frame	21.5	871	812	418	1677

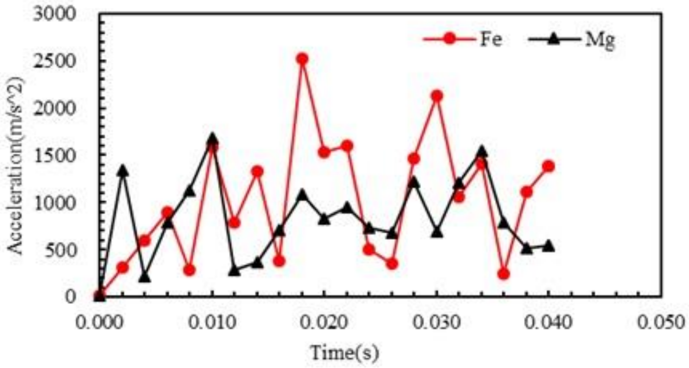


Fig 8

5. Conclusion

In this paper, the finite element model is established for the non-loaded frame of a certain type of truck, the experimental verification and the dynamic impact simulation analysis under different materials, the following conclusions are drawn.

1) According to the verification results of the acceleration decay process of the dynamic impact test, it can be concluded that the finite element model of the frame is consistent with the actual model, and the correctness of the finite element model is verified.

2) Magnesium alloy has the advantage of small density compared with steel material. The result of replacing the traditional steel structure with magnesium alloy results, the frame quality is reduced by 76.7%, and the lightweight effect is remarkable.

3) Comparing the dynamic impact results of the frame under the two materials, the energy absorption capacity of the magnesium alloy frame is due to the steel material frame, and the three indexes of the mass center acceleration of the magnesium alloy collision are smaller than the steel frame. Effectively improve the safety of the frame.

References

[1] R. Krauskopf, Introduction to Geochemistry, McGraw-Hill, 2003.

[2] S. Das, Magnesium for automotive applications: Primary production cost assessment, JOM Journal of the Minerals, Metals and Materials Society 55(11), pp. 22-26, 2003.

[3] S. Das, Primary magnesium production costs for automotive applications, JOM 60(11),

pp. 63-69, 2008.

[4] Wang Nailiang, Ji Puguang, Yin Fuxing, Research of M2052 high damping alloy applied in the vibration reduction of structural component[J], 2017.

[5] Medraj M, Parvez A. Analyse the importance of Magne-sium-aluminium-strontium alloys for more fuel-efficient automo-biles. Automotive (2007) 45–47.

[6] Baril E, Labelle P, Pekguleryuz MO. Elevated temperature Mg-Al-Sr: Creep resistance, mechanical properties, and micro-structure. Jom-Journal of the Minerals Metals & Materials Society 55(11) (2003) A34–A39.

[7] Aghion E, Bronfin B, Von Buch F, Schumann S, Friedrich H. Newly developed magnesium alloys for powertrain applications. Jom-J Miner Metals Mater Society 55(11) (2003): A30–A33

[8] Novotny S, Geiger M (2003) Process design for hydroforming of lightweight metal sheets at elevated temperatures. J Mater Process Technol 138:594–599

[9] Polmear IJ (1994) Magnesium alloys and applications. Mater Sci Technol 10(1) (1994) 1–14.

[10] MSC, Nastran Advanced Dynamic Analysis User's Guide. MSC. Software, USA,2002.

[11] S. Poulikidou, C. Schneider. A material selection approach to evaluate material substitution for minimizing the life cycle environmental impact of vehicles. Materials and Design 83(2015) 704-712.