Research and application of manufacturing technology of advanced high strength steel sheet automotive battery pack frame

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This thesis investigates the high-strength steel forming technology in battery pack frames and its application in automotive lightweighting. Through finite element simulations and experimental tests on the structural parts of battery packs for new energy vehicles, the engineering application prospects of high-strength steel materials in battery pack frames are explored. The results show that advanced high-strength steel materials have significant advantages in the safety protection and lightweighting of battery pack frames. By designing a structure conducive to roll forming, it is possible to reduce cost and improve productivity while ensuring accurate formability and reliability. In this study, 1180DP advanced high-strength steel material was successfully used to fabricate the battery pack frame, which provides an effective solution for the lightweighting of battery packs.

Keywords: Automotive lightweighting; Advanced high-strength steel; Battery pack frame; Roll forming; Roll forming die.

1. Introduction

With the rapid development of electric vehicles, automotive battery packs, as one of the core components, are subject to higher requirements for safety, lightweight and cost-effectiveness. In the design of battery packs, the selection of frame structure and manufacturing technology play a crucial role. As a lightweight and high-strength material suitable for automotive structures, the research and application of advanced high-strength steel plate in the manufacturing technology of automotive battery pack frames has become one of the hot spots of research.

Advanced high-strength steel plate has high yield strength and excellent elongation properties, which can realize a more lightweight structural design [1]. The use of advanced high-strength steel plates in the manufacturing process of automotive battery pack frames can reduce the amount of material used, improve the strength and stiffness of the structure, and reduce the overall weight. At the same time, the high strength and excellent toughness of advanced high-strength steel plates can provide better safety performance and protect the cell monomers inside the battery pack, as situations such as vibration and collision of the battery pack may occur.

In terms of manufacturing technology, a common method is to use stamping and welding processes to manufacture automotive battery pack frames, but there are many

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difficulties in forming complex structures. The stamping and welding properties of advanced high-strength steel sheets are critical to the manufacture of high-quality frames, so process optimization for the characteristics of advanced high-strength steel sheets is needed to ensure the stability and reliability of the stamping and welding processes. In addition, in order to further improve production efficiency and reduce costs, advanced forming processes, such as roll forming, can be explored to realize the continuous production of battery pack frame structural parts [2].

In practical applications, the advanced high-strength steel plate automotive battery pack frame manufacturing technology has achieved some successful cases. Through structural optimization and improvement of manufacturing process, advanced high-tensile steel plate automotive battery pack frame can achieve higher safety, lightweight and cost-effectiveness.

2. Advanced high-strength and roll forming technology

Advanced high-strength steel materials and roll forming technology are two important parts that have been widely researched and applied in the field of body lightweighting. The combination of these two technologies can improve the performance of materials and realize the goal of lightweight design.

Advanced high-strength steel materials are a class of steels with high yield strength and excellent elongation properties. They typically achieve a balance of high strength and toughness by optimizing alloy formulations and heat treatment processes. Compared to conventional steels, advanced high-strength steel materials have better tensile strength, yield strength and impact toughness, while maintaining high elongation properties. This makes them ideal for use in lightweight designs to reduce body weight and improve safety.

Roll forming technology is a commonly used method of forming sheet metal by passing the sheet through a series of rollers using a roll press, causing it to plastically deform under force [3]. Compared with the traditional press forming, roll forming has higher deformation capacity and forming accuracy, and can realize more complex forming forms, which makes roll forming a more ideal choice for processing advanced high-strength steel materials.

In the field of automobile manufacturing, advanced high-strength steel materials and roll forming technology can be combined with each other to achieve a more lightweight body structure. High-strength materials can reduce the amount of material used, while roll forming technology can provide better control and forming accuracy during material deformation. This combination can achieve higher structural stiffness and strength while reducing body weight.

3. Design and analysis of the battery pack frame

3.1. *Framework structure of battery pack*

The high-strength steel battery pack frame assumes the important role of supporting and protecting the battery module in electric vehicles. Since the vehicle will encounter different road conditions and vibration environments during driving, the metal frame battery pack must have good vibration resistance and structural stability. Vibration modal analysis is an engineering analysis method used to evaluate and optimize the vibration characteristics of a structure, which is of great significance for the design and performance analysis of metal frame battery packs. Take the battery pack structure of a new energy vehicle as an example to illustrate the principles and design methods of material selection and target requirements, and the battery pack frame model of this vehicle model is shown in Fig. 1.

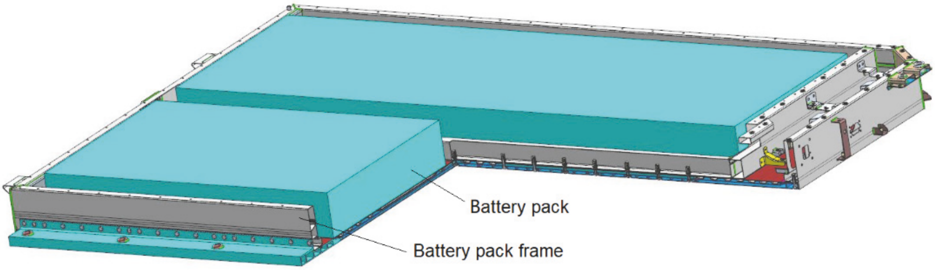

Figure 1 Frame structure of the battery pack

3.2. *Battery pack vibration modal analysis*

Vibration modal analysis can help evaluate the dynamic response and characteristics of metal frame battery packs in a vibration environment. By analyzing the intrinsic frequency, vibration pattern and mode form of the structure, the response of the metal frame under different frequencies of vibration can be understood, and then the stability, dynamic stiffness and natural frequency of the structure can be evaluated as well as other parameters. Vibration modal analysis can be used to match the vibration characteristics of a metal frame battery pack to other systems. For example, the battery module itself will have specific intrinsic frequencies and vibration characteristics. If the vibration frequency of the battery pack is matched to that of the battery module, this may lead to resonance phenomena and vibration concentration, increasing the risk of vibration stress and fatigue damage to the structure. Through vibration modal analysis, the intrinsic frequency of the metal frame can be determined and adjusted to avoid resonance with other systems.

By understanding the vibration characteristics of metal frame battery packs, it is possible to optimize and improve the structure based on the results of the analysis. By adjusting the design parameters such as material selection, structural form, and connection method, the vibration resistance and vibration characteristics of the structure can be improved, vibration interference and vibration transmission can be reduced, and the stability and safety of the metal frame can be improved.

Vibration modal analysis of metal frame battery packs can help evaluate and optimize their vibration characteristics and improve the stability and vibration resistance of the structure. This is essential to ensure the safety, reliability and longevity of the battery pack, while also helping to optimize the driving comfort and ride experience of the electric vehicle.

3.2.1. *Material Characterization*

The use of advanced high-strength steel has obvious advantages for lightweighting and cost reduction. Considering the material cost and the mechanical properties of the material, two advanced high-strength steels, GC820/1180DP and HC1200/1500MS, are selected for comparison. Fig. 1 and Fig. 2 are the material composition and mechanical properties of the two materials, respectively, comparison shows that with the increase in carbon content, the material's strength increases significantly, the brittleness is also a corresponding increase in the material's elongation decreases accordingly. The composition of the material is shown in Table 1.

Table 1 Chemical composition of advanced high strength steels 1180 DP and 1500MS (wt.%)

Material	C（%）	Si（%）	Mn（%）	P（%）	S（%）	Al（%）
GC820/1180DP	0.13	0.43	2.53	0.008	0	0.028
HC1200/1500MS	0.207	0.503	2.12	0.009	0.0005	0.05

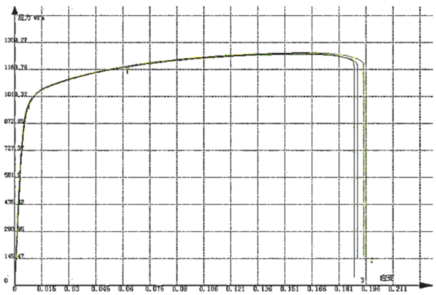

Fig. 2 Tensile curve of GC820/1180DP material.

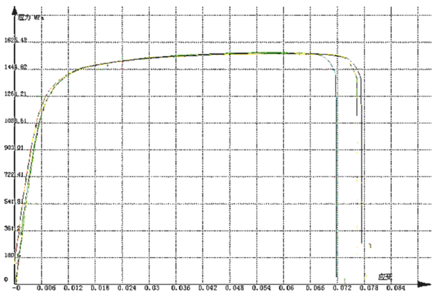

Fig.3 Tensile curve of HC1200/1500MS material

3.2.2. *Vibration modal analysis results*

In order to further analyze the safety of different materials in the application to the production of the battery pack frame, respectively, GC820/1180DP and HC1200/1500MS two kinds of materials for the molding calculation and analysis, its first-order modal values as shown in Table 3, the modal analysis is shown in the following Figures 4 and 5, which the material thickness of GC820/1180DP material is 1.0mm, HC 1200/1500MS material thickness is 0.8mm.

Table 3 GC820/1180DP, HC1200/1500MS battery pack case modal values.

	GC 820/1180DP	HC 1200/1500MS
Thickness（mm）	1.0	0.8
Modal value（Hz）	39.9	38.3

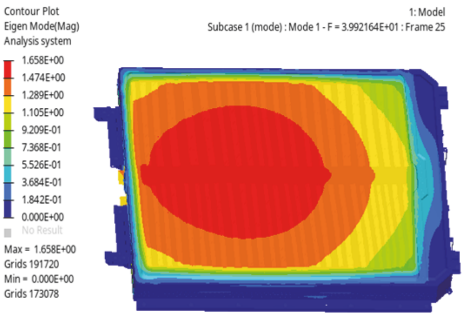

Fig. 4 Results of the first-order modal analysis of the whole package case of GC820/1180DP material (thickness of 1.0mm)

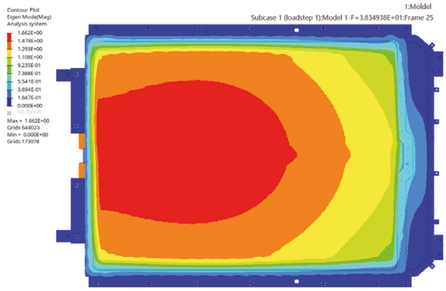

Fig. 5 Results of the first-order modal analysis of the whole package case of HC 1200/1500MS material (thickness of 0.8mm)

It can be seen from the modal analysis graphs that with the increasing strength of the used materials and the reduction of the material thickness, the first-order modal values of the whole package case show a decreasing trend, but the overall decrease is small.
By simulating and analyzing the strength of the whole package of GC820/1180DP and HC1200/1500MS materials, the strength values are shown in Table 4, and the strength simulation results are shown in Figures 6 and 7.

Table 4 Strength values of GC820/1180DP and HC1200/1500MS battery pack cases

	GC 820/1180DP	HC 1200/1500MS
Thickness (mm)	1.0	0.8
Deflection (mm)	0.55	0.59

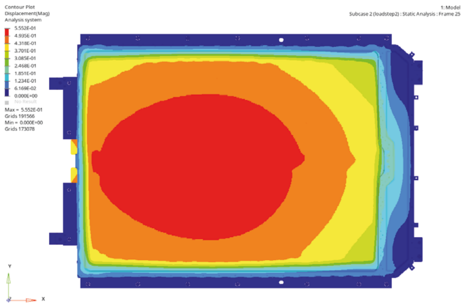

Fig. 6 Strength analysis results of the whole package case for GC 820/1180DP material (thickness of 1.0mm)

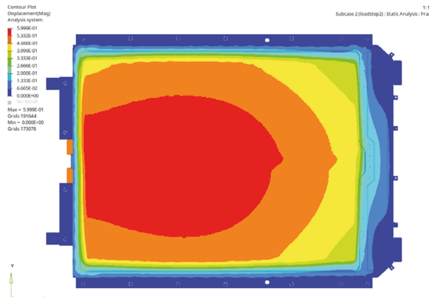

Fig. 7 Strength analysis results of the whole package case for HC 1200/1500MS material (thickness of 0.8mm)

Calculations show that as the strength of the whole pack increases and the material thickness decreases, the deformation of the whole pack does not change much, which indicates that it has a better ability to resist deformation when encountering external forces. After the vibration modal analysis of materials with different material thicknesses, it can be seen that as the strength of the material increases, the modal and strength of the whole pack case of the battery pack are within the safe demand range. It shows that the use of thinner high-strength steel material can balance the lightweight and safety performance of the battery pack. Therefore, from the comprehensive consideration of lightweight and material performance, GC 820/1180DP ultra-high-strength steel is more valuable for engineering applications.

4. Roll forming process and mold for battery pack frame

Adopting advanced high-strength steel roll forming technology, AHSS DP1180 high-strength steel plate can be roll formed into the battery pack frame, which can avoid the shortcomings of high-strength steel cold stamping such as cracking, rebound and warpage. Roll forming is a process based on the principle of progressive forming, which utilizes a multi-pass roll forming die to continuously roll deform the steel plate, which is a progressive forming method to achieve the desired shape and size. Precise deformation of high-strength steel plates can be achieved by adjusting the parameters of the roll forming process, such as the spacing of the roll forming dies and the shape of the roll forming dies.

The study was carried out in the company's existing roll pressing line for the production of "日" type roll pressed parts. The roll pressing line is shown in Figure 8. The existing roll forming line has a 32-section roll forming line, which is mainly welded by laser welding during the production process.

Fig. 8 Roll forming line (32 passes)

4.1. *Battery pack frame part modeling*

At present, researchers have studied more on the cross-sectional deformation of simple cross-sectional profiles. In the existing automobile crash beams and body structural components, because most of the research objects are mainly rectangular or round tubes with simple cross-section, the laws obtained have reference value but are not very applicable to profiles with complex cross-section, especially the "day" cross-section profiles involved in this study [4].

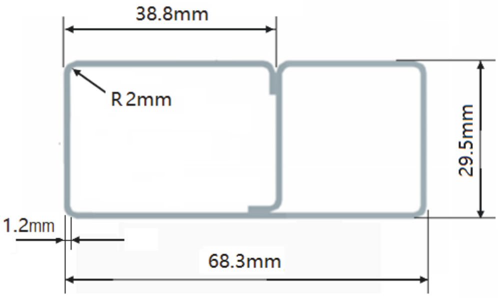

Fig. 9 Cross-section of the battery pack frame

4.2. *New roll forming process for battery pack frame*

In the roll forming design of the rolled part, the initial design of the roll forming diagram is shown in Figure 10 below, and the stress situation in the roll pressing process is shown in Figure 11. By simulating the roll pressure of the rolled parts in the roll pressing process, it can be found that the stress concentration and uneven distribution in the roll pressing process will cause cracking and twisting of the material during the roll pressing, so it is necessary to reoptimize the design of the roll pressing process.

Figure 10 Roll pressing diagram of the product molding process

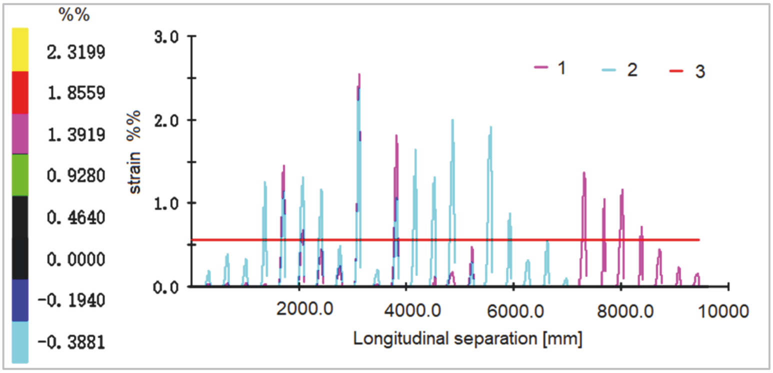

Figure 11 Stress change of sheet material in the roll forming process before optimization

In order to reduce the stress concentration and uneven distribution in the roll pressing process, and to avoid serious cracking and distortion of the material, it is necessary to optimize the design of the roll pressing process to reduce the roll pressing angle and the distribution of stress in the front section. The optimized design of the roll pressing process is shown in Figure 12, and the stress situation of the roll pressing process is shown in Figure 13. It can be found that the stress of the roll pressing process is significantly reduced (from the original maximum of 2500 microstrain, reduced to a maximum of 1630 microstrain), and the risk of roll pressing cracking and twisting is reduced. Therefore, it is determined to carry out roll pressing production according to the optimized roll pressing process scheme.

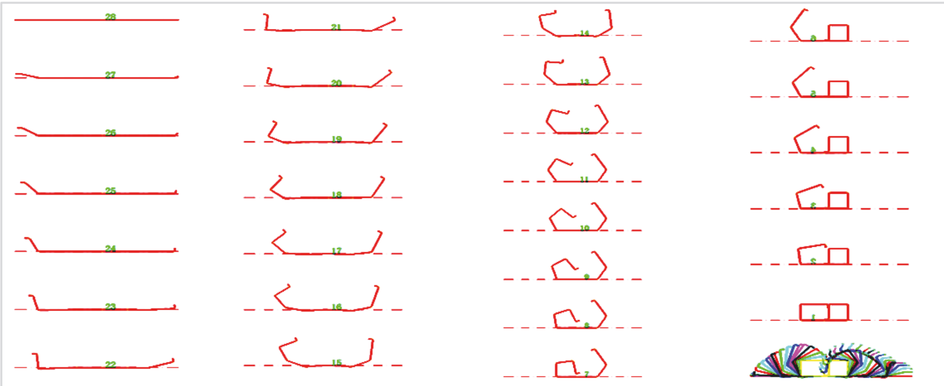

Figure 12 Optimized roll forming process flow diagram

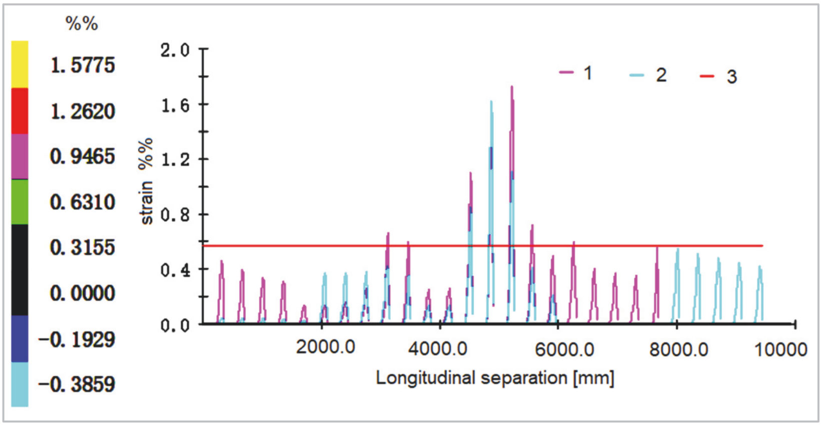

Fig. 13 Stress change of sheet material in optimized roll forming process

The parameters related to the roll forming process and the roll forming equipment are as follows: 1) the forming machine adopts 80-axis roll forming line, and the number of forming segments is 48 segments; 2) the welding method is laser welding; 3) the forming speed is 4-6m/min.

4.3. *Battery pack frame roll mold design*

Roller press dies can be designed and manufactured to meet specific forming requirements. The contour shape of the convex roll die matches the shape of the molded part, and the material is continuously pressed and deformed by the upper and lower rolls of the roll press. The contour of the concave die conforms to the internal shape of the molded part, and the material is continuously pressed and deformed by the upper and lower rolls of the roll press.

During the forming process, a revised roll design is required to ensure the accuracy of the formed rolled product. The original roll design and product accuracy are shown in Fig.14, and the upper and lower rolls are of flat design. In testing the original program, it was found that there was rebound in the straight part of the rolled product, which resulted in poor accuracy of the produced product. The original tolerance range is ±0.5mm, while the error at the straight end is +0.973mm, exceeding the error allowance by 0.473mm.

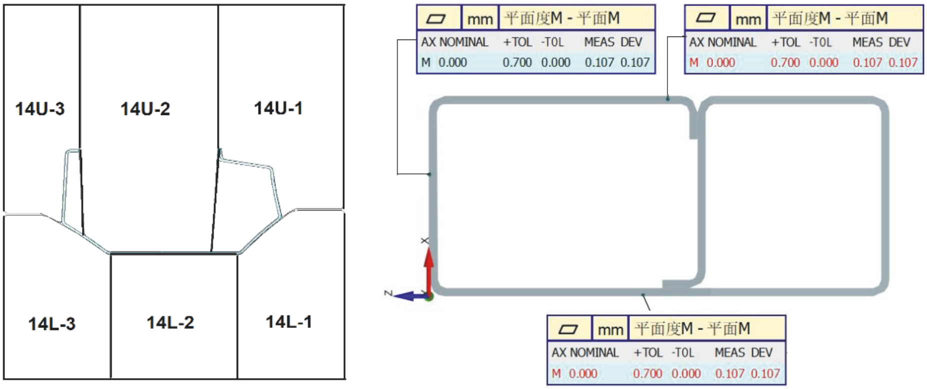

Figure 14 Roller design of the original program debugging (left) and product testing data graph (right)

In order to ensure the dimensional requirements of the formed product, the rollers are redesigned, due to the existence of a certain amount of residual stress in the material during the rolling process will cause the product to rebound affecting the dimensional accuracy of the product, so it is necessary to consider adding a certain amount of compensation in the design of the rollers. Redesigned roller and product accuracy is shown in Figure 15 below. After adding rebound compensation to the bottom of the roller, the product accuracy meets the requirements.

The roll mold manufacturing process requires control and monitoring of the roll forming process to ensure that the formed battery pack frame meets the design requirements, including real-time monitoring and adjustment of process parameters, temperature, pressure, etc., to ensure the stability of forming quality and performance.

Roll material used in the roll forming process is Cr12MoV, heat-treated surface hardness of HRC58-62, the precision requirements of the roll in the process as shown in Figure 16.

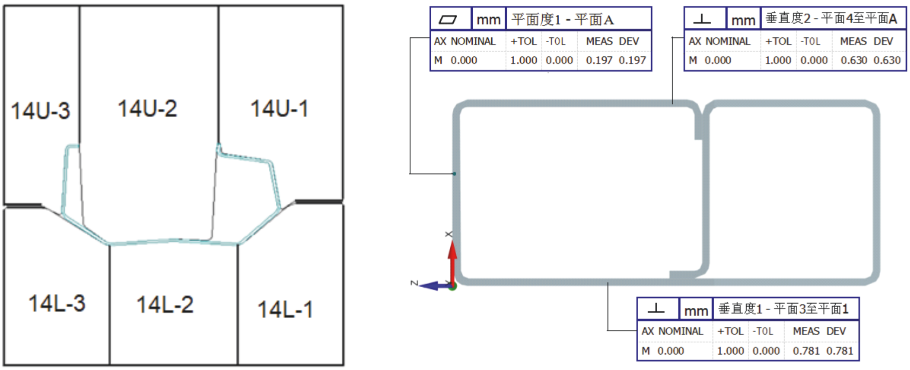

Figure 15 Optimized roller (left) and product accuracy test data (right)

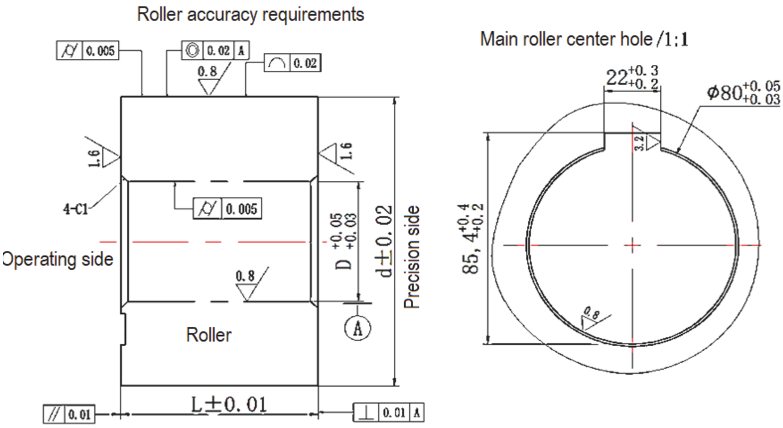

Figure 16 shaft diameter of 80mm roller processing accuracy standards

Roller press equipment and related technical parameters are: 1) roller lower shaft center to the base plate distance of 290mm; 2) roller upper and lower shaft minimum and maximum adjustable for 160mm-300mm; 3) mounting roller distance of 550mm; 4) roller material Cr12MoV, with vacuum quenching, hardness of HRC58-62; 5) each piece of the roller thickness tolerance of ± 0.01; 6) The keyway of the roller is 22mm flat key. The roll pressure of each pass in the roll pressing process is shown in Fig. 17 below, and the pressure of the roll path is from 70,000N to 77,000N, which can be seen that the force in the roll pressing process is more uniform.

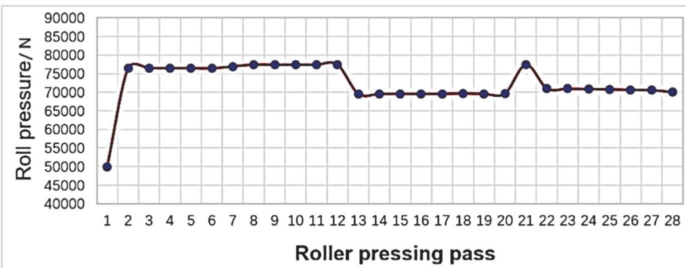

Fig. 17 Calculation of roll pressure in each pass during roll pressing

5. Conclusion

The study demonstrates that advanced high-strength steel (AHSS) materials enhance the safety and lightweight design of battery pack frames. Finite element simulations and experimental tests investigated the engineering applications of AHSS materials. A structure designed for roll forming reduces costs and enhances productivity. The battery pack frame was fabricated using DP1180 AHSS, providing a solution for lightweight battery packs. AHSS possesses high yield strength and ductility, enabling lighter weight designs. Roll forming technology allows for intricate forms, resulting in lighter weight body structures, increased strength, reduced overall weight, and fewer joining welds and joints.

Vibration modal analysis plays a crucial role in the design and performance analysis of metal frame battery packs. It facilitates the assessment of stability parameters, dynamic stiffness, and natural frequency. Adjusting design parameters enhances vibration resistance, improving stability and safety. Roll forming enables precise deformation of high-strength steel plates. Technical parameters and design requirements of roll forming equipment and molds are described. Real-time monitoring and adjustment of process parameters ensures forming quality and performance.

The research and application of AHSS manufacturing technology for automotive battery pack frames are significant in the electric vehicle industry. Utilizing AHSS materials and roll forming technology achieves lightweight and safe battery pack frames. Further research and optimization of material selection, process parameter control, and roll forming die design are necessary to advance AHSS automotive battery pack frames.

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