Research and application of roll forming technology of 1500MPa advanced high strength steel for automobile bumper

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In this paper, the advanced high-strength steel roll forming technology for automobile crash beams and its applications are studied. Firstly, the importance and research background of automobile crash beams and the advantages of high-strength steel materials in improving the safety performance of automobiles are introduced. Then the key parameters of the roll forming process are discussed in detail, including the elements of roller design, load distribution of the multi-pass roll forming tooling, and roller gap adjustment control. The design of the roll forming process was determined by analyzing the material properties of high-strength steel. Then the simulation and data analysis of the roll forming process were carried out, and the sheet strain in each pass was predicted by finite element simulation, and the mechanical properties and surface quality of the formed parts were evaluated. Finally, the production test of roll forming of high-strength steel for crash beams was carried out, and the crash beams meeting the design requirements were successfully manufactured by accurate roll forming mold processing and high quality mold materials. The dimensional accuracies of the formed parts were examined, and the results showed that the dimensional accuracies of the formed parts were within the permissible range. This study proves the feasibility and superiority of advanced high-strength steel roll forming technology in the manufacture of automotive crash beams.

Keywords: Automotive crash beam; Advanced high strength steel; Roll forming; Process optimization; Incremental forming.

1. Introduction

As an important safety component, automobile crash beams have a long history of research and rich research results. In the international arena, early research focused on examining the energy absorption effect and impact resistance of crash beams of different materials and structural designs through experimental methods. With the development of material science, computer simulation technology and manufacturing process, the research in recent years has focused more on how to make lighter, stronger and safer crash beams through advanced materials and innovative manufacturing process. The emergence of high-strength steel has brought new opportunities to this research field. In developed countries of the automotive industry, such as Europe and the United States, high-strength steel roll forming technology has been widely studied and gradually applied in actual production, and its research results have not only improved the performance of the crash beam, but also contributed to the technological progress of the entire automotive industry [1].

Automotive crash beam, a kind of safety protection device located at the front and rear ends of the car, is designed at the beginning of the idea is to be able to effectively absorb

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and disperse the energy generated by the collision in the event of a collision, in order to minimize the damage to the occupants of the car. Its role is not only to absorb the collision force, but also in different forms of impact, through its unique structural design, the impact force will be uniformly transmitted to other parts of the car body, so as to avoid the concentration of force on a part of the body to cause excessive damage. In terms of construction, crash beams are usually made of high-strength materials that can deform plastically during impact while maintaining a certain degree of structural integrity, preventing the collision force from acting directly on the passenger compartment. Its structure is characterized by simplicity and robustness, and is usually arranged horizontally to complement the longitudinal mechanics of the vehicle to achieve optimal energy absorption.

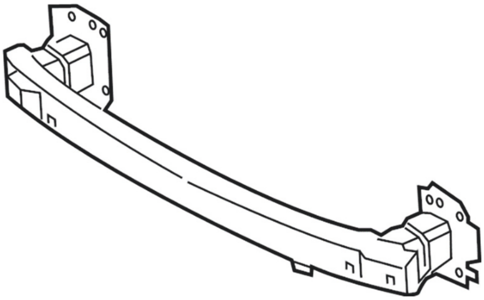

Fig. 1 Schematic diagram of a front bumper beam of an automobile

In the rapid progress of the automotive industry, the design of the crash beam is continuously optimized and the structure is becoming more and more complex, evolving from a simple steel tube structure to a multi-cavity structure, or a special shape structure made of multiple materials to meet the ever-increasing safety standards. Designers need to consider not only the performance in frontal, side and rear-end crashes, but also the overall aesthetics and aerodynamics of the vehicle. As a result, the design of crash beams is no longer limited to the traditional linear or U-shaped structure, but is more about harmony and consistency with the overall design of the vehicle, as well as reducing its own weight as much as possible without sacrificing performance.

2. Advanced high-strength steel and roll forming technology

In terms of material selection for automotive crash beams, high-strength steel is popular because of its excellent performance. High-strength steel refers to steel grades that have higher strength and better toughness than conventional carbon steels, and can provide equal or higher load-carrying capacity in smaller cross-section sizes, a characteristic that makes high-strength steel an ideal material for improving automotive safety performance. When used in the manufacture of crash beams, we can see that the advantages they bring are manifold. First of all, high tensile steel has higher strength, which means that in a collision, the beam can withstand greater impact without break, effectively maintaining structural integrity and providing a stronger protective barrier for occupants. Secondly, the good plasticity of high-strength steel makes it in the absorption of collision energy can produce more obvious plastic deformation, this deformation can absorb impact energy to a greater extent, reducing the impact on the passenger compartment. In addition, the application of high-strength steel is also in line with the development trend of automotive lightweighting, by reducing the weight of the impact beam, can reduce the overall vehicle mass, thereby improving the fuel economy and dynamic performance of the vehicle.

However, these advantages of high-strength steel do not come without a price. They are much more difficult to process than ordinary steels, mainly due to the high resistance to plastic deformation associated with high strength, as well as the rebound phenomenon that can occur during the forming process. As a result, conventional press forming technology often requires greater forming forces and more complex mold design when applied to high-strength steels. In contrast, roll forming technology has gradually become the technology of choice for the manufacture of high-strength steel crash beams due to its unique process advantages.

Taken together, whether from the perspective of enhancing automobile safety performance, or from the perspective of promoting the technological progress of the automobile industry and promoting the general background of automobile lightweight design, the study of automobile crash beams, especially the crash beams manufactured by high-strength steel roll-forming technology, is of great practical significance and far-reaching theoretical value. It can not only provide more reliable safety protection for the occupants, but also provide innovative power for the sustainable development of the automobile industry.

2.1. *Analysis of High Strength Steel Material Properties*

High-strength steel is a widely used material in modern industry, especially in the field of automobile manufacturing, because of its excellent strength to toughness ratio, it has become an ideal choice to improve the safety performance of vehicles. Before discussing the roll forming technology of high-strength steel in depth, it is necessary to have a comprehensive understanding of the material properties of high-strength steel, including its chemical composition, microstructure, mechanical properties and the mutual influence with the forming process.

Table 1 Chemical composition of HC1200/1500MS steel (wt.%)

Material	C	Si	Mn	P	S	Al
HC1200/1500MS	0.207	0.503	2.12	0.009	0.0005	0.05

Table 2 Tensile test results of HC1200/1500MS steel

Material	**Yield Strength /MPa**	**Tensile Strength /MPa**	**Elongation /%**	**Uniform elongation %**
HC1200/1500MS	1357	1578	5.9	3.4

The chemical composition of advanced high-strength steels is usually composed of low-carbon microalloys, as well as trace amounts of alloying elements such as manganese, silicon, and aluminum. The precise ratio of these elements not only determines the hardness of the steel, but also affects the plasticity and toughness of the material. The material composition of a typical advanced high-strength steel HC1200/1500MS is shown in Table 1. Through the cold rolling and heat treatment process, high-strength steel can obtain a variety of microstructures, such as fine-grained ferrite, bainite or martensite, so that the material has excellent mechanical properties, the mechanical properties of the pieces Table 2.

In terms of mechanical properties, high-strength steel has high yield strength and tensile strength, and can withstand large loads without permanent deformation. In addition, good elongation and impact resistance are also performance indicators that cannot be ignored for high strength steel, as shown in Figure 2. The combined effect of these mechanical properties makes high-strength steels have special behavioral modes during roll forming, such as elastic rebound, stress concentration, and buckling instability, which need to be focused on in our roll forming technology.

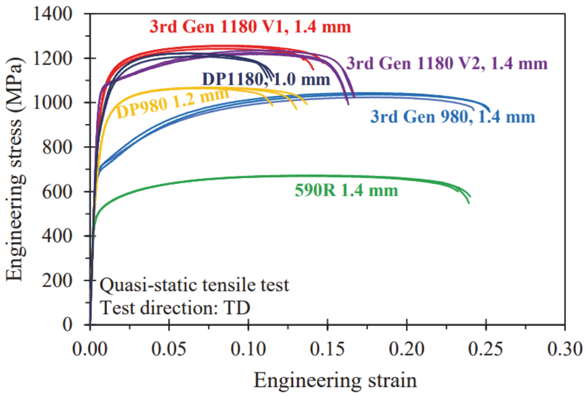

Fig. 2 Engineering stress-strain diagram of advanced high-strength steel [2]

The analysis of the properties of high-strength steel materials provides a solid foundation for us to grasp the application details of roll forming technology more accurately, and provides the necessary theoretical support for the realization of high-quality automotive bumper beam forming.

2.2. *Roll forming process*

The progressive forming stage is the core of the roll forming process, and its main purpose is to make the plate undergo continuous bending through the gradual pressing of multiple sets of rollers to gradually form the required cross-section shape, see Fig. 3. Under the pressure of multiple pairs of roll pressing molds, the deformation amount of each step is subject to the amount of deformation that does not produce a large residual stress, and in the process of multiple bending and deformation by pressure, the bending angle is under a certain range of control to prevent the accumulation of deformation, see Fig. 4. Accumulation of deformation stress, see Figure 3 In this process, roller gap, pressure, speed and synchronization and other parameters will directly affect the precision and surface quality of the formed parts. In addition, the processing temperature is also a control factor, the appropriate temperature can reduce the elastic rebound of the material and improve the stability of forming.

Roll forming technology is a continuous bending deformation through the metal plate gradually formed into the desired cross-section shape of the process. In order to ensure that the forming process is carried out smoothly and the quality of the formed parts meets the requirements, each aspect of the process must be closely planned and controlled. The roll forming process usually consists of material preparation, coil slitting roll forming, straightening and cut-off steps, see Figure 4.

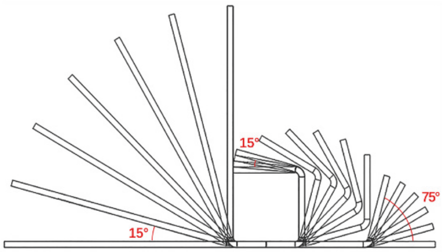

Fig. 3 The process of progressive forming by roll forming of sheet material [3]

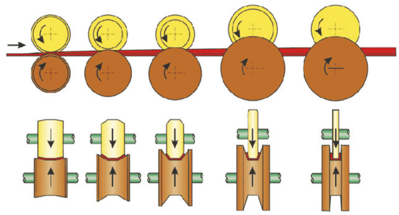

Fig. 4 Principle of roll forming equipment for steel plates [4]

After the forming is completed, the straightening process is essential to eliminate warping and bending caused by uneven internal stresses in the material. Finally, the continuous formed parts are cut into predetermined lengths by precise cutting for subsequent assembly and use.

2.3. *Analysis of key parameters of roll forming technology*

The key parameters of roll forming technology include, but are not limited to, roller design, forming speed, roll gap adjustment, temperature control, etc. Reasonable selection and adjustment of these parameters are crucial to ensure the stability of the forming process and the quality of the formed parts.

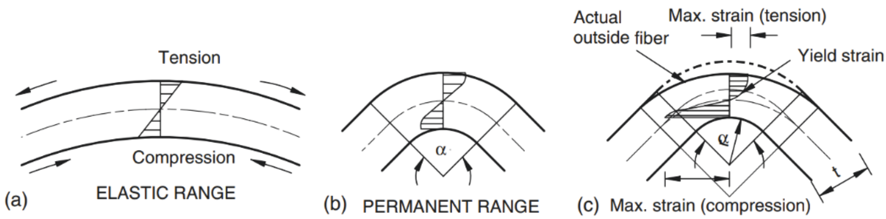

Fig. 5 Forming forces in high-strength steel leading to plastic and elastic deformation [5].

Forming forces exceeding the yield strength of the material lead to plastic and elastic deformation, as shown in Fig. 5. Plastic deformation holds the metal in the shape to be formed and elastic deformation causes springback. Figure 5a shows the plastic and elastic

…the same amount of elastic
…reases due to the increased relative amount of elastic

(1) Strip width calculation

Strip width calculation is an important step in the roll forming process. In the roll forming process of high-strength steel, the actual width change caused by the deformation and thinning of the sheet needs to be considered. The cross-section for roll forming usually consists of a combination of one or more elbows and planes. The process of calculating the strip (billet) width consists primarily of estimating the arc lengths of the bends (centerlines) and adding the sum of these bends to the lengths of all the planes associated with completing the cross-section.

During roll forming, bends are formed gradually until the final forming angle is reached. Bending the metal puts the inner bending radius in compression while the outer bending radius elongates. Somewhere between the inner and outer bending radii is a portion of the material that is not affected (or neutralized) by the forming. This is the true arc length of the bend that needs to be predicted. Although in theory the outer radius will be exactly one material thickness greater than the inner radius of the bend, a slight thinning (necking) usually occurs naturally. This thinning can cause problems when calculating strip widths because excess material not consumed within the bend angle is usually transferred to adjacent planes, which may result in burrs or other defects. Thinning is more pronounced in thicker materials or when the inner bend radius is less than the recommended ASTM specification for a given material type and grade. Therefore, this thinning phenomenon needs to be additionally considered when calculating strip widths to minimize the impact of potential errors on the final part geometry.

The mechanical properties of the metal material, including yield strength, ultimate tensile strength, and elongation, also need to be considered in the strip width calculation. As a rule of thumb, the strip width can be estimated by calculating the bending allowance and arc length, and then adding the remaining plane of the profile to it.

(2) Roller design

Rolling die (roller) design is a key link in the realization of high-strength steel roll forming, a reasonable roller profile can reduce the rebound effect of the material, reduce the stress concentration phenomenon, thereby improving the forming accuracy. Roller material selection also need to consider wear resistance and fatigue resistance, in order to cope with the high hardness of high-strength steel plate material and the wear problems… continuous forming.

(3) Roll speed desi…

cracks or fractures; while too slow forming speed will reduce production efficiency, and may lead to heat accumulation, affecting the mechanical properties of the material. Therefore, through an in-depth analysis of the physical properties of the material, selecting the optimal forming speed to balance productivity and product quality is a key link in roll forming technology.

(4) Roller gap adjustment

Adjustment of roller gap is also a technical difficulty. Appropriate roller gap can make the material in the forming process get uniform pressure distribution, reduce the local excessive deformation. In addition, the dynamic adjustment of roll gap can cope with the fluctuation of material thickness and ensure the consistency of the size of the formed parts.

Through the detailed analysis and optimization of the key parameters in roll forming technology, the stability of the roll forming process of high-strength steel and the quality of the formed parts can be ensured, which provides a solid technical guarantee for the safety performance of automotive crash beams. The precise control of these parameters is the cornerstone for realizing high-efficiency and high-quality production of automobile crash beams, which is also one of the core contents of this thesis.

3. Research on roll forming process of high-strength steel for bumper

3.1. *Roll forming process and parameter design of part with cross-section shape*

After material testing to determine the mechanical properties of the material, the next focus is on the roll forming process parameters of high-strength steel for precision design. The design process is based on the mechanical properties of the material, the characteristics of roll forming machinery and the complexity of the forming process. First, a roll-forming part with a closed cross-section was designed, as shown in Figure 6. The outer dimensions of the cross-section are height h=135±0.5mm and width w=40±0.5mm.The thickness of the sheet is t=1.10mm.

The roll-formed profile is formed by roll bending, in which the outer arc radius is R2000.The key parameters affecting the forming quality of the material in the roll forming process are analyzed, including the roll pitch, the roll speed, the roll diameter size, and the roll temperature, etc. These parameters affect the forming quality of the material in the forming process. These parameters have a direct influence on the degree of deformation, deformation rate and thermal state of the material in the forming process, which in turn determines the geometric accuracy, surface quality and microstructure of the formed parts.

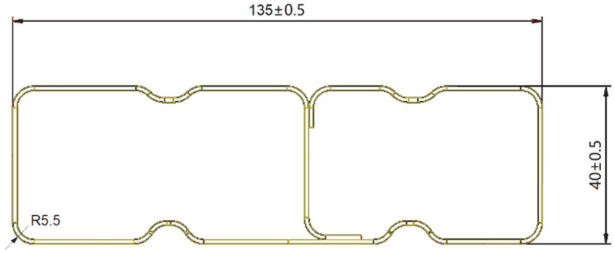

Fig. 6 Cross-sectional structure design of a crash beam

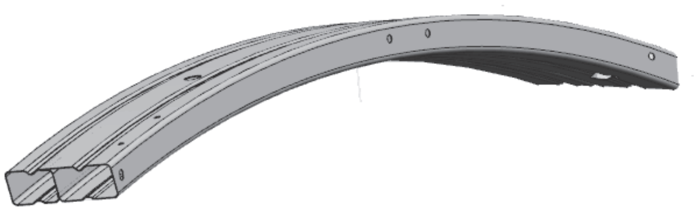

Fig. 7 Three-dimensional structure of the front bumper beam of a passenger car

For the roll pitch, a preliminary range of roll pitch is determined through theoretical calculations and preliminary tests. Considering the dual effects of roll pitch on material fluidity and forming force, a step-by-step approximation method was adopted to refine and adjust the parameters of roll pitch in order to find the optimal balance point. In the selection of rolling speed, based on the deformation characteristics of the material and the requirements of forming efficiency, the test program at different speeds was formulated, and a suitable speed interval was determined through comparative analysis. As for the size of the roll diameter, combined with the actual situation of the equipment and the size requirements of the roller parts, a moderate roll diameter was selected to ensure that the material can achieve a smooth flow in the molding process. In addition, the control of roller temperature is also an important aspect of this experimental study. By setting different temperature conditions, the effects of temperature change on the plastic deformation capacity and microstructure of the material were analyzed, and the temperature control strategy was further optimized.

3.2. *Simulation and data analysis of roll forming process*

According to the structural shape of the design of the cross-section of the impact beam and the characteristics of the selected advanced high-strength steel material, the process plan of roll forming with 40-48 passes is formulated, and through computer simulation, the deformation of each roll pass is shown in Fig. 8, and the data of the finite element simulation is shown in Table 3. 46 roll passes are determined by evaluation, and there are also 2 passes of laser welding, and the last pass is for the cut-off process.

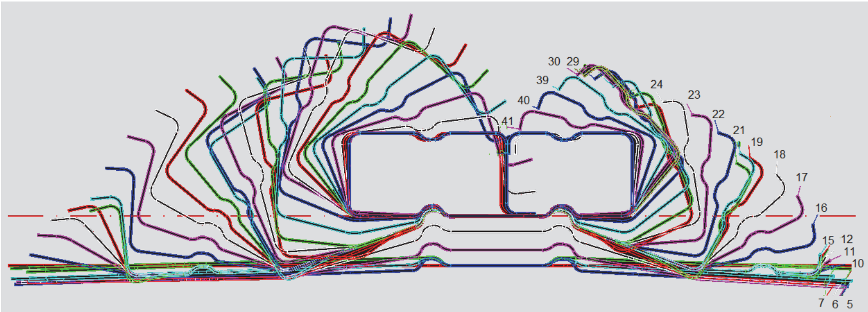

Fig. 8 The result of roll pressing progressive molding simulation according to 45 roll passes

Table 3 HC1200/1500MS Simulated parameter settings

Mesh-Settings:	Material Properties:
SubDiv Straigth 0.5	Name HC1200_1500MS comment
SubDiv Arcs 0.3	
SubDiv Z 0.5	sg [t/mm3]0.0000e+00
Poisson 0.30	Poisson 0.30
Layers 1.0	Young's Modulus 210.0 [GPa]
Technical Data Sheet: yes	Technical Data Sheet: yes YS 1200.0 [MPa]
Mesh All no	UTS 1500.0 [MPa]
Ref Station 46	Ag 2.00
UTS 1500.0 [MPa]	
Starting Station: 0	
End Station: 46	

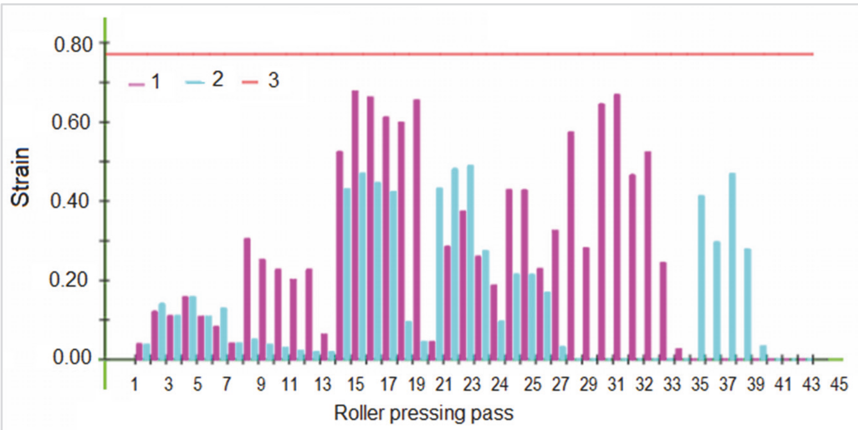

Fig. 9 Calculation of sheet strain per pass predicted by simulation

In order to avoid uneven stress and stress concentration in certain passes, simulation calculations of the loading and deformation stress of the sheet were performed, and the results are shown in Fig. 9. By adjusting and optimizing, the strain of the sheet on all the roll dies is lower than the rated value of the material, and no additional elastic stresses are generated. The No. 3 (orange) line in the figure is the permissible strain security. The strains of 11,21, and 37 passes were analyzed respectively, and the yield strength, tensile strength, and elongation of the formed parts were Checked to evaluate their final product stress state, see Fig. 10.

The test results show that the mechanical properties of the formed parts can be significantly improved by the optimized roll pressing process parameters, especially in improving the yield strength and tensile strength. In addition, the inspection of the surface quality of the molded parts also shows that the adopted process parameters can effectively reduce the surface defects and ensure the overall quality of the molded parts.

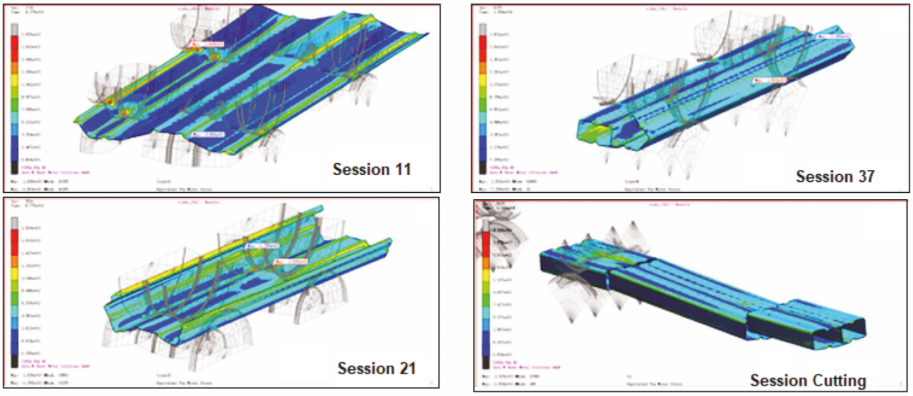

Fig. 10 Simulation results of the deformation strain at the 11th, 21st and 27th passes, and the strain state at the final cut-off station.

4. Production test of roll-forming parts made of high-strength steel for crash beams

4.1. *Production test*

In the test production process, it is necessary to adjust the load and Roller gap of the roll forming tooling to ensure that the structural dimensions of the formed part meet the design requirements. During the production process, process parameters, temperature, pressure, etc. are monitored forming and adjustment to ensure the stability of the forming quality and performance. In order to ensure the stability of production quality, accurate roll pressing mold processing and high quality mold material strength and surface treatment process to ensure that the mold damage resistance. The material of the rollers used in the roll pressing process is Cr12MoV, and the surface hardness after heat treatment is HRC58-62. The parts formed at the end of the production line have a precise cross-section shape, as shown in Figure 11. After the final roll bending, the actual bumper beam part is obtained, as shown in Figure 12.

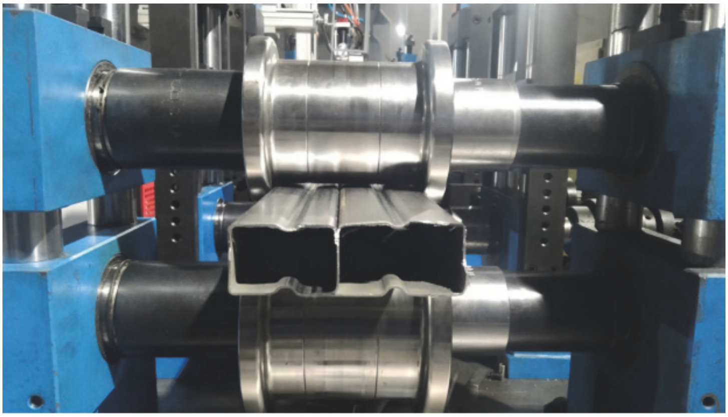

Fig. 11 Cross-sectional shape of the part at the end of actual roll forming

Fig. 12 Photographs of automobile bumper beams formed by roll forming and roll bending of high-strength steels

4.2. *Dimensional accuracy testing of roll-forming crash beams*

In the manufacturing process of automobile crash beams, performance testing and evaluation is an indispensable part. After all, only after rigorous testing and evaluation can we ensure that the quality of the crash beam meets the automobile safety standards. In this study, a series of test standards and evaluation systems are adopted in the performance test of roll-forming crash beams to comprehensively assess the performance of the crash beams. The test results of the automotive crash beam forming geometry inspection test H = 135.33 mm; W = 39.98 mm. are within the allowable dimensional tolerance. After the final roll bending, the outer arc of the part is smooth, the dimensional accuracy is within the specified range, there is no wrinkle and twist defects, and the quality is excellent.

Table 4 Product dimensional test results

Measurement of cross-section dimensions	Height H (mm)	Width w (mm)
Product design size	135±0.5mm	40±0.5mm
Actual product size	135.33mm	39.98
Dimensional accuracy	Qualified	Qualified

After a series of tests and evaluations, the superiority of roll forming technology in making high-strength steel crash beams can be fully recognized. The test results show that the anticollision beams produced by the well-designed roll forming process meet high standards in terms of dimensional accuracy, material mechanical properties and collision energy-absorbing effect, which fully proves the high reliability of the technology in practical application.

5. Conclusion and Prospect

In this study, the following conclusions were drawn from the study of roll forming technology of 1500 MPa advanced high strength steel for automotive crash beams.

Advanced high-strength steel materials have excellent mechanical properties, including high strength, good plasticity and toughness, which are ideal for improving the safety performance of automobiles. The application of high-strength steel can improve the strength and stiffness of the crash beam, thus providing a more reliable protective barrier and reducing the impact of the collision on the occupant compartment. Roll forming technology is an effective process for manufacturing high-strength steel crash beams. Effective forming of high-strength steel materials can be achieved through precision design and optimization of key parameters of the roll forming process, such as roll forming die design, uniform distribution, roller gap adjustment and speed control. Roll forming process simulation and data analysis can predict material deformation and forming quality, optimize process parameters and improve forming effect. The results of the production test show that the well-designed roll forming process can produce a crash beam that meets the design requirements. The dimensional accuracy and surface quality of the molded parts meet the requirements, which proves the reliability and effectiveness of roll forming technology in practical application. This provides important technical support for improving the safety performance of automobiles, promoting the technological progress of the automobile industry and facilitating the lightweight design of automobiles.

In summary, the advanced high-strength steel roll forming technology has important application value in the manufacture of automobile crash beams. Through the optimization of process parameters and precision control, the effective forming of high-strength steel materials can be realized, and the mechanical properties and surface quality of the crash beam can be improved. This is of great significance for improving the safety performance of automobiles, promoting the technological progress of the automobile industry and facilitating the lightweight design of automobiles. Future research can further explore the application of roll forming technology in the manufacture of other automotive parts and further optimize the process parameters to improve production efficiency and reduce manufacturing costs.

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