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Cold Stamping Forming Simulation and Springback Analysis of High Strength Steel Plate for Automobile Body

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Abstract:

Springback is an inevitable physical phenomenon in cold stamping forming, which directly affects the forming accuracy and surface quality of stamping parts. When the springback exceeds the allowable error range, forming defects are formed, which brings great difficulties to mold design. Under this background, this paper analyzes the stamping forming process and springback process of high-strength steel plate based on AUTOFORM software, and discusses the influence rules of different forming processes and die parameters, including the blank holder force, die clearance and stamping speed on the forming quality of steel plate by orthogonal analysis. The springback simulation analysis is used to guide the improvement of stamping process, and the measured springback is compared and verified. The results show that the blank holder force and die clearance have the greatest influence on the thinning rate and the maximum springback value. The springback of parts can be basically controlled within 1mm, the qualified rate of parts can be improved, and the number of die trials can be reduced.

Keywords*: Springback, Cold stamping, High strength steel plate, Automobile body, AUTOFORM.*

I. INTRODUCTION

In automobile manufacturing, nearly 70% to 80% of parts are obtained by cold stamping forming, which has the advantages of high production efficiency, simple operation and high material utilization rate. Compared with the traditional thermoforming technology of high-strength plate, cold stamping forming technology is more environmentally friendly, lower in production cost, faster in production time and better in strength [1-4], which is widely used in automobile manufacturing [5].

However, springback is an inevitable physical phenomenon in cold stamping, which directly affects the forming accuracy and surface quality of stamping parts [6-7]. When the springback exceeds the allowable error range, forming defects are formed, which brings great difficulties to the design of the mold, and the mold surface must be repeatedly modified to produce products that meet the requirements. Especially, the

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springback of stamping parts made of high strength steel and other materials is much larger than that of stamping parts made of ordinary low carbon steel, which makes the springback problem more prominent.

The traditional solution is to constantly repair and test the mold on site to optimize the shape of the mold surface, and the whole process is time-consuming and laborious. If the springback can be known in advance before mold manufacturing, so as to guide the modification of mold profile, the times of mold trial can be greatly reduced and the production efficiency can be improved. Waluyo et al. proposed a numerical method combining displacement adjustment (DA) method and spring forward algorithm to improve the accuracy of springback analysis and die compensation process, so as to improve the accuracy of cold stamping products [8]. Liu et al. discussed the springback performance of ultra-high strength steel in cold bending through finite element simulation analysis and experiments, and predicted and compensated the springback to improve the forming accuracy [9]. Tomasz et al. present the results of predictions of springback of cold-rolled anisotropic steel sheets using an approach based on a multilayer perceptron-based artificial neural network coupled with a genetic algorithm [10]. Finite element method is a widely used simulation method of stamping forming, and the springback of parts can be quickly and accurately obtained by using simulation method, just as the above research has been proved to be able to be used to predict the springback of steel stamping forming. However, the application research of influencing factors analysis and springback analysis for stamping forming of high-strength steel plates for vehicles is still lacking.

Therefore, based on the AUTOFORM software, this paper analyzes the stamping process and springback process of high-strength steel plate, discusses the influence law of different forming processes and die parameters on the forming quality of steel plate, and mainly analyzes the influence of blank holder force, die clearance and stamping speed on the forming quality. The springback analysis is used to guide the optimization and adjustment of stamping process, so as to shorten the research and development cycle of die and improve the forming quality of stamping parts.

II. STAMPING FORMING PROCESS

2.1 Cold Stamping Material

In order to effectively reduce the weight of vehicles, high-strength steel plates are increasingly used in automobiles. The steel plate studied in this paper is a reinforcing support beam used in the A-pillar of the car body, as shown in Fig.1, which is used to protect the safety of the cab and realize the torsional stability of the whole car when an accident occurs. The forming quality of the steel plate will directly affect the quality control and safety stability of the car.

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Fig 1: Physical drawing of high strength steel plate for vehicle.

In the process of cold stamping, the high-strength steel plate will slip and produce dislocation strengthening, which can greatly improve the tensile strength of parts. In addition, a hardened layer will be formed on the surface of the plate during cold stamping, resulting in surface compressive stress and improving the fatigue strength of the workpiece. In view of the high strength requirement of this part, the A-pillar supporting beam of the car body is produced by cold stamping.

Due to the SPCM1180YL-55/55 type high-strength interstitial free steel has excellent mechanical properties and good cold formability, this stamping part is developed with this type of material. The mechanical properties of steel plate are as follows: the yield strength is 1174 MPa, tensile strength is 1366 MPa, Lackford coefficient Ra is 0.94, hardening exposure n is 0.07, and the rated load is 1.2 t.

2.2 Stamping Forming Process

The forming process of the high-strength steel plate includes: (1) continuous blanking process BL: obtaining the shape and size of the blank required by stamping; (2) forming process FO: stamping the high-strength steel plate to plastically deform so as to obtain parts with certain shape, size and precision requirements; (3) flanging and shaping process FL: forming the shape of the plate that has not been fully formed in stamping and forming process; and (4) trimming and punching process TR: trim the edges of the formed parts neatly or cut into the desired shape, as shown in Fig.2.

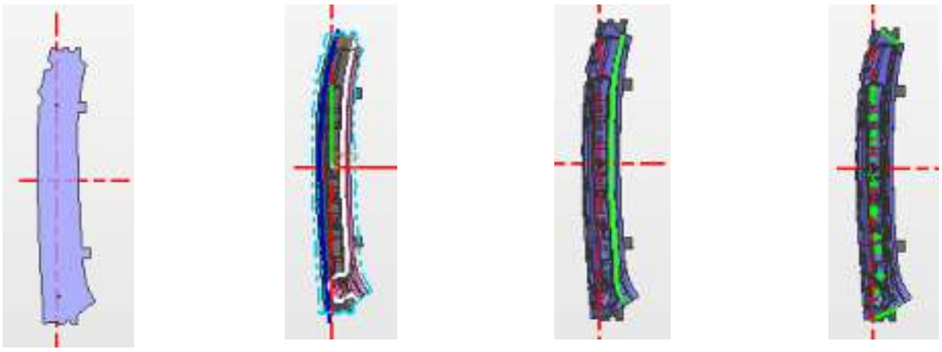

Fig 2: Forming process.

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III. STAMPING FORMING SIMULATION ANALYSIS

3.1 Simulation Parameter Setting

The forming process of high-strength plate is analyzed based on AUTOFORM software. Firstly, the three-dimensional structure model established in UG is imported into AUTOFORM in IGES file format, and the initial simulation parameters are set to simulate stamping forming, trimming and springback analysis. The simulation type is set to incremental method, the element type selects the shell element with higher calculation accuracy and the stamping process of wave forming and trimming is set as single-action stretching. It has the same shape and size as the outer surface of the boss plate of the female die, and the male die is produced by the inward bias of the female die. In the springback analysis process, considering the difficulty of setting springback constraint points, the free springback method is selected. The simulation parameters are shown in the following TABLE I.

TABLE I. Simulation parameters

Plate thickness	1.0 mm	Blank holder stroke	100 mm
Blank holder force	1750 kN	Accuracy	Standard
Forming force	6500 kN	Friction factor	0.15

3.2 Key Factors of Forming Quality

The thinning rate and springback of the sheet are selected as the performance indexes, and the core area of the plate is not cracked or wrinkled during forming as the constraint condition. The main purpose is to explore the influence law of different forming processes and die parameters on the forming quality of the plate. Three influencing factors, blank holder force, die clearance and stamping speed, are analyzed by simulation, and their levels are set as follows:

Blank holder force is an important factor to determine the forming quality of plate metal, and the change of its magnitude can affect the strain path of the material. Blanking force: 1600 kN, 1750 kN and 1900 kN.

The importance of die clearance to plate forming is mainly reflected in its influence on radial restraint of plate metal, and its value is usually equal a plate thickness. In this paper, the die clearance is 0.9 mm, 1.0 mm and 1.1 mm.

According to the actual situation of plate production, the stamping speed selected in this paper are 3 m/s, 4 m/s and 5 m/s respectively.

A three-factor and three-level orthogonal test table L9 was designed, and a total of nine groups of tests were conducted, as shown in the following TABLE II.

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TABLE II. Orthogonal test (L9)

NO.	Stamping speed (m/s)	Blank holder force (kN)	Die clearance (mm)	Thinning rate (%)	Maximum springback (mm)
1	3	1600	0.9	8.0	3.7
2	3	1750	1.1	7.2	5.0
3	3	1900	1.0	8.4	3.3
4	4	1600	1.1	6.7	5.8
5	4	1750	1.0	7.8	4.0
6	4	1900	0.9	8.8	2.8
7	5	1600	1.0	7.4	4.4
8	5	1750	0.9	8.5	3.2
9	5	1900	1.1	8.1	4.3

Fig.3 shows the influence of blank holder force, stamping speed and die clearance on the forming thinning rate of sheet metal. It can be seen from the figure that blank holder force has a positive correlation with the thinning rate, while mold clearance has a negative correlation with the thinning rate. The influence of stamping speed on the forming thinning rate fluctuates within a certain range.

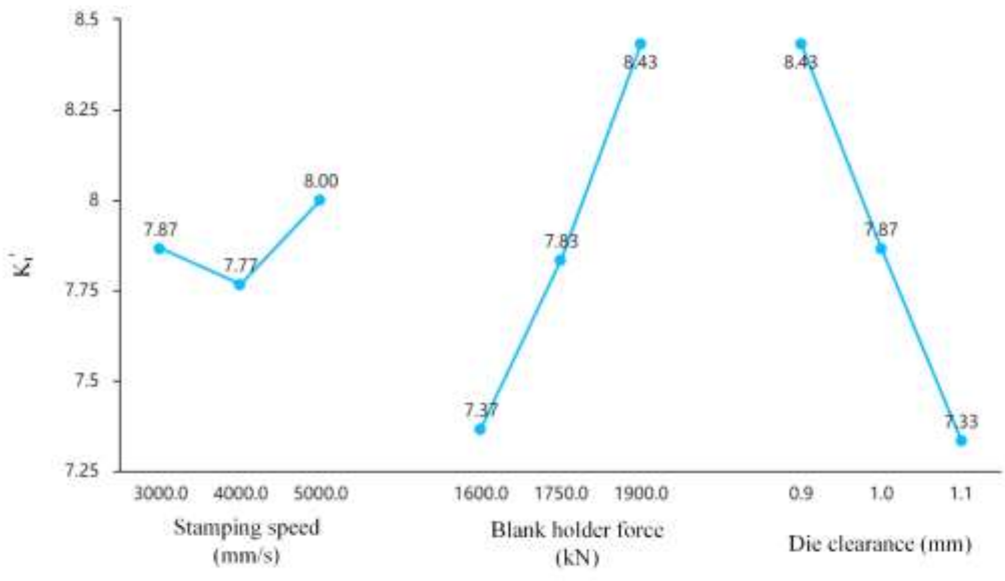

Fig 3: Influence of various factors on forming thinning rate.

The influence degree of each factor on forming thinning rate is investigated by the range analysis, as shown in Table III. The K_t and K_t' are the sum of thinning rate and its average value of each factor at a certain level, respectively. And the range R is the difference between the maximum average value K'_{tmax} and the minimum average value K'_{tmin} of each factor, which reflects the influence degree of a certain factor on thinning rate. From the Table III, it can be seen that the R_t value corresponding to die clearance and

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blank holder force is obviously larger than that corresponding to stamping speed, which shows that die clearance and blank holder force are the key factors to determine the sheet thinning rate.

TABLE III. Range analysis of thinning rate

	Blank holder force (kN)	Die clearance (mm)	Stamping speed (m/s)
K_t	22.1	25.3	23.6
	23.5	23.6	23.3
	25.3	22.0	24.0
K_t’	7.37	8.43	7.87
	7.83	7.87	7.77
	8.43	7.33	8.00
R_t=$K’_{tmax}$-$K’_{tmin}$	1.07	1.10	0.23

It can be seen from Fig.4 that the springback value of steel plate is not sensitive to stamping speed factors, but sensitive to blank holder force and die clearance factors. Specifically, the maximum springback is linearly inversely proportional to the blank holder force, but positively correlated with the die clearance. This is because the larger the die gap, the smaller the contact area between the die and the sheet metal, which weakens the extrusion and friction effect of the die on the sheet metal, and finally leads to insufficient plastic deformation of the plate metal and larger springback.

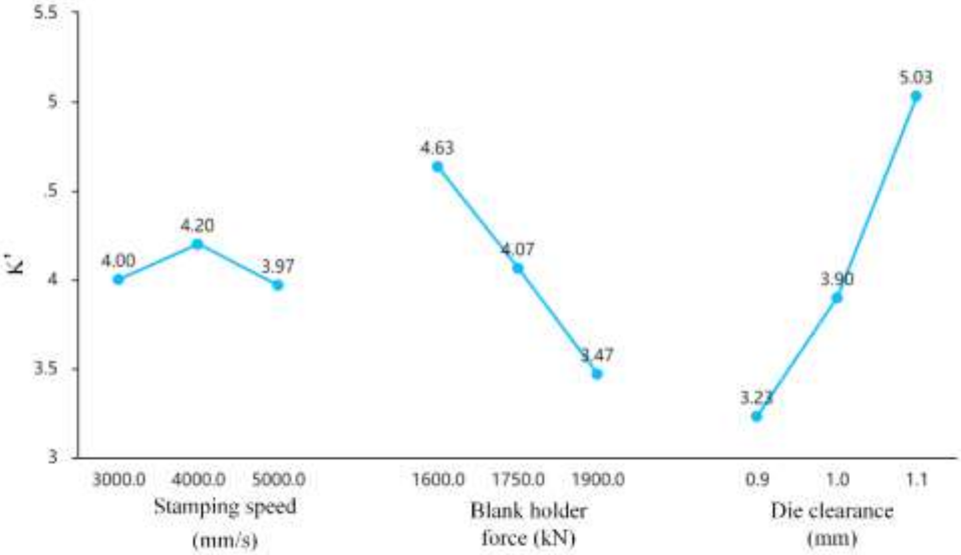

Fig 4: Influence of various factors on springback.

TABLE IV shows the range analysis results of the maximum springback value. The range values R_s of blank holder force, die clearance and stamping speed are 1.17, 1.80 and 0.23 respectively, that is, according to the ranking of R_s values, the primary and secondary factors affecting the maximum springback value are die clearance, blank holder force and stamping speed respectively.

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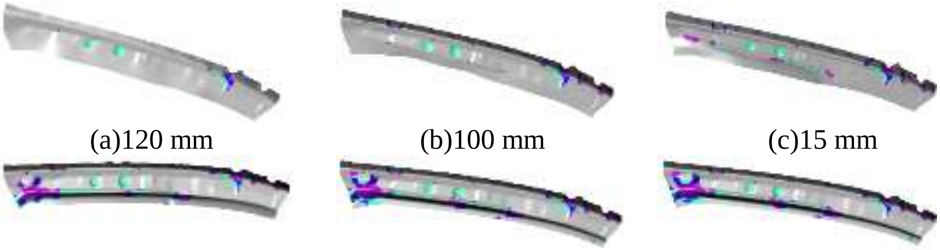
TABLE IV. Range analysis of maximum springback

	Blank holder force (kN)	Die clearance (mm)	Stamping speed (m/s)
K_s	13.90	9.70	12.00
	12.20	11.70	12.60
	10.40	15.10	11.90
K_s'	4.63	3.23	4.00
	4.07	3.90	4.20
	3.47	5.03	3.97
$R_s=K'_{smax}-K'_{smin}$	1.17	1.80	0.23

According to the above orthogonal analysis results, it is difficult to realize the optimal allocation of thinning rate and springback. Considering that the springback index of automotive high-strength steel plate is the most critical, this paper uses this index to set stamping parameters. The die clearance is 0.9 mm, the blank holder force is 1900 kN, and the stamping speed is 4 m/s. Based on the selected parameters, the springback simulation of steel plate is followed up.

3.3 Forming Simulation Analysis

The forming process of the parts is shown in Fig.5, which reflects the distribution of material inflow in the whole process of steel plate stamping.



(a)120 mm (b)100 mm (c)15 mm
(d)10 mm (e)5 mm (f) 0 mm

Fig 5: Distance to the draw home.

The forming limit diagram can fully reflect the instability of parts under complicated stress-strain conditions, such as cracking and wrinkling. Through the forming limit diagram, the defects of materials in the forming process can be quickly found, as shown in the Fig.6. It can be seen from the figure that most of the points are in the green area, some points are in the purple critical area, and there is a certain distance from the forming limit curve. Therefore, it can be concluded that most areas of the parts are fully drawn, but there are some areas with insufficient drawing, and there is even the possibility of wrinkling, which leads to larger springback.

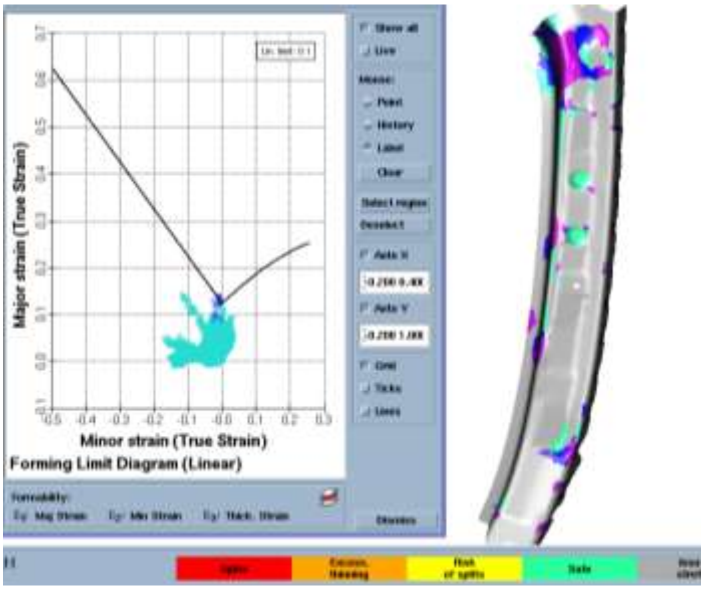


Fig 6: Forming limit diagram.

The distribution chart of blank thinning rate and wrinkling trend chart are shown in the Fig. 7 and Fig.8. The distribution characteristics of sheet material thickness are uniform, and the minimum thickness is located at the top corner of boss. The thinning thickness is 0.1mm, and the sheet thinning rate is 8.8%, so there is no danger of cracking.

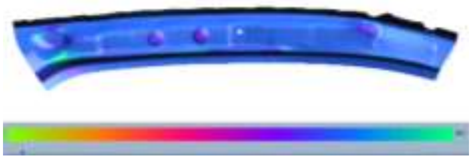


Fig 7: Blank thinning rate distribution diagram.

Fig 8: Wrinkling criterion plot.

IV. SPRINGBACK ANALYSIS AND VERIFICATION

The springback of complex parts varies in different areas. In order to fully understand the springback of parts, cross sections should be made at various positions of the model to comprehensively measure the springback of parts, as shown in Fig.9. The springback deformation trend of parts is stable, but there are some cases where the local springback value is larger, especially the springback deformation within 0.5 mm of the characteristic part is more significant.

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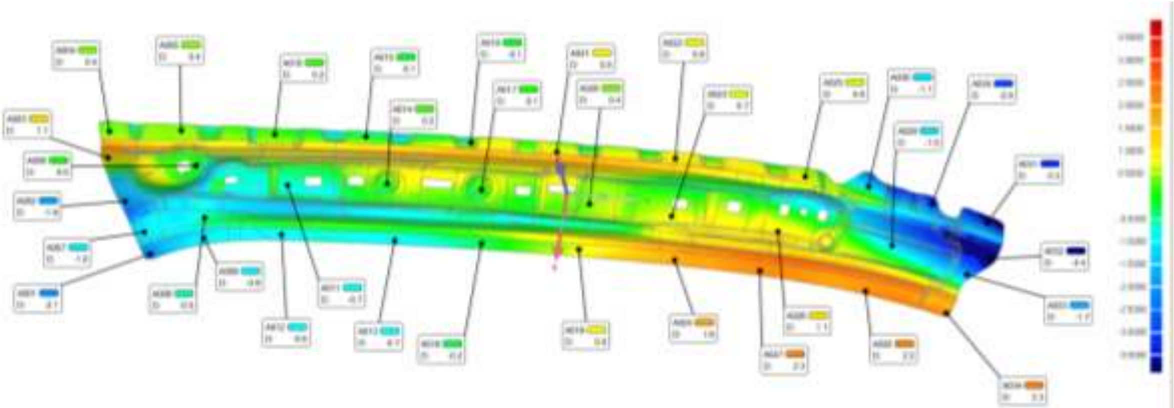

Fig 9: Springback deformation trend of primary products.

In order to further reduce the springback value, the springback simulation value is used to adjust the overall profile of the die to control the approximate deformation of the part, and the stamping process of high-strength steel plate is improved by combining the fine adjustment mode of local characteristic fold line deformation and local characteristic plastic deformation. The springback value after the improved process is generally controlled within the range of 1mm, and the local springback of the die after fine grinding is appropriately reduced, as shown in Fig.10.

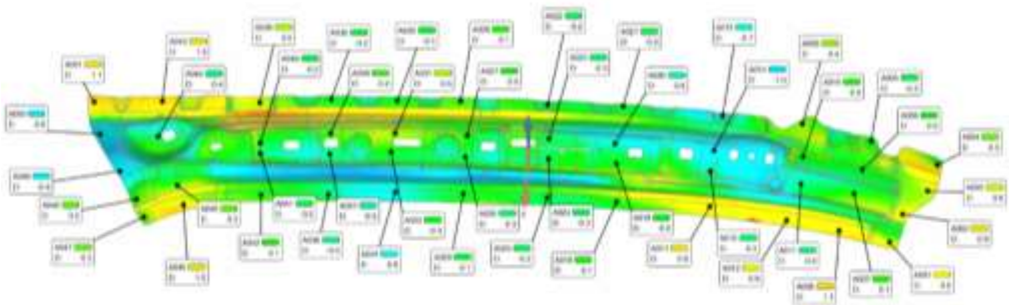

Fig 10: Springback deformation trend of improved products.

Fig. 11 is a three-coordinate measured diagram of the springback value of parts. It can be seen from the diagram that adjusting the processing technology based on the finite element analysis method achieves the expected effect, and the springback value of key areas is basically controlled within 1 mm, which is consistent with the springback simulation trend and reduces the springback phenomenon of products.

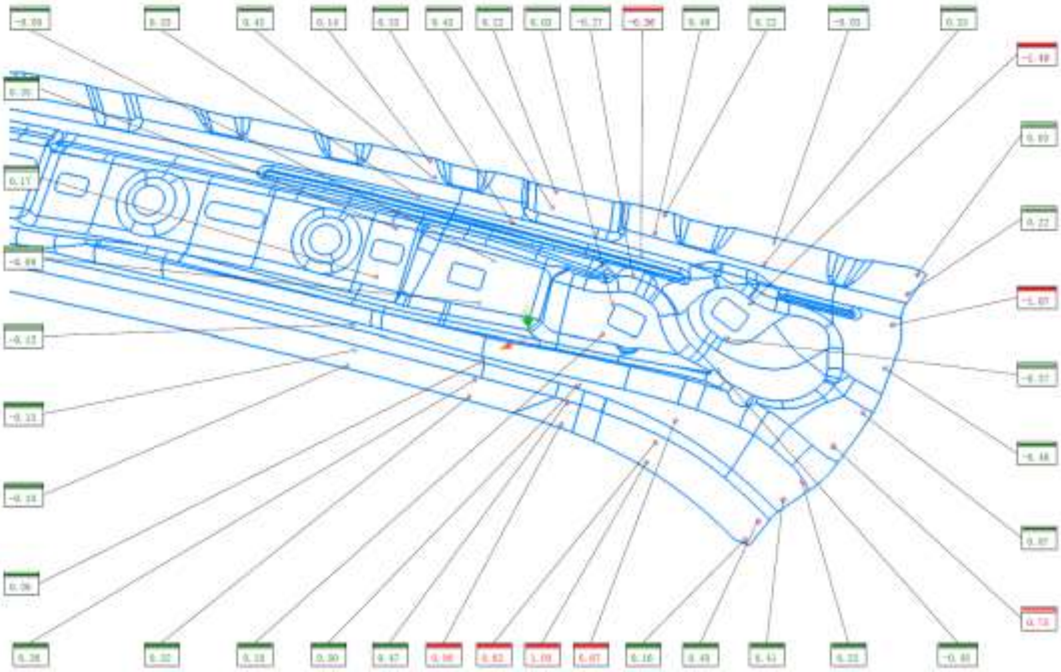

Fig 11: Measured springback value.

V. CONCLUSION

(1) Through orthogonal simulation analysis, the influence of die clearance, blank holder force and stamping speed on the forming quality (thinning rate and maximum springback) of high-strength steel plate is analyzed. The results show that die clearance and blank holder force are the most critical factors to determine the thinning rate and the maximum springback of high-strength steel plate. This conclusion can provide theoretical support for improving the forming quality of products in the future.

(2) The finite element springback simulation value is used to adjust the overall contour of the die to control the general deformation trend of parts, and the springback value of the part is basically controlled within 1 mm. The stamping process of high-strength steel plate is fine-tuned and improved by combining the deformation of local characteristic broken lines and plastic deformation, so as to reduce the times of die test and improve the qualified rate of parts.

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