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Research Article

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Automotive covering parts drawing forming numerical simulation and the 6σ robust optimization of process parameters

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ABSTRACT

In order to solve the problem that due to the unreasonable parameter Settings when use CAE analysis to produce the cars covering parts mould, such as sheet wrinkling, cracking, and more than an acceptable range of rebound. This article used CAE analysis software to find relatively reasonable parameters to achieve a reasonable analysis in the process of sheet metal forming defects and to put forward a practical and reliable process. The paper takes the automobile panel stamping forming process as the research object based on the numerical simulation of Auto form CAE analysis technology, the automotive covering parts forming process is simulated, and choose friction coefficient, blank-holder force, stamping speed, die gap as the design optimization variables, the maximum thinning rate, maximum wrinkling height and maximum rebound as the evaluation indexes, a 6σ robust optimization was carried on for the automobile covering parts drawing forming process parameters, then optimized and analyzed the process parameters of car door inner parts drawing forming to get the best process parameters combination is 84.21 tons of blank-holder force, 0.148 of friction coefficient ,0.69 mm of die gap and 2.203m/s of stamping speed. From the process parameters it can be got that the maximum thinning rate is 27.22%, the maximum wrinkling height is 47.52%, the maximum rebound is 1.953 mm .From the production verification, it can be concluded that the products meet the quality requirements.

Key words: Drawing; Forming; 6σ; Optimization

INTRODUCTION

Automobile covering part is an important part of cars, whose characteristic are thin-material, large-size, complex shape and high requirements of surface quality and precision. With the rapid development of automobile industry, Manufacturing mode of traditional panel can't adapt to the further development of automobile industry any more which has seriously hampered the new development mode of auto industry. CAE software for sheet metal forming has been used extensively in enterprises , it has become an indispensable tool for early prediction of sheet metal forming. The position of cracking, height of wrinkling, rebound and the position of impact line and slip line can be predicted through the analysis of CAE, which provides a reliable basis for the early optimization of mold process and structure. It plays an irreplaceable role in ensuring the quality of mold, improving utilization rate of material ,shortening the development cycle and reducing the producing cost and workload of fitter. If parameters are unreasonable in CAE analysis, sheet wrinkling, cracking and unacceptable rebound will appear. The presence of these defects illustrated there is a strong possibility in production site .If it is not solved well, mold manufacturing will face great workload, low efficiency, and larger investment and other problems. It has become a problem faced directly with applications and researches in automotive mold companies that how to find the most reasonable parameters quickly and accurately by CAE so that a reasonable analysis of defects in sheet metal forming can be achieved and reliable technology solutions could be raised. Literature [1] presents a robust optimization design method of process parameters in plastic forming whose control objects are size and shape precision, which cannot be used before mold manufacturing as it is based on experiments of mold blanking. Literature [2] builds the parametric model of die by STLMesher software, based on which test designing, high precision approximate model which can represent the actual stamping process and Monte Carlo simulation technology are combined to construct 6σ robust optimization design method according to product quality engineering. This paper studied automotive panel stamping molding process, drawing forming process of automobile panel is simulated based on Auto form numerical simulation technology. It selects the coefficient of friction, BHF, punching speed, die gap as optimization variables and the greatest thinning rate, the maximum wrinking height and the maximum rebound as the evaluation indexes, then process parameters of automobile panel forming are optimized by 6σ robust optimization design method. Parts quality meets the requirements through the production verification

SIMULATION AND ORTHOGONAL TEST OF DRAWING FORMING

Automotive Panel Drawing Forming Simulation. The door inner panel of a new automotive panel is researched in this paper, its product model is shown in Figure 1.The product is analyzed in Auto form .

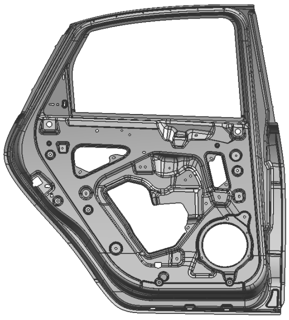


Fig. 1: Product model

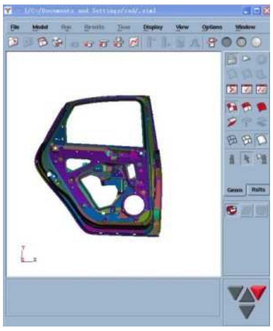


Fig .2: Model in Auto form

Export the product model in IGES format, and read it into Auto form[3,4], the digital-analog in Auto form is shown in Figure 2. Drawing forming simulation is shown in Figure 3, the drawing FLD is shown in Figure 4,From Figure 3 and Figure 4, simulation results show that multiple serious cracking exists in the corner area of product sidewall, which does not meet the quality requirements. After analysis ,it is found virtual coefficient of draw bead was set too large, which should be further adjusted. Callout the blank line and deformation result of product at the end of simulation, measure the inflows of drawing forming sheet, which is shown in Figure 5. According to the corresponding of draw bead coefficient and the sheet metal inflows , draw bead coefficient is adjusted based on experience, then continue simulation until relatively reasonable draw bead is debugged.

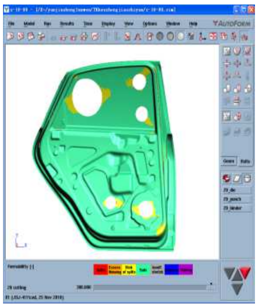


Fig .3: Drawing forming

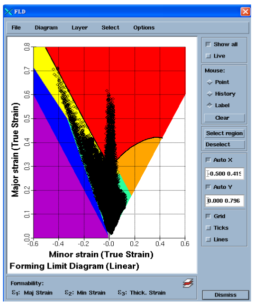


Fig.4: Drawing FLD

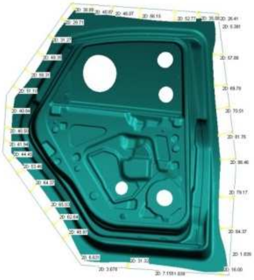


Fig. 5: Sheet inflows

Orthogonal Test of Automotive Panel Drawing Forming.

For the inner plates whose appearance cannot be seen after assembly, their forming quality is evaluated mainly by cracking, wrinkling and the amount of rebound, which are reflected separately by the maximum thinning rate, the maximum wrinkling height and the maximum amount of rebound in this test, BHF, friction coefficient, die gap and punching speed are selected as test elements, which are respectively represented with A, B, C, D .

Table 1 shows the factors and values of their levels in the orthogonal test.

Table1. Factors and levels of orthogonal test

factors levels	BHF A(T)	friction coefficient B	die gap C(mm)	punching speed D(m/s)
1	80	0.10	0.5	1
2	85	0.12	0.6	2
3	90	0.14	0.7	3
4	95	0.16	0.8	4
5	100	0.18	0.9	5

According to factors and levels and the interaction between the factors, this test selects orthogonal table L25(56).

The orthogonal test results of automobile panel drawing forming is shown in Table 2

Table 2. Orthogonal test results of drawing forming

Test NO	BHF A(T)	friction coefficient B	die gap C(mm)	punching speed D(m/s)	maximum thinning rate(%)	maximum wrinkling height(%)	maximum amount of rebound(mm)
1	80	0.10	0.5	1	27.27	65.85	2.203
2	85	0.12	0.6	2	27.57	59.63	2.094
3	90	0.14	0.7	3	27.45	66.24	1.977
4	95	0.16	0.8	4	26.93	66.71	2.014
5	100	0.18	0.9	5	31.81	69.91	1.916
6	80	0.10	0.5	1	27.53	71.60	2.176
7	85	0.12	0.6	2	27.83	67.31	2.092
8	90	0.14	0.7	3	27.61	80.72	1.949
9	95	0.16	0.8	4	28.97	80.22	2.067
10	100	0.18	0.9	5	35.39	55.42	2.047
11	80	0.10	0.5	1	27.43	90.54	2.123
12	85	0.12	0.6	2	27.92	87.41	2.113
13	90	0.14	0.7	3	29.40	91.83	1.933
14	95	0.16	0.8	4	27.41	49.21	2.129
15	100	0.18	0.9	5	35.64	68.69	2.077
16	80	0.10	0.5	1	28.27	103.04	2.078
17	85	0.12	0.6	2	28.47	76.96	2.044
18	90	0.15	0.7	3	27.77	54.43	2.128
19	95	0.16	0.8	4	28.14	51.07	2.095
20	100	0.18	0.9	5	38.16	51.59	2.159
21	80	0.10	0.5	1	34.57	67.97	2.226
22	85	0.12	0.6	2	28.44	52.74	2.032
23	90	0.14	0.7	3	27.80	53.10	2.032
24	95	0.16	0.8	4	28.85	53.84	2.003
25	100	0.18	0.9	5	38.75	58.74	2.158

ANALYSIS OF TEST RUSULTS

Range analysis is used to analyze the results. Calculate the sum of the maximum amount of under each level ,that are K1, K2, K3, K4, K5, calculate the average of sum of variation in each evaluation index, that are k1, k2, k3 , k4, k5, finally calculate the range.

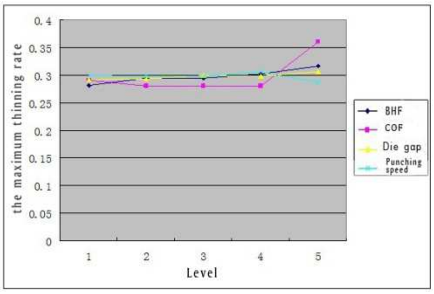
Analysis of the influence trend of process parameters on the maximum thinning rate

Table 3 shows the influence of factors on the maximum thinning rate in size order: friction coefficient> BHF> punching speed> die gap.

Table 3. Influence data of parameters on the maximum thinning rate

	A	B	C	D
K1	141.03	145.07	146.28	150.12
K2	147.33	140.23	146.68	149.48
K3	147.80	140.03	149.72	149.61
K4	150.81	140.30	149.48	152.74
K5	158.41	179.75	153.22	143.43
k1	28.21	29.01	29.26	30.02
k2	29.47	28.05	29.34	29.90
k3	29.56	28.01	29.94	29.92
k4	30.16	28.06	29.90	30.55
k5	31.68	35.95	30.64	28.69
R	3.47	7.94	1.38	1.86
Sorts	2	1	4	3

In Table 3, K1,K2, K3 are respectively the sum of the maximum thinning rate under levels of 1,2,3,4,5 and k1,k2, k3 are respectively the average of the sum of the maximum thinning rate under levels of 1,2,3,4,5.The range R reflects the influence degree of factors on the maximum thinning rate. Figure 6 shows the maximum thinning rate in each level of each factor. The optimum combination is A1B3C1D4.We can obtain the maximum thinning rate when friction coefficient is 0.14 ,BHF is 80 ton ,punching speed is 4m/s, die gap is 0.5mm. This combination of process parameters has not been obtained in the test, use Auto form validate it and get the maximum thinning rate is 27.47%,which is close to the minimum when compared with results of 25 groups experiments, the results are shown in Figure 7.



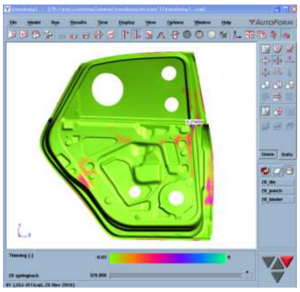


Fig .6: Influence trends of factors Fig .7: Influence of factors on thinning rate on the maximum thinning rate

Analysis of the influence trend of process parameters on the maximum wrinkle height.

Table 4 shows the influence of factors on the maximum wrinkle height in size order: die gap > BHF> friction coefficient > punching speed .

Table 4. Influence data of parameters on the maximum wrinkle height

	A	B	C	D
K1	328.34	399.00	277.65	338.17
K2	355.27	344.05	304.09	363.76
K3	387.68	346.32	329.52	322.75
K4	337.09	301.05	396.62	325.11
K5	286.39	304.35	386.89	344.98
k1	65.67	79.80	55.53	67.63
k2	71.05	68.81	60.82	72.75
k3	77.54	69.26	65.90	64.55
k4	67.42	60.21	79.32	65.02
k5	57.28	60.87	77.38	69.00
R	20.26	19.59	23.79	8.20
Sorts	2	3	1	4

Figure 8 shows the maximum wrinkle height in each level of each factor, The optimum combination is A5B4C1D3.We can obtain the maximum wrinkle height when BHF is 100 ton ,friction coefficient is 0.16 , die gap is 0.5mm,punching speed is 3m/s. This combination of process parameters has not been obtained in the test, use Auto form to validate it and get the maximum Wrinkle height is 27.47%,which is close to the minimum when compared with results of 25 groups experiments

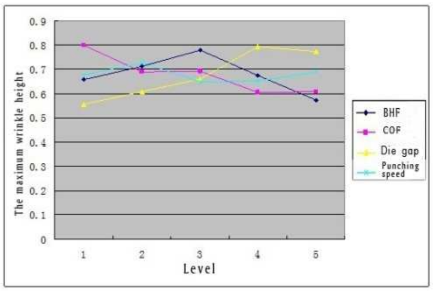


Fig .8: Influence trends of factors on the maximum wrinkle height

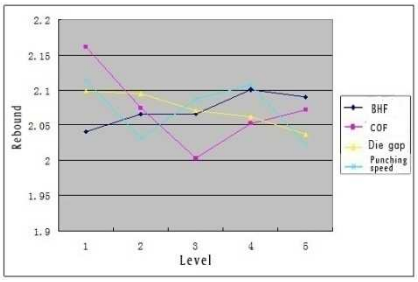


Fig.9: Influence trends of factors on the amount of rebound

Analysis of the influence trend of process parameters on the amount of rebound.

Table 5 shows the influence of factors on the amount of rebound in size order: friction coefficient > punching speed > die gap > BHF.

Table 5. Influence data of parameters on the amount of rebound

	A	B	C	D
K1	10.204	10.806	10.539	10.574
K2	10.331	10.375	10.474	10.155
K3	10.375	10.019	10.354	10.484
K4	10.504	10.308	10.312	10.537
K5	10.451	10.357	10.186	10.115
k1	2.041	2.161	2.108	2.115
k2	2.066	2.075	2.095	2.031
k3	2.075	2.004	2.071	2.097
k4	2.101	2.062	2.062	2.107
k5	2.090	2.071	2.037	2.023
R	0.060	0.157	0.071	0.092
Sorts	4	1	3	2

Figure 9 shows the amount of rebound in each level of each factor. The optimum combination is A1B3C5D5.We can obtain the minimum amount of rebound when BHF is 80 ton ,friction coefficient is 0.14 , die gap is 0.9mm,punching speed is 5m/s. This combination of process parameters has not been obtained in the test, use Auto form to validate it and get the minimum amount of rebound is 1.9129mm ,which is close to the minimum when compared with results of 25 groups experiments

ROBUST OPTIMIZATION OF PROCESS PARMETERS OF AUTOMOBILE PANEL DRAWING FORMING

In this paper, 6σ robust optimization was used to optimize the process parameters of the door inner panels drawing forming of automobile panel [5]-[12]. The best combination of parameters are compared with the combination obtained by determined optimization method, and the better group is selected to guide the mold commissioning on site, and the result is good.

Objective Function and Design Variables.

The value of evaluation indexes weight is represented by W_i , and i represents the i-th test index. The sum of all values is 1. The maximum thinning rate and the maximum wrinkling height is the important factors that makes the stampings unqualified, so their each weight is 0.4.Rebound is less important in drawing stage, so its weight is 0.2.

Compare and score the value of every index of each test, Y (j) represents the fraction, and j represents the j-th test number. The maximum value A_{jmax} and the lowest value A_{jmin} of test indexes are determined respectively as 52 points and 100 points under 100 score system. All values are sorted in increasing order and the difference between adjacent two numbers is 2 points. The objective function of synthetical weighted mark is established as Eq.1.

$$F_j^* = \sum_{j=1}^{4}[Y(j)\times W_i] \tag{1}$$

Where , F_j^* represents the value of synthetical weighted mark, $Y(j)$ represents the scores of each test result, W_i represents evaluation index weight of each test.

Design Method of Robust Optimization.

The typical formula of robust optimization can be defined as Eq.2.

$$\begin{aligned} &\mathrm{minF}(\mu_y(X),\sigma_y(X)) \\ &s\cdot t\cdot \mu_{gi(x)} + n\sigma_{gi(x)} \le 0 \\ &\mathrm{X}_{\mathrm{L}} + n\sigma_x \le \mu_x \le \mathrm{X}_U - n\sigma_x \end{aligned} \tag{2}$$

Where, $\mu_y(X)$ and $\sigma_y(X)$ are respectively the mean value and mean square deviation of F(X), $\mu_{gi(x)}$ and $\sigma_{gi(x)}$ are respectively the mean value and mean square deviation of constraint function gi(X), X_{L} and X_U are respectively the upper limit and lower limit of X. We call it 6σ robust optimization when n is 6.

The weight, evaluation index and objective function are the same when compare and score the value of every index of each test by synthetic weighted mark method, $Y(j)$ represents the fraction, and j represents the j-th test number. The maximum value A_{jmax} and the lowest value A_{jmin} of test indexes are determined respectively as 54 points and 100 points under 100 score system. All values are sorted in increasing order and the difference value between adjacent two numbers is 2 points. 24 groups of iterative result of 6σ robust optimization are scored by synthetic weighted mark method and the results are shown in table 6.

Table 6. Synthetic weighted mark of 6σ robust optimizaiton results

Test NO.	maximum thinning rate(%)		maximum wrinkling height(%)		maximum amount of rebound(mm)		synthetic weighted mark Y^*
	value	evaluation	value	evaluation	value	evaluation	
1	31.60	56	51.81	92	2.152	58	70.8
2	27.75	72	73.12	64	2.168	56	65.6
3	27.38	90	49.65	98	2.052	76	90.4
4	27.59	80	59.36	76	2.147	60	74.4
5	26.88	100	51.68	94	2.081	70	91.6
6	27.59	82	62.04	72	2.042	78	77.2
7	31.41	60	63.88	70	2.038	80	68.0
8	29.22	64	73.65	62	2.121	62	62.8
9	30.05	62	47.90	100	2.231	54	75.6
10	31.30	60	53.52	90	1.988	82	77.3
11	28.07	66	52.08	90	2.011	84	79.2
12	27.67	78	77.93	58	1.946	98	74.0
13	28.01	68	92.26	54	2.098	66	62.0
14	27.75	74	79.22	56	2.104	64	64.8
15	31.59	58	53.68	88	1.880	100	78.4
16	27.83	70	67.56	66	2.011	86	71.6
17	27.36	92	74.08	60	2.069	72	75.2
18	32.06	54	55.67	82	1.986	90	72.4
19	27.27	76	66.54	68	1.998	88	75.2
20	27.57	84	56.85	80	2.016	82	82.0
21	27.33	94	55.28	84	2.097	68	84.8
22	27.46	86	54.14	86	1.968	96	88.0
23	27.20	96	56.94	78	1.969	94	88.4
24	27.18	98	50.34	96	1.937	92	96.0

From the table we can know that the 24th score is the highest , the maximum thinning rate, the maximum wrinkling height and the maximum amount of rebound are respectively 27.22%,47.52% and 1.953mm.The best process combination determines BHF as 84.21 ton, friction coefficient as 0.148, die gap as 0.69mm,stamping speed as 2.203m/s.

Comparison Between Determined Optimization and 6σ Robust 0ptimization.

The comparison of optimum process combination between determined optimization and 6σ robust optimization of door inner plate of some automobile panel is shown in table 7 .The comparison of the best evaluation indexes between determined optimization and 6σ robust optimization is shown in table 8.

Table 7. Comparison of optimum process combination between determined optimization and 6σ robust optimization

items method	BHF (T)	friction coefficient	die gap (mm)	punching speed (m/s)
6σ robust optimization	84.21	0.148	0.696	2.203
determined optimization	95.34	0.158	0.726	1

Table 8. Comparison of the best evaluation indexes between determined optimization and 6σ robust optimization

items method	maximum thinning rate(%)	maximum wrinkling height(%)	maximum amount of rebound(mm)
6σ robust optimization	27.22	47.52	1.953
determined optimization	27.18	50.34	1.973

It can be seen from Table 7 that the coefficient of friction and BHF of optimum process combination obtained by 6σ robust optimization are bigger than the ones obtained by determined optimization, which illustrates that 6σ robust optimization is more energy conservation and cost saving. The stamping speed of 6σ robust optimization is faster than the one of determined optimization, which illustrates that the production efficiency of the optimum process combination obtained by 6σ robust optimization is higher.

It can be seen from Table 8 that the maximum thinning rate obtained by 6σ robust optimization is slightly larger than the rate obtained by determined optimization, but they are in allowable range of material thinning rate, which indicates that the process parameters of 6σ robust optimization makes better rigidity. The value of the maximum wrinkling height obtained by 6σ robust optimization is smaller than the one obtained by determined optimization, which indicates that 6σ robust optimization results can obtain higher accuracy , so that debugging time of fitter is reduced. The value of the maximum rebound obtained by 6σ robust optimization is smaller than the one obtained by determined optimization, which indicates that 6σ robust optimization results makes the dimensional precision higher, so that the amount of later shaping and press pressure are reduced. So 6σ robust optimization is more suitable for the process parameters optimization of automobile panel drawing forming.

PRODUCTION APPLICATION

The optimal process parameters and the scheme of mold design that obtained through simulation and optimization of process parameters are applied directly to some car factory in the actual production ,we manufacture the automotive panel die, and finally debug the die by drawing forming process parameters. The problems on site should be feed back to the CAE since there exists errors between CAE analysis results and actual debugging. The product is analyzed by CAE again after modifying the parameters according to the theory of knowledge and experience, then guide the debugging process on site. The maximum thinning rate of the product finally obtained by the process parameters is 27.22%,the maximum wrinkling height is 47.52% and the maximum amount of rebound is 1.953mm.The mold and product of the parts are shown in Figure 10.The first round coincidence rate of mold reached 93%,which is 15% higher than the average rate before optimization. Debugging cycle shortens 17 to 25 days, the practicability and economy is strong

Fig.10: Mold and product of parts

CONCLUSION

(1)The optimum process parameters combination obtained by 6σ robust optimization is as follows: BHF is 84.21 ton, friction coefficient is 0.148, die gap is 0.69mm. The maximum thinning rate of the parts obtained by the parameters is27.22%, the maximum wrinkling height is 47.52% and the maximum amount of rebound is 1.953mm.

(2)The maximum thinning rate obtained by 6σ robust optimization is slightly larger than the rate obtained by determined optimization and the value of the maximum wrinkling height is smaller than the one obtained by determined optimization, which indicates that 6σ robust optimization results can obtain higher accuracy, so that debugging time of fitter is reduced. The value of the maximum rebound obtained by 6σ robust optimization is smaller than the one obtained by determined optimization, which indicates that 6σ robust optimization results makes the dimensional precision higher, so that the amount of later shaping is reduced. So 6σ robust optimization is more suitable for the process parameters optimization of automobile panel drawing forming.

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