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THE STUDY ON AN AUTOMOTIVE REFILL OPENING CAP PREFORMING PROCESS BASED ON SINGLE POINT INCREMENTAL FORMING

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Preliminary Note – Prethodno priopćenje

In this paper, the preform of an automotive refill opening cap is manufactured through the incremental sheet forming (ISF) with large rigidity because of the lower thickness reduction percentage, and the production cost is reduced. Four processing parameters, including the preforming height (PH), the preforming press amount (PPA), the preforming tool diameter (PTD) and the preforming angle (PA), are optimized by orthogonal tests and response surface methods, and the max thickness reduction percentage (MTRP) is taken as the test target. Results: The optimal processing parameters include a PH of 15 mm, a PPA of 0,5 mm, a PTD of 8 mm and a PA of 40°.

Keywords: Al alloy sheet, forming, mechanical properties, response surface method, error analysis

INTRODUCTION

With the development of modern industry, fast forming technologies are increasingly used and studied, and incremental sheet forming (ISF) technology has been extensively developed. This technology is also called layered manufacture technology, which increases sheet deformation through small region contact between the moving rigidity tool and the metal sheet, so this technology can reduce the amount of research and the development cycle and raise productivity. The technology does not need to manufacture the corresponding die or only requires the production of half of the die.

Emmens et al. [1] comprehensively reviewed incremental forming developments through recent years. Skjoedt et al. [2] researched the deformation of cylindrical cups with vertical walls through ISF, successfully manufacturing this part. Cui and Gao [3] investigated three multi-pass strategies of ISF to produce hole-flanging parts. Manco et al. [4] researched the effect of the tool path in single incremental forming for the part formability, gaining a feasible tool path of ISF. Malhotra et al. [5] investigated the effect of the tool path for material flow phenomenon, using the compound tool path to eliminate the material flow during ISF.

The automotive refill opening cap manufactured through the traditional punching process usually performs with less rigidity. In this paper, the preforming process adopted incremental sheet forming to manufacture the performing part. Four parameters, including the preforming height (PH), the preforming press amount (PPA), the pre-forming tool diameter (PTD) and the pre-forming angle (PA), were taken as the experimental factors in the preforming stage, and the max thickness reduction percentage (MTRP) was taken as the test target. The effect of factors would be analyzed through the respond surface method and an orthogonal test for the target.

EXPERIMENT WORK

In this section, the forming scheme of the automotive refill opening cap is introduced, as shown in Figure 1. The forming process, including preforming, blanking, drawing and bending, will be adopted using ISF in the preforming stage. The effect of forming quality is investigated with parameters such as the PH, the PPA, the PTD and the PA. As a result, the impact trend of every parameter can be obtained for the MTRP in incremental forming through a numerical simulation. The affection degree of the parameters is then determined for the forming quality by the orthogonal test.

The material basal parameters are gained through a mechanical property test with an AA 5052 aluminum

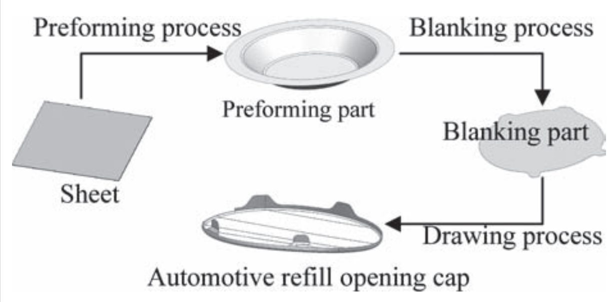

Figure 1 The forming scheme of the automotive refill opening cap

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alloy sheet, presented in Table 1. The sheet can be simplified as a transverse anisotropic material in the numerical simulation to improve the calculation efficiency, and the material's mechanical properties are shown in Table 2.

Four parameters, including the PH, the PPA, the PTD and the PA, are taken as the factors of the orthogonal test, and the level of every factor is determined by the data from the single factor test. The design of factors and levels are shown in Table 3.

The second-order models are adopted to analyze the international effection of major factors, and the model is shown in equation 1:

$$y = \beta_0 + \sum_{i=1}^{m} \beta_i x_i + \sum_{i=1}^{m} \beta_{ii} x_i^2 + \sum_{i<j}^{m} \beta_{ij} x_i x_j + \varepsilon \qquad (1)$$

where b_0 is the constant effect and b_i is the linearity effect. m and ε are the number of tests and aberration effects, respectively. b_{ii} and b_{ij} are the second-order effect and interaction effect, respectively.

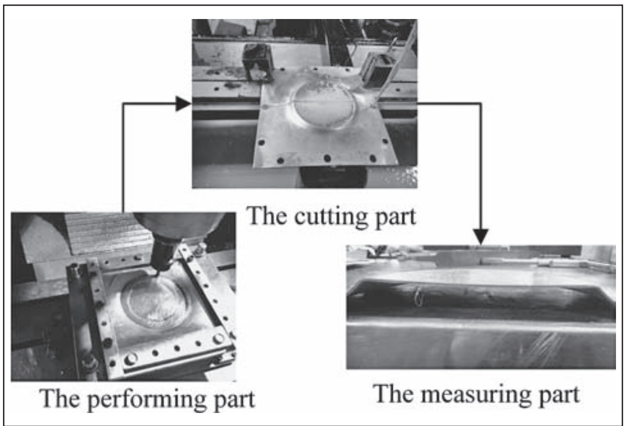

Figure 2 The experimental scheme

Table 1 **Mechanical properties of the AA5052 Al alloy sheet with a 0,6 mm thickness**

Material AA5052	0,6 mm
Density / kg/m^3	2 690
E / Gpa	70,7
Poisson's ratio	0,33
*R*e / Mpa	190
*R*m / Mpa	355
Tangent modulus / Gpa	26,6
Hardening exponent	0,13

Table 2 **Mechanical properties of the AA5052 aluminum alloy sheet with a 0,6 mm thickness for three directions**

Material AA5052	Rolling (0°)	Diagonal (45°)	Transverse (90°)
Re / MPa	187	189	190
*R*m / MPa	353	355	355
A / %	5	8	6
E / GPa	70,5	71,7	70,7

Table 3 **The level of the orthogonal test**

Level	A	B	C	D
	PH / mm	PPA / mm	PTD / mm	PA / °
1	15	0,5	6	35
2	20	0,75	8	40
3	25	1	10	45

The forming equipment and device are used to manufacture the preforming part, and the wire cutting machine is adopted to cut the performing part. Then the MTRP of optimal group is measured to verify simulating results. The experimental scheme is shown in Figure 2.

RESULTS AND DISCUSSION

The test results are presented in Table 4.The results are analyzed through a mean analysis methodology, and the effect of these factors is presented in Table 5.

The PH and the PPA are the major factors for the MTRP, and the PA and the PTD have a smaller effect on the test target according with Table 5. Therefore, the interaction of the major factors can be analyzed for the effect of the target through the response surface method. The results of response surface design are presented in Table 6, and the response is gained, as shown in equation 2:

$$y = -5{,}377 + 0{,}\ 96x_1 - 1{,}211x_2 - 0{,}015x_1^2 + \\ + 2{,}475x_2^2 + 0{,}003x_1x_2 \qquad (2)$$

where x_1 and x_2 are the PH and the PPA, respectively, and y is the MTRP.

The response model is produced according with equation 2, as shown in Figure 3. The minimum of the MTRP is located at a PH of 15 mm and a PPA of 0,5 mm, as shown in Figure 3.

Table 4 **Results of the orthogonal test**

Test	A	B	C	D	MTRP
1	1	1	1	1	6,959
2	1	2	2	2	6,64
3	1	3	3	3	6,576
4	2	1	2	3	9,073
5	2	2	3	1	8,928
6	2	3	1	2	7,046
7	3	1	3	2	9,898
8	3	2	1	3	11,213
9	3	3	2	1	9,365

Table 5 **The mean analysis of results**

Level	A	B	C	D	Sum
1	6,725	8,643	8,406	8,417	75,698
2	8,349	8,927	8,359	7,861	
3	10,159	7,662	8,467	8,954	
Mean	3,434	1,265	0,108	1,093	-

Table 6 **The response surface test**

Test	A	B	C	D	MTRP
	PH / mm	PPA / mm	PTD / mm	PA / °	
1	15	1	8	40	7,138
2	20	0,5	8	40	7,917
3	20	0,75	8	40	8,741
4	25	0,5	8	40	9,493
5	25	0,75	8	40	9,831

The optimal parameters are determined through the orthogonal test and the response surface design, and they are a PH of 15 mm, a PPA of 0,5 mm, a PTD of 8 mm and a PA of 40°. These parameters are used to simulate the deformation of the preforming part in incremental forming stage. The result of the numerical simulation is taken as the optimization group, and the minimum of the MTRP is taken as the control group from the orthogonal test. The results of two groups are shown in Figure 4. The result of the control group is shown in Figure 4 with an MTRP of 6,64 %, and the result of the optimal group is shown in Figure 4 with an MTRP of 4,4 %. The MTRP is decreased through the optimal methodology, which efficiently improved the rigidity of the part after deformation.

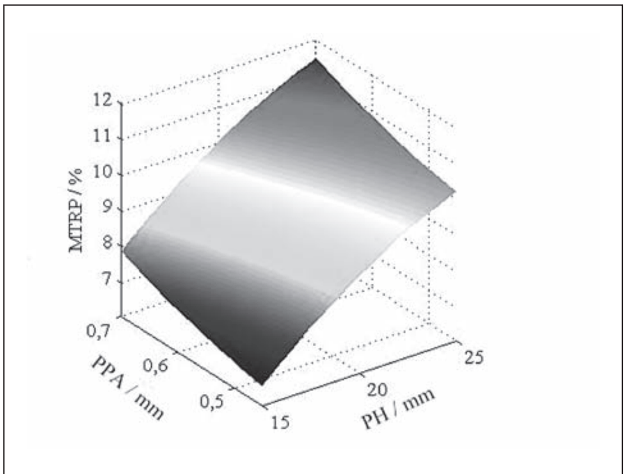

Figure 3 The model of response

The preforming part is manufactured through incremental forming deceive with optimal parameters, and the wire cutting machine is adopted to cut the performing part, and the thickness reduce percentages of five positions (shown in Figure 5)can be measured. The result of optimal group is compared with the actual result, and all errors are lower 5 %, presenting in Table7, so the optimal results are accurate.

Table 7 **Results of error analysis**

Position	Simulation result	Actual result	Error / %
A	0,0441	0,045	2
B	0,031	0,03	3,3
C	0,0266	0,027	1,5
D	0,0178	0,0185	3,8
E	0,0135	0,014	3,6

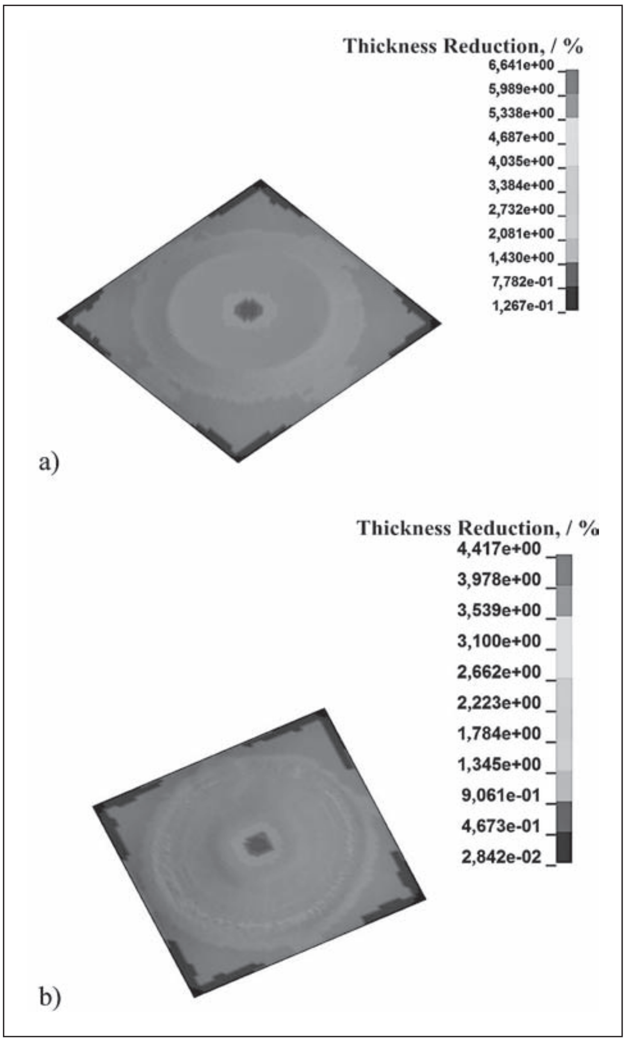

Figure 4 The results of the simulation**:** a) control group; b) optimization group.

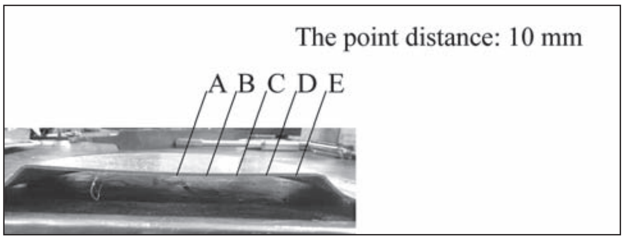

Figure 5 The measured positions

CONCLUSION

In this paper, the preforming part of an automotive refill opening cap manufactured through the incremental sheet forming with large rigidity because of the lower thickness reduction percentage, and the production cost was reduced. The effect of factors would be analyzed through the respond surface method and an orthogonal test for the target, and the actual experiment is adopted to verify the simulation results, and all errors are lower 5 %, so the optimal results are accurate. The optimal processing parameters are obtained through analysis, included a PH of 15 mm, a PPA of 0,5 mm, a PTD of 8 mm and a PA of 40° in incremental forming stage.

Acknowledgements

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