

OPTIMIZING THE PROCESSING PARAMETERS FOR MINIMIZING SHRINKAGE OF ABS PRODUCT DURING INJECTION MOLDING PROCESS

VAN-LONG Trinh

School of Mechanical and Automotive Engineering, Hanoi University of Industry, 298 Caudien Street, Hanoi 100000, Vietnam; e-mail: longtv@hau.edu.vn

Abstract: Product quality is a very important criteria of a production process such as injection molding process. There are still fierce defects that exist on the molded product such as shrinkage, weldlines, and warpage. To improve product quality of injection molding process, it is clear that defects have been eliminated out of molded parts. The shrinkage is occurred and appeared on the final product during injection molding process that related to injection processing parameters such as injection pressure, melting temperature, filling time, and mold temperature. This paper demonstrates an optimal method of processing parameters by using Taguchi method and RSM technique to minimize the shrinkage of product during injection molding process. The product material is acrylonitrile butadiene styrene (ABS) with good characteristics of toughness, strength, and chemical resistance. The shrinkage analysis and simulation tasks are conducted by using EasyFill software. The results show that the optimal shrinkage can be reached. The optimal shrinkage is lower about 0.52% in comparison to the minimal value of proposal experiments and about 22.14% the maximum value of the experimental matrix. The paper hopes that the results are useful for engineers and practical production in the near future.

KEYWORDS: Injection molding, Shrinkage, Processing parameters, Optimization, Taguchi method, RSM

1 Introduction

Injection molding is the top plastic manufacturing method that produces a huge amount of plastic product with diversity shape and sophisticated geometries. These plastic products have been applied in practical applications such as aerospace, electrical equipment, household tools, and automobile parts [1]. There are ailing defects existed on the plastic product that produced by injection molding process such as shrinkage [2], weldlines [3], and warpage [4]. Once these defects are eliminated out of the molding part during injection molding process (IMP), product quality will be increased [5]. Shrinkage has directly effect on the overall dimension of the final product that may influence on the service of the part in the practical applications such as in semiconductor system and immersion system [6]. The shrinkage is normally occurred and effected on the final part during IMP that it has related to processing parameters including the injection pressure, the melting temperature, the filling time, and the mold temperature [7, 8]. Quality control is a very important task during injection molding process to ensure the perfection of plastic parts [9, 10]. There are many methods that have been introduced to deal with reduction of defects during injection molding process such as using numerical methods to predict weldlines of plastic product during injection molding process [10], evaluating defects of weldlines and shrinkage of molded part during injection molding process via using response surface methodology [11], using grey correction analysis technique to get multi-objective goals of an IM process of a car lamp part [12], applying a deep learning model to predict the weight of the molded part during injection molding process [13], using fuzzy logic technique to predict shrinkage and warpage of molded part [14], and

using response surface method to reduce warpage of plastic part during injection molding process [15]. Response surface methodology (RSM) is an effective method to optimize an engineering object that have relate to the engineering process with different processing parameters [16]. RSM has received a lot of solicitousness by its effectiveness in solving problems related to optimization of engineering processes such as using RSM method to optimize characteristics of engine performance [17], using RSM for optimizing the production of bioethanol product [18], applying RSM to get optimal compressive strength during production of concrete [19], using RSM technique to have optimal production of biohydrogen product [20], investigating the influence of processing factors on tensile strength of the printed part during printing process using Box-Behnken method [21], and using RSM to reach an optimal injection molding process of electrical vehicle part [22]. Some statistic techniques have been used to find technical problems such as using factorial design to evaluate the impact of parameters on the dimension of the product during laser cutting process [23] and using hybrid model of Grey and Taguchi methods to optimize parameters during machining Inconel material [24]. Acrylonitrile butadiene styrene (ABS) is an engineering plastic material that it has outstanding characteristics of strength, toughness, and chemical resistance for fabricating useful products [25]. This work illustrates an optimal method of PP via using Taguchi method and RSM technique to reduce the shrinkage of the plastic product during IMP. The product material is acrylonitrile butadiene styrene (ABS) with good characteristics of toughness, strength, and chemical resistance. The shrinkage analysis and simulation tasks are conducted by using EasyFill software. The results show that the shrinkage can be reduced of about 0.52% and 22.14% in comparison to the minimal value of proposal experiments and the maximum value of the experimental matrix. The paper hopes that the results are useful for engineers and practical production in the near future.

2 Materials and methods

Figure 1 illustrates detail views of the product with basic dimensions including 2.5 mm in the thickness, 150 mm of the big diameter, 145 mm of the small diameter, and 15 mm in the height. Figure 1(a) illustrates the section view of product. Figure 1 (b) shows the top view of product. Figure 1(c) illustrates the isometric view of product. The sample material is acrylonitrile butadiene styrene with mechanical specifications as shown in Table 1 [26].

Table 1 The mechanical properties of ABS

Mechanical properties	Unit	Value
Melt density	g/cm ³	1.04
Melt flow index	g/min	0.7/1
Flexural modulus	MPa	45.1
Injecting temperature	°C	200-240

The injecting parameters are picked for the experiments to evaluate the shrinkage of molded part including the injection pressure (A), melt temperature (B), mold temperature (C), and filling time (D) [27]. Table 2 shows the injecting parameters and the levels following the Box-Behnken design method [28].

Table 3 illustrates the code table designed by using Box-Behnken methodology. The experimental matrix shows 27 tasks arranged in companying with the coded signals. Table 4 illustrates the matrix of experiments and its input factor values that designed using Box-

Behnken methodology (BBM). The input factors are the injection pressure (A), the mold temperature (C), the melt temperature (B), and the filling time (D).

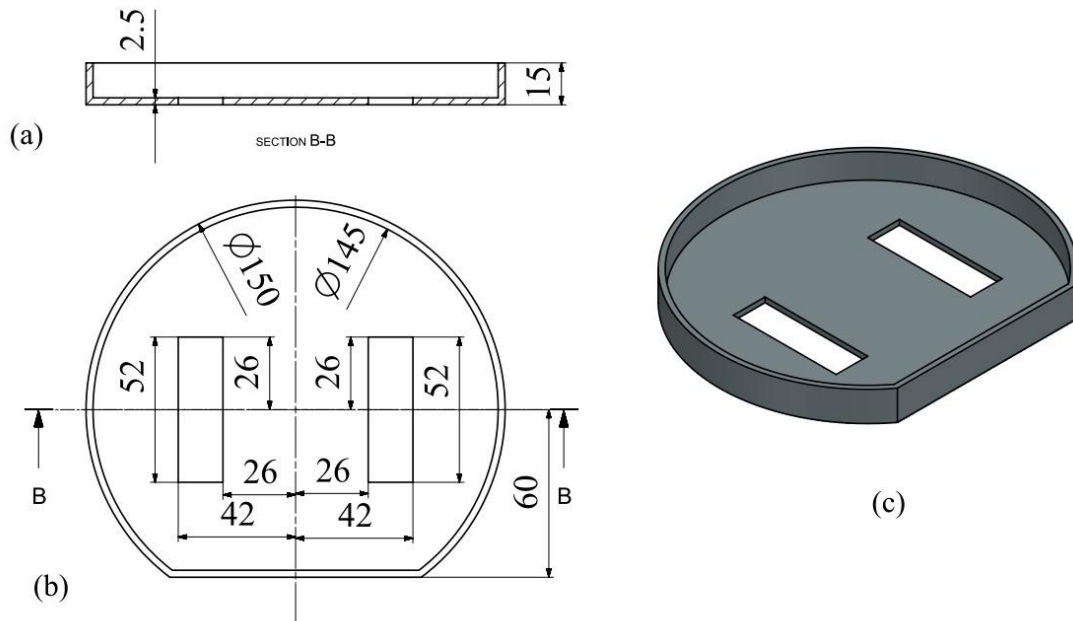


Fig. 1 The drawing views of the product

Table 2 The injecting molding conditions and its levels

Processing parameters	Code	Level 1			Unit
		Level 1	Level 2	Level 3	
Injection pressure	A	75	105	135	MPa
Melt temperature	B	220	235	250	°C
Mold temperature	C	40	50	60	°C
Filling time	D	1	1.5	2	s

Table 3 The design table conducted by following Box-Behnken methodology

Run	A	B	C	D
1	1	0	1	0
2	-1	1	0	0
3	0	0	1	1
4	0	1	1	0
5	0	0	1	-1
6	0	1	-1	0
7	-1	0	1	0
8	0	0	0	0
9	0	0	0	0
10	1	1	0	0
11	1	0	0	-1
12	0	0	-1	1
13	1	0	0	1
14	0	-1	0	1
15	-1	0	-1	0
16	0	-1	-1	0
17	0	-1	1	0

18	0	0	0	0
19	0	1	0	-1
20	-1	-1	0	0
21	1	0	-1	0
22	0	-1	0	-1
23	1	-1	0	0
24	0	0	-1	-1
25	0	1	0	1
26	-1	0	0	1
27	-1	0	0	-1

Table 4 The matrix of experiments and its factor values that designed using Box-Behnken methodology

Run	A	B	C	D	A (MPa)	B (°C)	C (°C)	D (s)
1	1	0	1	0	135	235	60	1.5
2	-1	1	0	0	75	250	50	1.5
3	0	0	1	1	105	235	60	2
4	0	1	1	0	105	250	60	1.5
5	0	0	1	-1	105	235	60	1
6	0	1	-1	0	105	250	40	1.5
7	-1	0	1	0	75	235	60	1.5
8	0	0	0	0	105	235	50	1.5
9	0	0	0	0	105	235	50	1.5
10	1	1	0	0	135	250	50	1.5
11	1	0	0	-1	135	235	50	1
12	0	0	-1	1	105	235	40	2
13	1	0	0	1	135	235	50	2
14	0	-1	0	1	105	220	50	2
15	-1	0	-1	0	75	235	40	1.5
16	0	-1	-1	0	105	220	40	1.5
17	0	-1	1	0	105	220	60	1.5
18	0	0	0	0	105	235	50	1.5
19	0	1	0	-1	105	250	50	1
20	-1	-1	0	0	75	220	50	1.5
21	1	0	-1	0	135	235	40	1.5
22	0	-1	0	-1	105	220	50	1
23	1	-1	0	0	135	220	50	1.5
24	0	0	-1	-1	105	235	40	1
25	0	1	0	1	105	250	50	2
26	-1	0	0	1	75	235	50	2
27	-1	0	0	-1	75	235	50	1

3 Results and discussions

All of experiments are conducted by shrinkage analysis tool via using EasyFill software. The basic simulation settings have the part volume of 51937.98 mm³ and 153.845 x 10³ meshing elements. The input parameters are chosen for analyzing and simulating including the injection pressure (A), the mold temperature (C), the melt temperature (B), and the filling time (D). Figure 2 illustrates the shrinkage result of injecting molding process through experimental progress by EasyFill software. Table 5 demonstrates the experiments and the

shrinkage results of 27 tasks. The table illustrates that minimum shrinkage belongs to the test number of 16 with the shrinkage result of 3.281% and maximum shrinkage is 4.192% belonging to the test of 4, respectively. Table 6 presents the coded coefficients in the design table following the Box-BehnKen method. The table displays that the input factors have P-values with reasonable levels. Table 7 demonstrates the analysis of variance (ANOVA) results. The table display that the model is significant by 99.97% contribution. The B factor contribution is 58.29%. The C factor contribution is 41.56%. The A and D parameters have minimal contributions on this model.

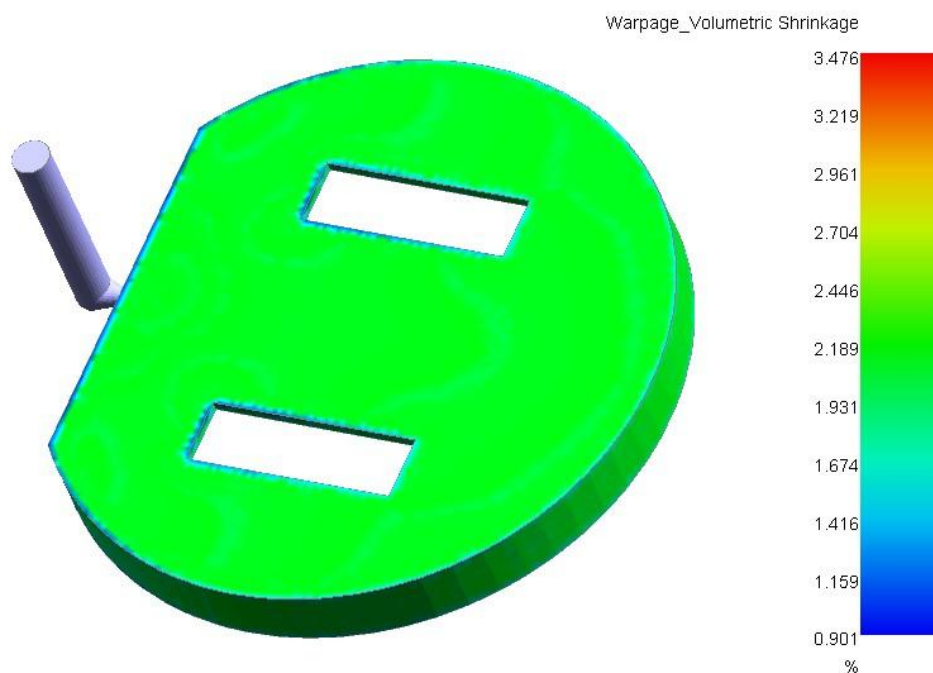


Fig. 2 The shrinkage analysis result of test No22 in the experimental table

Table 5 The shrinkage results after conducted by EasyFill software

Run	A	B	C	D	A (MPa)	B (°C)	C (°C)	D (s)	Shrinkage (%)
1	1	0	1	0	135	235	60	1.5	3.946
2	-1	1	0	0	75	250	50	1.5	3.985
3	0	0	1	1	105	235	60	2	3.949
4	0	1	1	0	105	250	60	1.5	4.192
5	0	0	1	-1	105	235	60	1	3.93
6	0	1	-1	0	105	250	40	1.5	3.777
7	-1	0	1	0	75	235	60	1.5	3.946
8	0	0	0	0	105	235	50	1.5	3.738
9	0	0	0	0	105	235	50	1.5	3.739
10	1	1	0	0	135	250	50	1.5	3.985
11	1	0	0	-1	135	235	50	1	3.72
12	0	0	-1	1	105	235	40	2	3.536
13	1	0	0	1	135	235	50	2	3.744
14	0	-1	0	1	105	220	50	2	3.494
15	-1	0	-1	0	75	235	40	1.5	3.529
16	0	-1	-1	0	105	220	40	1.5	3.281
17	0	-1	1	0	105	220	60	1.5	3.699
18	0	0	0	0	105	235	50	1.5	3.74

19	0	1	0	-1	105	250	50	1	3.966
20	-1	-1	0	0	75	220	50	1.5	3.492
21	1	0	-1	0	135	235	40	1.5	3.529
22	0	-1	0	-1	105	220	50	1	3.476
23	1	-1	0	0	135	220	50	1.5	3.492
24	0	0	-1	-1	105	235	40	1	3.508
25	0	1	0	1	105	250	50	2	3.992
26	-1	0	0	1	75	235	50	2	3.744
27	-1	0	0	-1	75	235	50	1	3.72

Table 6 The coded coefficients

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	3.73900	0.00041	(3.73812, 3.73988)	9222.91	0.000	
A	-0.000000	0.000203	(-0.000442, 0.000442)	-0.00	1.000	1.00
B	0.246917	0.000203	(0.246475, 0.247358)	1218.13	0.000	1.00
C	0.208500	0.000203	(0.208058, 0.208942)	1028.61	0.000	1.00
D	0.011583	0.000203	(0.011142, 0.012025)	57.14	0.000	1.00
A*A	-0.000167	0.000304	(-0.000829, 0.000496)	-0.55	0.594	1.25
B*B	-0.000292	0.000304	(-0.000954, 0.000371)	-0.96	0.356	1.25
C*C	-0.001417	0.000304	(-0.002079, -0.000754)	-4.66	0.001	1.25
D*D	-0.006792	0.000304	(-0.007454, -0.006129)	-22.34	0.000	1.25
A*B	0.000000	0.000351	(-0.000765, 0.000765)	0.00	1.000	1.00
A*C	-0.000000	0.000351	(-0.000765, 0.000765)	-0.00	1.000	1.00
A*D	0.000000	0.000351	(-0.000765, 0.000765)	0.00	1.000	1.00
B*C	-0.000750	0.000351	(-0.001515, 0.000015)	-2.14	0.054	1.00
B*D	0.002000	0.000351	(0.001235, 0.002765)	5.70	0.000	1.00
C*D	-0.002250	0.000351	(-0.003015, -0.001485)	-6.41	0.000	1.00

Table 7 The analysis of variance (ANOVA)

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	14	1.25522	100.00%	1.25522	0.089658	181842.08	0.000
Linear	4	1.25489	99.97%	1.25489	0.313723	636282.85	0.000
A	1	0.00000	0.00%	0.00000	0.000000	0.00	1.000
B	1	0.73161	58.29%	0.73161	0.731614	1483837.01	0.000
C	1	0.52167	41.56%	0.52167	0.521667	1058028.85	0.000
D	1	0.00161	0.13%	0.00161	0.001610	3265.52	0.000
Square	4	0.00029	0.02%	0.00029	0.000071	144.92	0.000
A*A	1	0.00002	0.00%	0.00000	0.000000	0.30	0.594
B*B	1	0.00002	0.00%	0.00000	0.000000	0.92	0.356
C*C	1	0.00000	0.00%	0.00001	0.000011	21.71	0.001
D*D	1	0.00025	0.02%	0.00025	0.000246	498.95	0.000
2-Way Interaction	6	0.00004	0.00%	0.00004	0.000006	13.01	0.000
A*B	1	0.00000	0.00%	0.00000	0.000000	0.00	1.000
A*C	1	0.00000	0.00%	0.00000	0.000000	0.00	1.000
A*D	1	0.00000	0.00%	0.00000	0.000000	0.00	1.000
B*C	1	0.00000	0.00%	0.00000	0.000002	4.56	0.054
B*D	1	0.00002	0.00%	0.00002	0.000016	32.45	0.000
C*D	1	0.00002	0.00%	0.00002	0.000020	41.07	0.000

Error	12	0.00001	0.00%	0.00001	0.000000		
Lack-of-Fit	10	0.00000	0.00%	0.00000	0.000000	0.39	0.873
Pure Error	2	0.00000	0.00%	0.00000	0.000001		
Total	26	1.25522	100.00%				

Figure 3 demonstrates the Pareto chart of standardized influences of processing factors on shrinkage using a Minitab tool with reliability of 95 percent. The cut-off line illustrates that the parameters have significant influences on the shrinkage as moving over the red line.

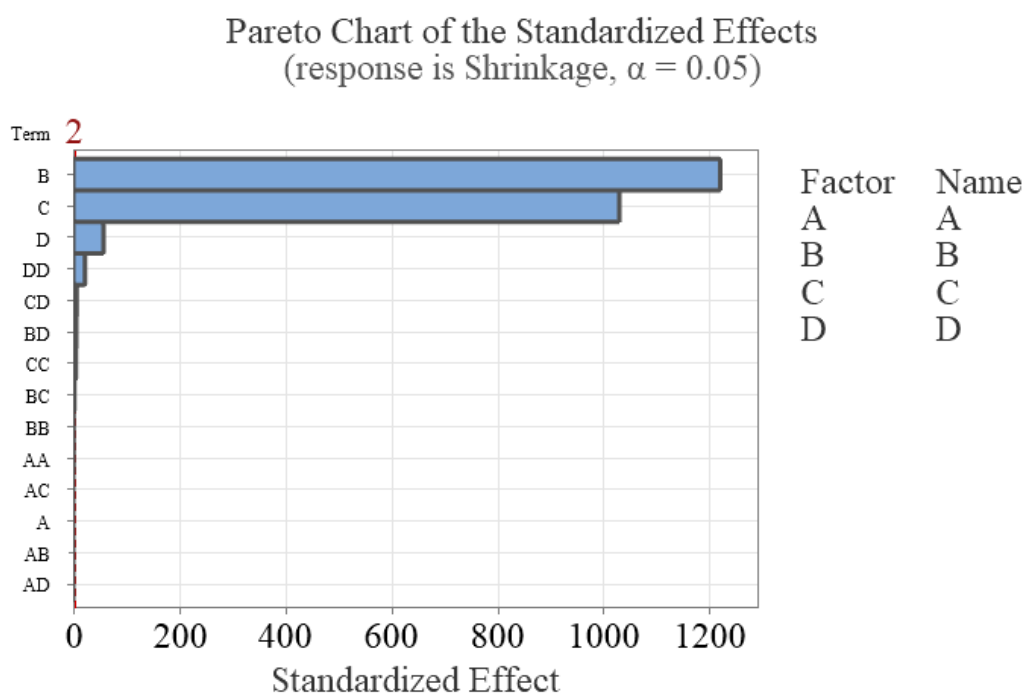


Fig. 3 The Pareto Chart of the standardized effects

The regression algorithm can be constructed to predict shrinkage of plastic product as following formula (1):

$$\begin{aligned} \text{Shrinkage} = & -1.3753 + 0.39 \times 10^{-4} A + 0.01692 B + 0.024117 C + 0.0645 D - 0.01 \times 10^{-4} B*B - \\ & 0.14 \times 10^{-4} C*C - 0.02717 D*D - 0.5 \times 10^{-5} B*C + 2.67 \times 10^{-4} B*D - 4.5 \times 10^{-4} C*D \end{aligned} \quad (1)$$

Table 8 demonstrates the minimal shrinkage with the prediction value of 3.262% corresponding to the optimal factors set for minimal shrinkage as the injection pressure at 135 MPa, melt temperature at 220°C, mold temperature at 40°C, and the filling time at 1s, respectively. The shrinkage was analyzed again by using EasyFill with the optimal factors set. Figure 4 demonstrates the shrinkage result after analyzing again with the shrinkage value of 3.264%. The goals show that the optimal shrinkage value is a bit difference with the prediction shrinkage value of 3.262% that produced by Box-Behnken method and lower about 0.52% than that of the minimum value of 3.281% in the matrix of the BBM experiments. The optimal shrinkage is smaller than the maximum shrinkage in the matrix of BBM experiments of about 22.14%. The results reveal that response surface method is an effective methodology to face with engineering problems that associated to processing factors such as in the IM process.

Table 8 The optimal shrinkage result with the minimal value and optimal value factors

Optimal injecting factor				Optimal shrinkage
A	B	C	D	
135 MPa	220 °C	40 °C	1 s	3.262 %

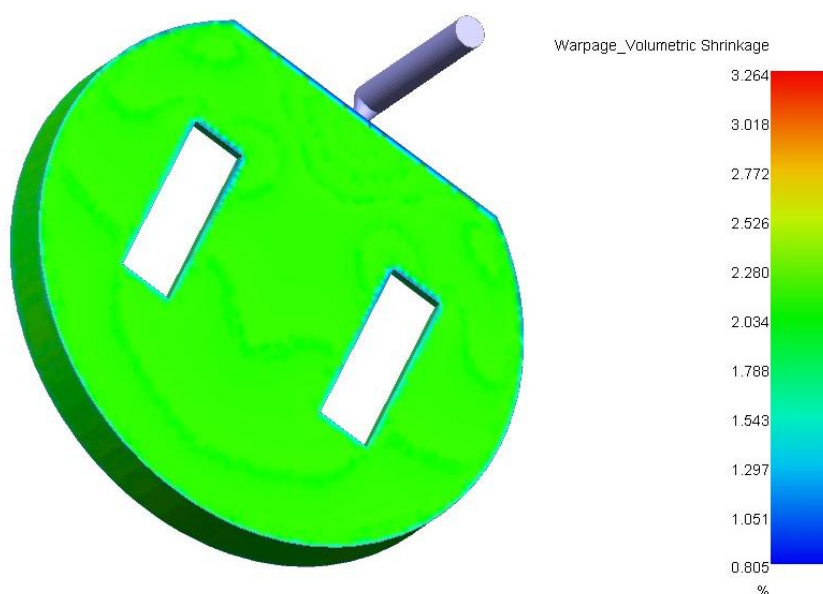


Fig. 4 The retested result of shrinkage under optimal conditions

CONCLUSIONS

Product quality improvement is dependent on reducing of defects during production processes such as injection molding process. The fierce defects are still existence on the molded product such as shrinkage, weldlines, and warpage. The shrinkage defect is occurred and lied on the molded product during injection molding process that tied in with injection processing factors such as injection pressure, melting temperature, filling time, and mold temperature. This paper demonstrates an optimal method of processing parameters by using Taguchi method and RSM technique to reduce the shrinkage of final product during IM process. The results show that the shrinkage can be reduced of about 0.52% and 22.14% in comparison to the minimal value of proposal experiments and the maximum value of the experimental matrix. The paper hopes that the results are useful for engineers and practical production in the near future.

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