

Experimental Study on the Effects of Compression Parameters on Molding Quality of Dried Fish Floss

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Abstract. Taking the molding block thickness, relaxation ratio and shatter resistance as evaluation indicators, the effects of compression parameters, which include mold form, compressive force, pressure-holding time and loading rate, on molding block quality of fish floss were investigated by means of single factor and orthogonal test. The results showed that: 1) the mold form, compressive force, pressure-holding time and loading rate have great impact on the molding block thickness, and the block thickness decreases with the increase of compressive force and pressure-holding time; 2) the loading rate and pressure-holding time affect the relaxation ratio of molding block significantly; 3) the pressure-holding time highly affects the shatter resistance of molding block, and the shatter resistance will be greatly improved after a period of pressure holding; 4) the interactions between different parameters have no significant effect on the molding block quality. The results can provide references for the development of compression molding equipment and selection of the technique parameters.

Keywords: Compression Molding, Technique Parameters, Molding Quality, Relaxation Ratio, Shatter Resistance.

1 Introduction

Dried fish floss is a kind of fish product, which is made with delicate techniques such as cooking, meat picking, seasoning, squeezing, frying etc. The compression molding is to suppress the loose dried fish floss under external force. As a result, the volume of dried fish floss decreases, while the density increases.

At present, the research of compression molding mainly focuses on the compression molding of agricultural material, such as food, biomass, and so on. Regarding the relationship between the physical characteristics of materials, compression parameters and the quality of molding block, many research results and conclusions have been achieved[1-4]. However, the research on the compression molding of meat product, such as fish floss, is less involved.

Taking the salted and dried fish floss as the research object, the effects of compression parameters, which include mold form, compressive force, pressure-holding time and loading rate, on molding block quality of fish floss were investigated by means of single factor and orthogonal test. On the basis of this, the reasonable mold form, loading

method and pressure-holding time were determined. The results can provide references for the development of compression molding equipment and selection of the technique parameters.

2 Materials and Devices

2.1 Materials

For this experiment, the salted and dried chub was broken into fish floss by a high-speed meatball machine.

2.2 Devices

A set of steel cylinder mold (Fig.1) with a pressure device was designed for the experiment. As shown in figure1, the part 2 and 3 respectively denote the punch and die of the mold.

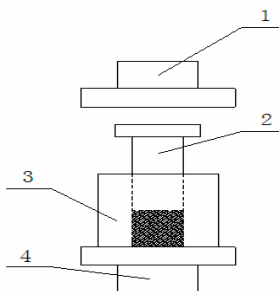


Fig. 1. Sketch map of the mold

1. Upper platen 2. Punch 3. Die 4. Bottom platen

2.3 Instruments

(1) RGT2000-10 Microcomputer Control Electronic Universal Testing Machine
Maximum load: 5KN; Test speed: 0.01-500mm/min; Manufacturer: Shenzhen Reger instrument Co., Ltd.

(2) YXQ.SG41.280 Portable Pressure Steam Sterilizer
Maximum working pressure: 0.15MPa; Maximum working temperature: 126°C; Net weight: 15.5kg.

(3) 202-00 Desktop Electric Oven
Temperature fluctuation: 0.1°C; Temperature range: 50-250°C; Manufacturer: Tianjin Taisite instrument Co., Ltd.

(4) HSN-22 high-speed meatball machine
Productivity: 80kg/h; Power: 2.2kw.

3 Methods

The compression molding test was conducted on the RGT2000-10 computer-controlled electronic universal testing machine. A set of steel cylinder molds with the square and round hole were designed for the experiment.

During the measurement, the die was placed on the bottom platen. The dried fish floss was first metered into the die, and then the punch was inserted in the die. Afterwards, adjust the location of the upper and bottom platen, so that the upper platen just contacts with the punch.

In order to investigate the effects of compression parameters on molding quality of fish floss, the single-factor experiments were successively carried out on the conditions of different mold forms, compressive forces, loading rates and pressure-holding times, while the physical characteristics, such as moisture content and particle size, remain the same. Additionally, the effects of interaction of loading rate with compressive force and pressure-holding time on the quality of molding block were determined by means of orthogonal test.

4 Results and Discussion

4.1 Effect of Mold Form on the Quality of Molding Block

In order to investigate the effect of mold form on the compression molding quality of fish floss, the single-factor experiments were carried out in the case of constant compressive force(3Mpa), pressure-holding time(60s) and loading rate(30mm/min),while the mold form is various. Specifically, the molds with the square or round inner hole, which is 25 mm and 30mm in diameter or edge, were employed to carry out the single-factor experiments of four levels.

4.1.1 Effect of Mold Form on the Thickness of Molding Block

Table 1 shows the variance analysis results of molding block thickness when using different mold forms. As shown in the table, when the significance level α is equal to 0.05, F-statistics is greater than the critical value F_α , and the P-value, which denotes the probability of having no significant effect on the experimental results, is greater than 0.01, but less than 0.05. The results indicate that mold form affects the thickness of molding block significantly. Additionally, observe the mean value of molding block thicknesses, it can be found that the thickness of molding block is relatively small when using the mold with the diameter of 30mm.

Table 1. Variance analysis of the molding block thickness when using different mold forms

Error source	SS	df	MS	F	P value	F_α
Inter	0.242	3	0.081	5.093	0.019	3.587
Intra	0.174	11	0.016			
Total	0.416					

Note: Inter shows “Inter-group error”; Intra shows “Intra-group error”.

4.1.2 Effect of Mold Form on the Relaxation Ratio of Molding Block

Table 2 shows the variance analysis results of molding block relaxation ratio when using different mold forms. When the significance level α is equal to 0.05, F-statistics is less than F_α , and P-value is greater than 0.05. The results clearly show that mold form has no significant effect on the relaxation ratio of molding block.

Table 2. Variance analysis of the molding block relaxation ratio when using different mold forms

Error source	SS	df	MS	F	P value	F_α
Inter	0.003	3	0.001	0.629	0.611	3.587
Intra	0.017	11	0.002			
Total	0.020					

4.1.3 Effect of Mold Form on the Shatter Resistance of Molding Block

Table 3 shows the variance analysis results of molding block shatter resistance when using different mold forms. Since F-statistics is less than the critical value F_α ($\alpha=0.05$), and P-value is greater than 0.05, It is, therefore, believed that mold form does not affect the shatter resistance of molding block significantly.

Table 3. Variance analysis of the molding block shatter resistance when using different mold forms

Error source	SS	df	MS	F	P value	F_α
Inter	0.0005	3	0.0002	1.601	0.245	3.587
Intra	0.0011	11	0.0001			
Total	0.0016					

4.2 Effect of Compressive Force on the Quality of Molding Block

In the case of constant mold inner diameter (30mm), pressure-holding time (60s), and loading rate (30mm/min), the compression molding test was performed to investigate the effects of compressive force on the quality of molding block. In order to reduce the measurement error, the compression experiment was repeated three times at each level of compressive force, corresponding to 1MPa, 2MPa, 3MPa, 4MPa, and 5MPa.

4.2.1 Effect of Compressive Force on the Thickness of Molding Block

Table 4 and Table 5 show the average and variance of molding block thickness when using different compressive forces. At the significance level of 0.01, F-statistics is greater than F_α ($\alpha=0.01$), P-value is less than 0.01. Apparently, the compressive force has a great impact on the thickness of molding block. In addition to this, observe the mean value of molding block thicknesses, it can be found that the greater the compressive force is, the thicker the molding block is, and when the compressive force

increases from 1MPa to 2MPa, the molding block thickness decreases significantly. Furthermore, the relationship between compressive force and molding block thickness can be represented mathematically as follows:

$$y=5.67+0.73/x \tag{1}$$

where the variable y and x respectively denote the molding block thickness and compressive force.

Table 4. Average and variance of the molding block thickness when using different compressive forces

Group	Point	Sum	Average	Variance
1MPa	3	19.23	6.41	0.003
2MPa	3	17.98	5.99	0.002
3MPa	3	17.95	5.98	0.013
4MPa	3	17.55	5.85	0.003
5MPa	3	17.40	5.80	0.018

Table 5. Variance analysis of the molding block thickness when using different compressive forces

Error source	SS	df	MS	F	P value	F_α
Inter	0.692	4	0.173	23.148	4.85E-5	3.48
Intra	0.075	10	0.007			
Total	0.767					

4.2.2 Effect of Compressive Force on the Relaxation Ratio of Molding Block

Table 6 shows the variance analysis results of molding block relaxation ratio when using different compressive forces. At the significance level of 0.05, F-statistics is less than F_α ($\alpha=0.05$), P-value is greater than 0.05. Therefore, it can be concluded that the compressive force has no significant effect on the relaxation ratio of molding block.

Table 6. Variance analysis of the molding block relaxation ratio when using different compressive forces

Error source	SS	df	MS	F	P value	F_α
Inter	0.003	4	0.0007	0.737	0.587	3.48
Intra	0.009	10	0.0009			
Total	0.012					

4.2.3 Effect of Compressive Force on the Shatter Resistance of Molding Block

Table 7 shows the variance analysis results of molding block shatter resistance when using different compressive forces. When the significance level α is equal to 0.05,

Table 7. Variance analysis of the molding block shatter resistance when using different compressive forces

Error source	SS	df	MS	F	P value	F_α
Inter	5.39E-5	4	1.35E-5	2.25	0.136	3.48
Intra	5.99E-5	10	5.99E-6			
Total	0.0001					

F-statistics is less than F_α ($\alpha=0.05$), P-value is greater than 0.05. It is clear that the compressive force has no significant effect on the shatter resistance of molding block.

4.3 Effect of Pressure-Holding Time on the Quality of Molding Block

In the case of constant mold inner diameter (30mm), compressive force (3MPa), and loading rate (30mm/min), the compression molding test was performed to investigate the effects of pressure-holding time on the quality of molding block. In order to reduce the measurement error, the compression experiment was repeated three times at each level of pressure-holding time, corresponding to 0s, 30s, 60s, 90s, and 120s.

4.3.1 Effect of Pressure-Holding Time on the Thickness of Molding Block

Table 8 and Table 9 show the average and variance of molding block thickness when using different pressure-holding times. At the significance level of 0.01, F-statistics is greater than F_α ($\alpha=0.01$), P-value is less than 0.01. The results show that the pressure-holding time affects the thickness of molding block significantly. The longer the pressure-holding time, the thinner the molding block. Specifically, when the pressure-holding time varies in the range of 0s~30s, the increase of pressure-holding time usually results in the great decrease of molding block thickness. After that, the thickness of molding block doesn't subject to the pressure-holding time and slightly decreases. Furthermore, the thickness basically maintains constant when the pressure-holding time exceeds 90 seconds.

The variation between pressure-holding time and molding block thickness can be represented by the following equation:

$$y = -486.8 + 4572.1/x \quad (2)$$

where the variable y and x respectively denote the molding block thickness and pressure-holding time.

Table 8. Average and variance of the molding block thickness when using different pressure-holding times

Group	Point	Sum	Average	Variance
0s	3	23.62	7.87	0.011
30s	3	18.84	6.28	0.005
60s	3	18.75	6.25	0.001
90s	3	17.77	5.92	0.012
120s	3	17.51	5.85	0.000

Table 9. Variance analysis of the molding block thickness when using different pressure-holding times

Error source	SS	df	MS	F	P value	F_α
Inter	8.179	4	2.045	355.09	0.000	3.48
Intra	0.058	10	0.006			
Total	8.236					

4.3.2 Effect of Pressure-Holding Time on the Relaxation Ratio of Molding Block

Table 10 displays the variance analysis results of molding block relaxation ratio when using different pressure-holding times. At the significance level of 0.01, F-statistics is greater than F_α ($\alpha=0.01$), P-value is less than 0.01. It’s clear that the pressure-holding time has great impact on the relaxation ratio of molding block. Beyond that, observe the mean value of molding block relaxation ratio, it can be found that the molding block relaxation ratio will be greatly improved after a period of pressure holding. The results suggest that, at the beginning of pressure holding, the compressive force increases to a maximum value, which usually results in great internal stress in the interior of molding block, and pressure holding can balance a large part of internal stress.

Table 10. Variance analysis of the molding block relaxation ratio when using different pressure-holding times

Error source	SS	df	MS	F	P value	F_α
Inter	0.028	4	0.0070	355.09	0.000	3.48
Intra	0.002	10	0.0003			
Total	0.030					

4.3.3 Effect of Pressure-Holding Time on the Shatter Resistance of Molding Block

Table 11 displays the variance analysis results of molding block shatter resistance when using different pressure-holding times. At the significance level of 0.05, F-statistics is greater than F_α ($\alpha=0.05$), P-value is greater than 0.01, but less than 0.05. The results suggest that pressure-holding time affects the shatter resistance of molding block significantly. Observe the mean value of molding block shatter resistance, it can

Table 11. Variance analysis of the molding block shatter resistance when using different pressure-holding times

Error source	SS	df	MS	F	P value	F_α
Inter	2.141	4	0.535	4.297	0.028	3.48
Intra	1.246	10	0.125			
Total	3.387					

be found that the molding block, with the pressure-holding time of 0s, is poor at the shatter resistance, and when the pressure-holding time is 30s, the molding block can achieve better shatter resistance.

4.4 Effect of Loading Rate on the Quality of Molding Block

In the case of constant mold inner diameter (30mm), compressive force (3MPa), and pressure-holding time (60s), the compression molding test was performed to investigate the effects of loading rate on the quality of molding block. In order to reduce the measurement error, the compression experiment was repeated three times at each level of loading rate, corresponding to 10mm/min, 20mm/min, and 30mm/min.

4.4.1 Effect of Loading Rate on the Thickness of Molding Block

Table 12 and Table 13 display the average and variance of molding block thickness when using different loading rates. At the significance level of 0.05, F-statistics is greater than F_α ($\alpha=0.05$), P-value is greater than 0.01, but less than 0.05. The results suggest that loading rate has great impact on the thickness of molding block. Figure 2 represents the relationship between loading rate and molding block thickness. As shown in the figure, when the loading rate increases from 10mm/min to 30mm/min, the thickness of molding block decreases firstly and then increases.

Table 12. Average and variance of the molding block thickness when using different loading rates

Group	Point	Sum	Average	Variance
10 mm/min	3	17.69	5.90	0.007
20 mm/min	3	17.43	5.81	0.008
30 mm/min	3	18.26	6.09	0.003

Table 13. Variance analysis of the molding block thickness when using different loading rates

Error source	SS	df	MS	F	P value	F_α
Inter	0.120	2	0.060	10.814	0.010	5.14
Intra	0.033	6	0.006			
Total	0.153					

4.4.2 Effect of Loading Rate on the Relaxation Ratio of Molding Block

Table 14 and Table 15 display the average and variance of molding block relaxation ratio when using different loading rates. At the significance level of 0.05, F-statistics is greater than F_α ($\alpha=0.05$), P-value is greater than 0.01, but less than 0.05. The results suggest that loading rate affects the relaxation ratio of molding block significantly.

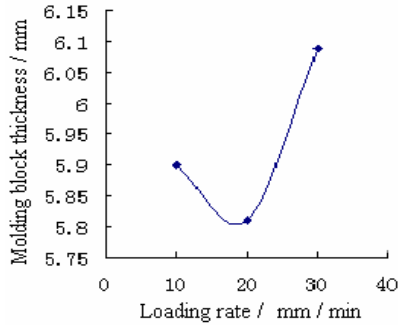


Fig. 2. Relationship between loading rate and molding block thickness

Table 14. Average and variance of the molding block relaxation ratio when using different loading rates

Group	Point	Sum	Average	Variance
10 mm/min	3	1.036	0.345	0.0002
20 mm/min	3	0.868	0.289	0.0004
30 mm/min	3	0.943	0.314	0.0002

Table 15. Variance analysis of the molding block relaxation ratio when using different loading rates

Error source	SS	df	MS	F	P value	F _α
Inter	0.005	2	0.0024	10.694	0.011	5.14
Intra	0.001	6	0.0002			
Total	0.006					

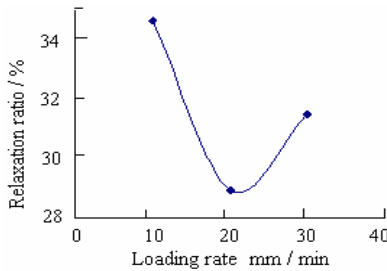


Fig. 3. Relationship between loading rate and relaxation ratio

Figure 3 represents the relationship between loading rate and relaxation ratio. As shown in the figure, when the loading rate increases from 10mm/min to 30mm/min, the relaxation ratio of molding block gradually decreases firstly and then increases.

4.4.3 Effect of Loading Rate on the Shatter Resistance of Molding Block

Table 16 displays the variance analysis results of molding block shatter resistance when using different loading rates. At the significance level of 0.05, F-statistics is less than F_α ($\alpha=0.05$), P-value is greater than 0.05. It can be concluded that the loading rate does not affect the shatter resistance of molding block significantly.

Table 16. Variance analysis of the molding block shatter resistance when using different loading rates

Error source	SS	df	MS	F	P value	F_α
Inter	1.32E-5	2	6.60E-6	2.77	0.141	5.14
Intra	1.43E-5	6	2.38E-6			
Total	2.75E-5					

4.5 Effect of Interaction on the Quality of Molding Block

As discussed above, loading rate, compressive force and pressure-holding time are the important technologic parameters in the process of compression molding. Taking the three parameters as experimental factors, the orthogonal tests were designed to explore whether there were interactions between these factors, and determine their major-minor sequence according to the effects on the molding block quality. For convenience, the factors of loading rate, compressive force and pressure-holding time were respectively marked as A, B, and C. In addition, the levels of factor A, B and C are 10 mm/min, 30 mm/min, 1 MPa, 3 MPa, 30 s and 90 s in turn.

4.5.1 Effect of Interaction on the Thickness of Molding Block

Table 17 displays the variance analysis results of molding block thickness when the interactions between the three factors are taken into account. As shown in the table, since $MS_{A \times C}$ is less than MS_e , the interaction between A and C has minor effect on the molding block thickness, so it can be subsumed in the term of error (e), and bring

Table 17. Variance analysis of the molding block thickness when considering the interactions between the factors

Error source	SS	df	MS	F	Significance
A	0.143	1	0.143	233.65	**
B	2.195	1	2.195	3582.88	**
A×B	0.007	1	0.007	10.80	
C	0.270	1	0.270	441.00	**
A×C	0.001	1	0.001		
B×C	0.002	1	0.002	3.45	
e	0.001	1	0.001		
e ^A	0.0012	2	0.0006		

about the new term of error (e^Δ).The results suggest that the three factors have significant effect on the thickness of molding block, and the major-minor sequence is B, C, and A. However, the interactions between the factors don't affect the thickness of molding block significantly.

4.5.2 Effect of Interaction on the Relaxation Ratio of Molding Block

Table 18 displays the variance analysis results of molding block relaxation ratio when the interactions between the factors are taken into account. As shown in the table, the factors of A, B, C and their interactions have no significant effect on the relaxation ratio of molding block.

Table 18. Variance analysis of the molding block relaxation ratio when considering the interactions between the factors

Error source	SS	df	MS	F	Significance
A	10727.2	1	10727.2	1.01	
B	10678.5	1	10678.5	1.00	
A× B	10652.0	1	10652.0	1.00	
C	10676.6	1	10676.6	1.00	
A× C	10668.7	1	10668.7	1.00	
B× C	10642.4	1	10642.4		
e	10649.0	1	10649.0		
e^Δ	21291.3	2	10645.7		

4.5.3 Effect of Interaction on the Shatter Resistance of Molding Block

Table 19 displays the variance analysis results of molding block shatter resistance when the interactions between the factors are taken into account. As shown in the table, the factors and interactions don't affect the shatter resistance of molding block significantly.

Table 19. Variance analysis of the molding block shatter resistance when considering the interactions between the factors

Error source	SS	df	MS	F	Significance
A	77217.8	1	77217.8		
B	77221.5	1	77221.5	1.00	
A× B	77217.8	1	77217.8		
C	77221.2	1	77221.2	1.00	
A× C	77217.7	1	77217.7		
B× C	77219.3	1	77219.3		
e	77218.3	1	77218.3		
e^Δ	308871.6	4	77217.90		

5 Conclusions

Taking the molding block thickness, relaxation ratio and shatter resistance as evaluation indicators, the effects of mold form, compressive force, pressure-holding time, loading rate and interactions between them on the block quality were investigated. The conclusions are summarized as follows:

- 1) Mold form affects the thickness of molding block significantly. For the four given molds, the thickness of molding block, compressed by the mold with the diameter of 30mm, is relatively small. Mold form has no significant effect on the relaxation ratio and shatter resistance.
- 2) Compressive force has great impact on the thickness of molding block. The thickness of molding block decreases with the increase of compressive force, and the greater the compressive force is, the smaller the thickness is. Compressive force does not affect the relaxation ratio and shatter resistance significantly.
- 3) Pressure-holding time has significant effect on the molding block thickness, relaxation ratio and shatter resistance. The longer the Pressure-holding time is, the smaller the thickness is. Specifically, when the pressure-holding time increases from 0s to 30s, its increase usually results in the great decrease of molding block thickness. After that, the block thickness doesn't subject to the pressure-holding time and slightly decreases. Furthermore, the thickness basically maintains constant when the pressure-holding time exceeds 90s. The molding block relaxation ratio will be improved after a period of pressure holding. However, when the pressure-holding time increases from 30s to 120s, the relaxation ratio almost remains the same. Likewise, after a period of pressure holding, the block shatter resistance will be greatly improved.
- 4) When the loading rate increases from 10mm/min to 30mm/min, the molding block thickness and relaxation ratio vary considerably. Specifically, the molding block thickness and relaxation ratio gradually decreases firstly and then increases. Loading rate has no great effect on the shatter resistance of molding block.
- 5) Compressive force, pressure-holding time and loading rate affect the thickness of molding block significantly, and the major-minor sequence is pressure-holding time, loading rate, and compressive force. The three factors have no significant effect on the relaxation ratio and shatter resistance. Additionally, the interactions don't affect the block quality.

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