DESIGN AND PARAMETER OPTIMIZATION OF WATER-RETAINING MOULDING DEVICE FOR STRAW AND COW DUNG MIXED MATERIALS
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秸秆-牛粪混合物料保水成型装置设计与参数优化

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ABSTRACT
A hydraulic horizontal water-retaining moulding device for mixed materials was designed and optimized. The effect of compression process parameters of the mixture of straw and cow dung on the effect of water retention moulding was analysed through experiment. The suitable value range and critical value of process parameters were obtained. The main power and structural parameters of the hydraulic system in the mixture compression unit were designed and calculated. Appropriate hydraulic and control components were selected. A test prototype of the hydraulic horizontal mixed material compressor machine was manufactured. Through the method of combination experiment and response surface optimization, the optimal combination of working parameters of the hydraulic horizontal water-retaining moulding device was obtained and verified. The dimensional stability of small-scale compost blocks made by the compressor could reach 84.71% under the condition of 250 mm/min for the compression speed, 55 kg for the feed amount and 200 s for the holding time.

摘要
设计并优化了一种液动卧式混合物料保水成型装置。试验分析秸秆与牛粪混合物料的压缩过程参数对保水成型效果的影响规律，得出过程参数适宜取值范围与临界值，并设计了装置液压系统主要动力与结构参数，选配适宜的液压与控制元件，制造液动卧式混合物料压缩试验样机；通过组合试验与响应面优化结合的方法，得出并验证液动卧式保水成型装置较优的工作参数组合：压缩速度 250 mm/min、喂入量 55 kg、保压时间 200 s，此条件下所制得微贮块的尺寸稳定性可达到 84.71%。

INTRODUCTION
The mixed straw and cow dung is a kind of dispersed and viscoelastic material that can rebound after compression. It is necessary to overcome the viscoelastic properties of the material and maintain proper moisture, during the compression process (*Wang et al., 2021a*). The existing compression moulding equipment is not completely suitable for the water-retaining moulding of the mixture material in the small-scale compost production with localized straw and cow dung (*Wang et al., 2021b*). The stress relaxation change and suitable pressure range of the moulding process of the mixed materials of straw and cow dung under suitable moisture conditions are different from the single material of straw or cow dung, which has an important impact on the quality of small-scale compost production and the productivity of compression moulding device (*Robert et al., 2012*). Researchers discussed the raw materials and technology of biomass small-scale blocks (*Moiceanu et al., 2015; Zhang et al., 2017; Voicu et al., 2019*). In particular, many studies have been carried out on the moulding mechanism and compression characteristics of the single straw material (*Nehru et al., 2010; Carone et al., 2011; Niccolò et al., 2019; Liang et al., 2020*). Pressure keeping and strain keeping are two key processes to enhance the dimensional stability of compressed straw (*Jia et al., 2020*). *Mirko et al*. (*2017*) compression tests were performed and they found traditional baling systems were not adequate to guarantee a good control on the linear dimensions and on the density of the bales since bale length had a great variability. *K. Theerarattananoon et al.* (*2011*) and *Kazuei et al.* (*2014*) have shown that the initial water content was an important factor affecting the productivity of straw briquettes, as the water content of the briquettes increases, their bulk density and true density decrease.

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In order to explore the influence of compression parameters in the water-retaining moulding process of the straw and cow dung mixed material, the appropriate value range and critical value of the key process parameters through the single factor experiment of the experiment bench and data acquisition system were determined. The hydraulic power system of the water-retaining moulding device was designed biased on the single factor experiment results. Moreover, through the three-dimensional quadratic regression orthogonal rotation combined experiment and field verification test, the working parameters of the prototype were optimized, and the working performance was verified.

MATERIALS AND METHODS

Examination conditions and methods

The experiment was conducted at the Key Laboratory of Agricultural Mechanization Engineering of Liaoning Province in Shenyang Agricultural University. The experiment maize straw was harvested in 2018 at North Mountain Scientific Research Base of Shenyang Agricultural University, and the experiment cow dung was taken from surrounding farmers. Before the experiment, it was randomly sampled and determined the moisture content range of maize straw and cow dung stored under natural conditions, using an electronic analytical balance (Germany Sartorius QUINTIX224-1CN) and a halogen fast moisture meter (Shenzhen Guanya Electronic Technology Co., Ltd. SFY-60) and other equipment. The ratio of straw to cow dung was 3:2 during the experiment. The self-made rubbing filament machine and mixer were used to pre-treat the materials to the moisture content level range of (60±2) %.

Single factor experimental design

The microcomputer-controlled two-way electronic universal testing machine (Jinan Dongfang Testing Instrument Co., Ltd. WSDS-50) and a self-made mould were used to conduct an experimental study on the water-retaining moulding process of the straw and cow dung mixed material. The water retention rate, compression rate and deformation rate were taken as the evaluation index of water-retaining moulding effect experiment indexes. Calculate the experiment index value according to formula (1), (2), and (3) respectively.

$$Y_1 = (1 - \frac{w_0 - w_1}{w_0}) \times 100 \tag{1}$$

$$Y_2 = \frac{V_0 - V_1}{V_0} \times 100 \tag{2}$$

$$Y_3 = \frac{V_2 - V_1}{V_1} \times 100 \tag{3}$$

where Y_1 is the water retention rate, %; w_0 is the moisture content of the material before compression, %; w_1 is the moisture content of the material after compression, %; Y_2 is the compression rate, %; V_0 is the material volume before compression, m^3; V_1 is the material volume after compression, m^3; Y_3 is the deformation rate, %; V_2 is the material relaxation volume after being placed for 72 h, m^3.

Take one kilogram of mixed material as a sample, carry out the single factor examination with the same compression time, and calculate the material moisture content and volume before compression, and the material moisture content and volume after compression. The relaxation volume was obtained by calculating the maximum size of the small-scale block in each direction of length, width, and height after being placed for 72 h. All the results were kept to two decimal places. The small-scale block sample compressed by single factor examination was shown in Figure 1.

Fig. 1 - Single factor examination compressed small-scale block sample

The examination factors and levels were shown in Table 1, and each examination number was subjected to 3 repeats. During the pressure single factor examination, the values of the non-variable factor examination were: compression speed 300 mm/min, and the pressure holding time 150 s; in the single factor examination process of the compression speed, the non-variable factor examination values were: pressure 18 kN, pressure holding time 150 s; in the single factor examination process of the pressure holding time, the values of the non-variable factor examination were: pressure 18 kN, compression speed 300 mm/min.

Table 1

Factors and levels of single factor experiment

Experimental factors		Experimental levels and number								
		1	2	3	4	5	6	7	8	9
Pressure	[kN]	6	9	12	15	18	21	24	27	30
Compression speed	[mm·min^{-1}]	100	150	200	250	300	350	400	450	500
Pressure holding time	[s]	30	60	90	120	150	180	210	240	270

Design of hydraulic mechanism of the hydraulic horizontal mixed material compression device

The hydraulic compression device of the mixed materials was mainly composed of an electric motor, a compression mechanism, a hydraulic system and a control system, as shown in Figure 2. The whole machine was equipped with three hydraulic execution units, which were used to drive the pressing plate to move and compress the material, drive the baffle plate to move and open-close the discharge port and drive the push plate to move the small-scale block. The three hydraulic units were composed of the pressing plate, flange and hydraulic pressure. The compression hydraulic cylinder was arranged in parallel with the opening and closing hydraulic cylinder. The discharge hydraulic cylinder and the compression hydraulic cylinder were arranged vertically. The machine design dimensions (length × width × height) were 2 600 mm×1 600 mm×1 200 mm, the compression chamber capacity was 0.26 m^3, the power input was 3.0 kW, and the overall weight was about 600 kg.

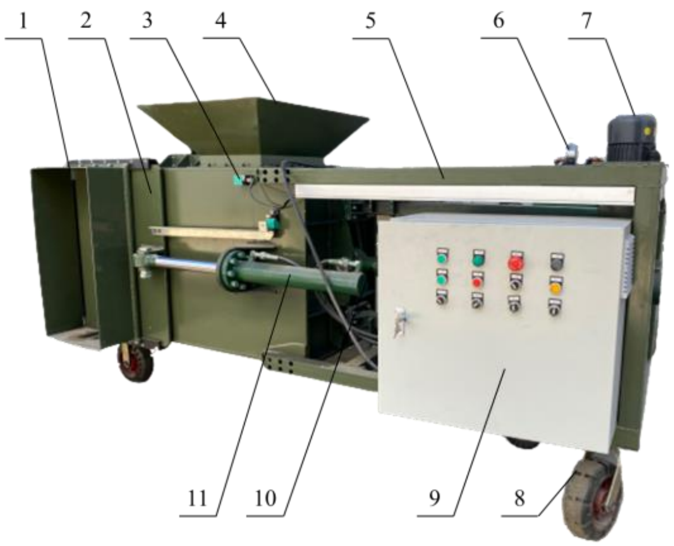

Fig. 2 - Structure schematic diagram of the hydraulic horizontal mixed material compression device
1-Discharge port; 2-Discharge baffle; 3-Sensor; 4-Feed inlet; 5-Frame; 6-Pressure gauge; 7-Motor; 8-Walking wheel; 9-Control cabinet; 10-Compression hydraulic cylinder; 11-Opening and closing hydraulic cylinder

The hydraulic mechanism had an important influence on the overall performance of the compressor, which was designed to include the selection and verification of hydraulic cylinders and system power components. The hydraulic system was mainly composed of hydraulic pump, electromagnetic reversing valve, hydraulic control one-way valve, sequence valve, overflow valve, hydraulic cylinder, oil tank, etc. When working, the motor drove the hydraulic pump coaxially, and the pressure was sent to the oil block through the high-pressure oil pipeline. It was connected in parallel with the compression hydraulic cylinder, the opening and closing hydraulic cylinder and the discharge hydraulic cylinder, and was connected with the Rexroth three-position four-way solenoid valve and two-position four-way solenoid valve.

The two-way solenoid reversing valve was connected in series with the two-position two-way manual reversing valve. At the same time, an electromagnetic relief valve was installed at the outlet of the high-pressure oil circuit to ensure the oil pressure in the system. When working at low pressure, the small load hydraulic cylinder (opening and closing hydraulic cylinder) could quickly enter and exit the oil and reduce the power of the motor.

In the compression process of the straw and cow dung mixed materials, the force of the compression mechanism was mainly the force acting on the pressure plate, including the friction between the material and the compression chamber when the pressure plate pushes the material, and the reaction of the material resisting deformation to the pressure plate force, and both of them changing with the increase of the compression process. Under the condition that the preload load was ignored, the solenoid hydraulic valves in the hydraulic system didn't interfere with each other's control of the advance and retreat routes, and the reciprocating speed of the hydraulic oil was the same. The calculations of the unit hydraulic cylinder working load ***F*** (kN), cylinder bore *D* (mm) and piston rod diameter *d* (mm) were based on equations (4), (5), and (6), respectively.

$$F = s \cdot P \tag{4}$$

$$D = \sqrt{\frac{4F}{\pi P_0}} \tag{5}$$

$$d = D\sqrt{\frac{\varphi - 1}{\varphi}} \tag{6}$$

where, P is the maximum pressure required for the hydraulic cylinder working, MPa; s is the pressure plate area, m^2; P_0 is the working pressure of the system, MPa; φ is the ratio of the round-trip speed of the hydraulic cylinder.

Taking the working pressure of the system as 10 MPa (*Chinese Academy of Agricultural Mechanization, 2007*), the ratio of the round-trip speed of the hydraulic cylinder φ=2 (*Wen, 2014*). It can be seen from the single factor examination that under the conditions of a suitable maximum pressure of 24 kN and an examination mould platen area of 0.04 m^2, the maximum pressure P required for the compression of the hydraulic cylinder and the push out of the hydraulic cylinder was 0.6 MPa. The main design parameters of the hydraulic cylinder were shown in Table 2.

Table 2

Main design parameters of hydraulic cylinder

Design parameter		Compression unit	Open and close unit	Discharge unit
Platen area *s*	[m^2]	0.30	0.24	0.24
Maximum pressure required for hydraulic cylinder work *P*	[MPa]	0.6	0.1	0.6
Working load *F*	[kN]	180	24	144
Calculated value of cylinder inner diameter *D*	[mm]	151.33	55.68	135.28
Calculated value of piston rod diameter *d*	[mm]	107.06	39.09	95.76
Selection value of cylinder inner diameter *D*	[mm]	160	63	140
Selection value of piston rod diameter *d*	[mm]	110	45	100
Piston stroke *l*	[mm]	900	430	600

Combination experimental design

The combination experiment was conducted at the Northeast Facility Horticultural Engineering Scientific Observation and Experimental Station of Shenyang Agricultural University. The stability of the small-scale block after 72 hours of standing and stacking was investigated for the moulding effect of the hydraulic horizontal mixed material compression device.

The dimensional stability of the small-scale block was selected as the experimental index (*Xin et al., 2017*), calculated according to formula (7).

$$Y_4 = (1 - \frac{V_2 - V_1}{V_1}) \times 100 \quad (7)$$

where Y_4 is the dimensional stability, %; the material volume after compression V_1 in this combination experiment was 0.12 m^3.

The experiment selected the compression speed, feeding amount and pressure holding time as the experiment factors, and carries out the ternary quadratic regression orthogonal rotation combination experiment. According to the analysis of the single factor experiment results, the value range of each factor and the experiment factor levels were shown in Table 3. In order to reduce the experiment operation error, the round integer in the parentheses in Table 3 was taken as the experiment value. The experiment process was shown in Figure 3.

Table 3

Factors and levels of combination experiment

Levels	Factors		
	Compression speed [mm·min^{-1}]	Feeding amount [kg]	Pressure holding time [s]
	x_1	x_2	x_3
1.682	400	150	210
1	339.18 (340.00)	129.73（130.00）	197.84（198.00）
0	250	100	180
-1	160.82 (160.00)	70.27 (70.00）	162.16（162.00）
-1.682	100	50	150
△*j*	89.18 (90.00)	29.73 (30.00)	17.84（18.00）

Fig. 3 - Experimental process

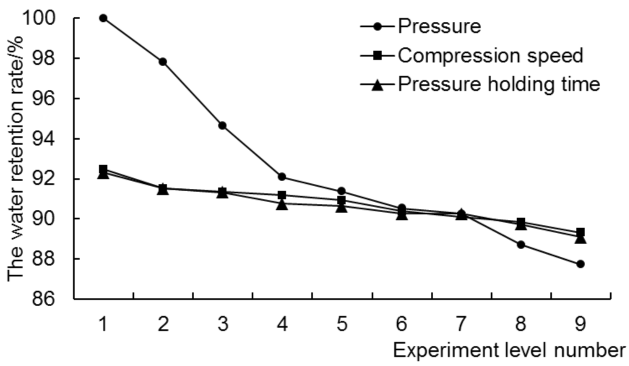

Fig. 4 - Statistical graph of single factor experimental results of the influence of compressed parameters on water retention rate

RESULTS

Single factor experiment results and analysis

Figure 4 shows the statistical diagram of the single factor experiment results of the influence of compression process parameters on the water retention rate. It can be seen from the diagram that the water retention rate decreased with the increase of pressure, compression speed and pressure retention time, and the decrease was larger with the increase of pressure. With the increase of compression speed and pressure holding time, the decrease was relatively gentle, and it was greater than 85% within the range of experiment parameters. When the pressure was 6-24 kN, the compression speed was 100-400 mm/min, and the pressure holding time was 30-210 s, the water retention rate of small-scale blocks was above 90%, and this range was regarded as a more suitable process parameter range for water-retaining of small-scale blocks.

Figure 5 shows the statistical diagram of the single factor experiment results of the influence of compression process parameters on the compression ratio. It can be seen from the figure that the compression ratio increased with the increase of pressure, compression speed and pressure holding time, and the increase with pressure increases is larger.

The increase in compression speed and holding time was relatively gentle, and was higher than 55% within the range of experiment parameters. When the pressure was 21-30 kN, the compression speed was 100-500 mm/min, and the holding time was 30-270 s, the material compression rate was above 65%, and this range was regarded as a more suitable process parameter range for material compression.

Figure 6 shows the statistical diagram of the single factor experiment results of the influence of compression process parameters on the deformation rate. It can be seen from the figure that the deformation rate first decreased and then increased with the increase of pressure, and the change was small with the increase of compression speed, and with the increase of pressure holding time. The deformation rates were all below 50% within the range of experiment parameters. When the pressure was 24 kN, the compression speed was 100-500 mm/min, and the pressure holding time was 150-240 s, the deformation rate was below 15%. This range was regarded as the process parameter range which was more suitable for the small-scale block to keep the shape stable.

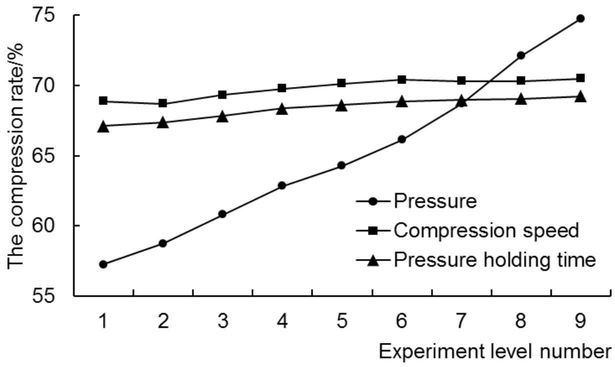

Fig. 5 - Statistical graph of single factor experimental results of the influence of compressed parameters on compression rate

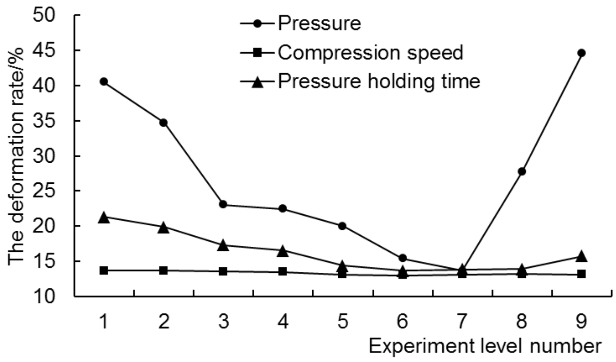

Fig. 6 - Statistical graph of single factor experimental results of the influence of compressed parameters on deformation rate

The reason for the above phenomenon was that under the same compression speed, the straw filaments in the mixture material had strong viscoelasticity, and the compressibility of the mixture material was negatively related to the pressure. After compression, the elasticity was stronger and the residual stress was larger, and the amount of stress relaxation also increased. When the pressure was at a higher level, the mixture material was further compacted after holding pressure, the material properties changed from viscoelastic deformation to yield deformation, and the compression performance and resistance to deformation of the mixture material were enhanced; with the increase of the compression process parameters, the mixture material after compaction and then compression, the water was pressed out, and the water retention performance of the mixture material was reduced.

Combination experiment results and analysis

The combination experiment plan and results were shown in Table 4. By using Design-Expert software, the quadratic polynomial regression model among the compression speed (X_1), feeding amount (X_2), pressure holding time (X_3), and dimensional stability (Y_4) were established for multiple regression analysis. The regression model was shown as formula (8).

$$Y_4=-82.87-1.98X_1-3.15X_2+1.49X_3-1.69X_1X_2-0.30X_1X_3-1.22X_2X_3-1.871X_1^2-2.53X_2^2+0.38X_3^2 \quad (4)$$

Table 4

Experimental plan and results

No.	Compression speed [mm·min^{-1}]	Feeding amount [kg]	Pressure holding time [s]	Y_4 [%]
1	1	1	1	71.25
2	1	1	-1	72.94
3	1	-1	1	85.30
4	1	-1	-1	80.37
5	-1	1	1	79.26
6	-1	1	-1	78.01
7	-1	-1	1	84.80
8	-1	-1	-1	80.43
9	1.682	0	0	73.05

Table 4
(continuation)

No.	Compression speed	Feeding amount	Pressure holding time	Y4
	[mm·min-1]	[kg]	[s]	[%]
10	-1.682	0	0	81.57
11	0	1.682	0	71.39
12	0	-1.682	0	79.49
13	0	0	1.682	87.08
14	0	0	-1.682	80.25
15	0	0	0	83.54
16	0	0	0	82.66
17	0	0	0	82.51
18	0	0	0	81.14
19	0	0	0	83.79
20	0	0	0	82.73
21	0	0	0	83.87
22	0	0	0	82.25
23	0	0	0	83.43

Significance test and analysis of variance were performed on the obtained ternary quadratic regression equation, and the results were shown in Table 5. It can be seen from the table that the primary and secondary order of the influence of each experiment factor on the dimensional stability was feeding amount > compression speed > pressure holding time. The compression speed (x_1), feeding amount (x_2) and pressure holding time (x_3) had extremely significant effects on the dimensional stability (P<0.01); the quadratic term of compression speed (x_1^2) and feeding amount (x_2^2) had extremely significant impact on the dimensional stability (P<0.01). In the interaction of factors, the interaction of compression speed and feeding amount (x_1x_2) had extremely significant impact on the dimensional stability (P<0.01), the interaction of feeding amount and pressure holding time (x_2x_3) had significant impact on the dimensional stability (P<0.05). The determination coefficient R^2=0.95, the regression equation significance level F_R=30.39, the lack of fit test F_{Lf}=3.48, P=0.0574, were all greater than 0.05 and the difference was not significant, indicating that the regression equations Y_4 was statistically significant.

The optimized regression equation after excluding insignificant terms such as x_1x_3 and x_3^2 of Y_4 at the significance level of P=0.05 was:

$$Y_4=-82.87-1.98X_1-3.15X_2+1.49X_3-1.69X_1X_2-1.22X_2X_3-1.871X_1^2-2.53X_2^2 \quad (6)$$

Table 5
Data significance experiment and analysis of variance

Source of variation	Dimensional stability Y_4				
	SS	DF	MS	*F value*	*P value*
Model	413.68	9	45.96	30.39	< 0.0001**
X_1	53.28	1	53.28	35.22	< 0.0001**
X_2	135.86	1	135.86	89.81	< 0.0001**
X_3	30.32	1	30.32	20.05	0.0006**
X_1X_2	22.82	1	22.82	15.09	0.0019**
X_1X_3	0.71	1	0.71	0.47	0.5068
X_2X_3	11.86	1	11.86	7.84	0.0150*
X_1^2	55.44	1	55.44	36.65	< 0.0001**
X_2^2	101.78	1	101.78	67.29	< 0.0001**
X_3^2	2.27	1	2.27	1.5	0.2420
Remaining	19.66	13	1.51		
Lack of Fit	13.48	5	2.7	3.48	0.0574
Pure Error	6.19	8	0.77		
Sum	433.34	22			

Analysis of influencing factors

The calculation results of the response surface of each experiment factor and its interaction on the experiment index were shown in Figure 7.

Figure 7a shows the response surface diagram of the influence of the interaction between the compression speed and the feeding amount on the dimensional stability when the pressure holding time was 0 level (180 s). The analysis showed that when the compression speed was constant and at the lower level of the experimental range, and the feeding amount gradually increased within the experimental range, the dimensional stability first improved and then decreased. When the compression speed was constant at the higher-level range of the experimental range, and the feeding amount gradually increased within the experimental range, the dimensional stability gradually decreased. When the feeding amount was constant and at the lower level range of the experimental range, and the compression speed was in the experimental range gradually increased, the dimensional stability first increased and then decreased. When the feeding amount was constant and at the higher level of the experimental range, and the compression speed gradually increased at the experimental range, the dimensional stability gradually decreased. The dimensional stability peak appeared at the middle horizontal interval. This might be because when the feeding amount was large, the compression amount of the material unit in the mixture would increase, and the friction and cohesive force between the material units would be strengthened, the stress relaxation would increase, so that the compaction of the small-scale block after compression would be increased. On the other hand, a higher compression speed increased the start time of viscous strain in the small-scale block after compression, and the residual stress relief time in the small-scale block was relatively reduced, thereby increasing the stress relaxation after compression and reducing the dimensional stability of the small-scale block.

Figure 7b shows the response surface diagram of the influence of the interaction between the compression speed and the pressure holding time on the dimensional stability when the feeding amount was 0 level (100 kg). The analysis showed that when the compression speed was constant and at the lower level of the experimental range, when the pressure holding time gradually increased within the experimental range, the dimensional stability first increased and then decreased. When the compression speed was constant, and at the higher level range of the experimental range, when the pressure holding time gradually increased within the experimental range, the dimensional stability gradually decreased; when the pressure holding time was constant and the compression speed gradually increased within the experimental interval, the dimensional stability increased first slightly lowered. This may be because under the same feeding amount, the stress increase relaxation caused by the compression speed increase and the stress relaxation decrease caused by the pressure holding time increase gradually offset with the compression process, so the interaction of the two factors on the dimensional stability of the small-scale block was not obvious.

Figure 7c shows the response surface diagram of the influence of the interaction between the feeding amount and the pressure holding time on the dimensional stability when the compression speed was 0 level (250 mm·min^{-1}). The analysis showed that when the feeding amount was constant and at the lower level of the experimental range, and the pressure holding time gradually increased within the experimental range, the dimensional stability did not change significantly. When the feeding amount was constant, and at the higher level of the experimental range, and the pressure holding time gradually increased within the experimental interval, the dimensional stability gradually decreased; when the pressure holding time was constant and the feeding amount gradually increased within the experimental range, the dimensional stability was gradually improved. This may be because the holding pressure could significantly reduce the residual stress in the small-scale block after decompression, thereby reducing the stress relaxation after compression and improving the dimensional stability of the small-scale block; the increase in the feeding amount increased the irreversible viscous reverse strain produced by the mixture materials. The viscoelasticity of the mixture materials was reduced, the yield deformation was increased, the residual stress was reduced, and the dimensional stability of the small-scale block was further improved.

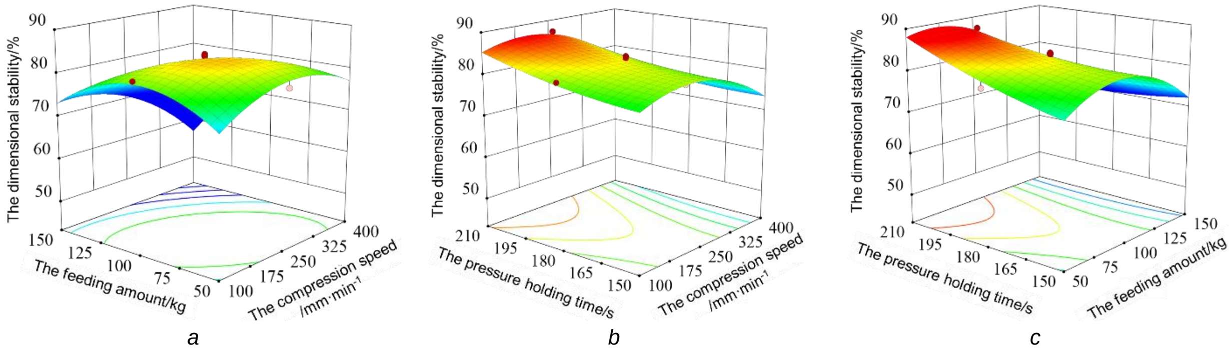

Fig. 7 - Response surface analysis of the factor interaction effect on the index

Parameter optimization and verification test

Set the target parameter the dimensional stability to maximize, and the factors parameter to the range of experiment to establish the optimal mathematical model formula for constraints as formula (9). Solve the optimal working parameter combination of the hydraulic horizontal mixed material compression device: the compression speed was 250.56 mm·min^{-1}, the feeding amount was 56.26 kg and the pressure holding time was 205.07 s, the overall operation effect being the best. The predicted dimensional stability will be 87.39%.

$$\begin{cases} \max \ Y_4(x_1, x_2, x_3) \\ s.t. \begin{cases} 100 \le x_1 \le 400 \\ 50 \le x_2 \le 150 \\ 150 \le x_3 \le 210 \end{cases} \end{cases} \tag{9}$$

In order to further verify the reliability and applicability of the mathematical model, the optimization results were tested and verified under the same experiment conditions, while the actual test results and the model prediction values were analysed for error. Considering the operability of the test, the optimization results were adjusted as follows: the compression speed was 250 mm·min^{-1}, the feeding amount was 55 kg and the pressure holding time was 200 s, and three repeated tests were carried out to obtain the best working parameter combination. The average values of the test values of dimensional stability was 84.71%, which was close to the predicted values of the model. The relative error between the actual and predicted values didn't exceed 3%, indicating the established model and analysis results were valid.

CONCLUSIONS

In this paper, a hydraulic horizontal mixed material compression device was developed to solve the problems of water easily loss and compression molding effectiveness slightly poor during the mixed materials compression process in the fertilizer production, according to the suitable pressure and intensity of pressure of the water-retaining moulding, the hydraulic system parameters were designed and calculated. The structure and working parameters of the compressor had been optimized through experiments. The water retention rate, compression rate, deformation rate and dimensional stability were taken as the water-retaining moulding effect experiment indexes, and the pressure, compression speed, feeding amount and pressure holding time under the composition condition of maize straw and cow dung was studied. The following conclusions were drawn:

1) The single factor experiment analysed the appropriate value range of the compression process parameters, and integrated the influence of each compression process parameter on the water-retaining moulding effect of the mixture material. The more appropriate process parameter range was 24 kN of the pressure, 100-400 mm·min^{-1} of the compression speed, and 150-210 s of the pressure holding time. The water retention rate of the small-scale block in this range was above 90%, the compression rate was above 65%, and the deformation rate was below 15%.

2) The combination experiment showed that the primary and secondary factors affecting dimensional stability are feeding amount > compression speed > pressure holding time, and the interaction of the factors was compression speed and feeding amount, feeding amount and pressure holding time. A response surface model was established, and the device's best working parameters were optimized through experiments. The optimization and verification results showed that the optimal working parameters combination of the hydraulic horizontal mixed material compression device was a compression speed of 250 mm·min^{-1}, a feeding amount of 55 kg, and a pressure holding time of 200 s. The average value of the actual value of the dimensional stability under this condition was 84.71%, which met the design requirements.

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REFERENCES

[1] Carone M.T., Pantaleo A., Pellerano A., (2011), Influence of process parameters and biomass characteristics on the durability of pellets from the pruning residues of Olea European L. *Biomass & Bioenergy*, Vol.35, pp. 401-410, Oxford/England.

[2] Chinese Academy of Agricultural Mechanization Sciences, (2007), Agricultural Machinery Design Manual. *China Agricultural Science and Technology Press*, Beijing/China.

[3] Jia Honglei, Chen Tianyou, Zhang Shengwei, et al., (2020), Effects of pressure maintenance and strain maintenance during compression on subsequent dimensional stability and density after relaxation of blocks of chopped corn straw. *BioResources*, Vol.15, Issue 2, pp. 3717-3736, North Carolina/United States.

[4] K. Theerarattananoon, F. Xu, J. Wilson, et al., (2011), Physical properties of pellets made from sorghum stalk, corn stover, wheat straw, and big bluestem. *Industrial Crops and Products*，Vol.33, Issue 2, pp. 325-332, Amsterdam/Netherlands.

[5] Kazuei Ishii, Toru Furuichi, (2014), Influence of moisture content, particle size and forming temperature on productivity and quality of rice straw pellets. *Waste Management*, Vol.34, Issue 12, pp. 2621-2626, Oxford/England.

[6] Lixian Zhang, Zhongping Yang, Qiang Zhang, et al., (2017), Mechanical behaviour of corn stalk pith: an experimental and modeling study. *INMATEH—Agricultural Engineering*, Vol.51, Issue 1, pp.39-48, Bucharest/Romania.

[7] Mirko Maraldi, Luisa Molari, Nicolò Regazzi, et al., (2017), Analysis of the parameters affecting the mechanical behaviour of straw bales under compression. *Biosystems Engineering*, Vol.160, pp. 179-193, San Diego/United States.

[8] Moiceanu G., Voicu Gh., Paraschiv G., (2015), Mechanical properties of energetic plant stems - review. *INMATEH—Agricultural Engineering*, Vol.45, Issue 1, pp.149-156, Bucharest/Romania.

[9] Nehru Chevanan, Alvin R. Womac, Venkata S.P. Bitra, et al., (2010), Bulk density and compaction behaviour of knife mill chopped switchgrass, wheat straw, and corn stover. *Bioresource Technology*, Vol.101, Issue 1, pp. 207-214, Oxford/England.

[10] Niccolò Pampuro, Giorgia Bagagiolo, Eugenio Cavallo, (2019), Energy requirements for wood chip compaction and transportation. *Fuel*, Vol.262, 16618, Oxford/England.

[11] Robert Samuelsson, Sylvia H. Larsson, Mikael Thyrel, et al., (2012), Moisture content and storage time influences the binding mechanisms in biofuel pellets. *Applied Energy*, Vol.99, pp. 109-115, Oxford/England.

[12] Voicu Gh., Moise V., Popa L., (2019), Kinematic analysis of a mechanism, with articulated precompaction bars, of municipal solid waste collecting machines. *INMATEH—Agricultural Engineering*, Vol.59, Issue 3, pp.93-100, Bucharest/Romania.

[13] Xin Mingjin, Chen Tianyou, Zhang Qiang, et al., (2017), Parameters optimization for moulding of vegetable seedling substrate nursery block with rice straw. *Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE)*, Vol.33, Issue 16, pp. 219-225, Beijing/China.

[14] Wang Ruili, Yu Jin, Wang Tiejun, et al., (2021a), Experimental study on moulding technology for a mixture of corn straw and cow manure. *BioResources*, Vol.16, Issue 1, pp. 1740-1756, North Carolina/ United States.

[15] Wang Tiejun, Wang Ruili, Sun Junde, et al., (2021b), Parameter optimization of the small-scale compost technology with localization maize stover and livestock manure. *Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE)*, Vol.37, Issue 2, pp. 251-257, Beijing/China.

[16] Wen Bangchun, (2014), Mechanical Design Manual (5th Edition). *Mechanical Industry Press*, Beijing/China.