Compression Creep Characteristics of Crushed Sugarcane End-Leaves

Ming Lei, Junle Lei,* Jiawei Luo, Jia Wang, Zhuo Li, and Binsheng You

The creep behavior of crushed sugarcane end-leaf (SEL) was studied, with consideration of different loading force, moisture content, and feeding amount. Statistical analysis software was used to develop and fit the regression data to a strain change law as a function of time. The four-element Burgers model was used. A further goal was to analyze the effect of different test conditions on the fitted creep characteristic parameters. The instantaneous elasticity coefficient E_0 was found to increase when the loading force increased; the value of delayed elasticity coefficient E_1 increased and the value of cohesion coefficient η_0 decreased when the feeding amount increased; the value of delayed elasticity coefficient E_1 and cohesion coefficient η_0 decreased when the moisture content was increased. Therefore, the loading force, moisture content, and feeding amount of crushed SEL all affected the creep capacity of crushed SEL in compression. The results can provide substantial theoretical reference for the silage production of crushed SEL.

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INTRODUCTION

Guangxi is the largest sugarcane production base in China, and the proportion of sugarcane planted area and output in the country has been stable at over 60% for a long time (Deng *et al*. 2022). Sugarcane end-leaf (SEL) is the general term for the top 2 to 3 tender nodes and leaves of sugarcane. It accounts for about 20% of the total weight of sugarcane. It is relatively low in sugar content because of its tenderness, rich in a variety of amino acids and polysaccharides, and good in palatability; it can be classified as a medium-value roughage resource, with an annual output of about 15 million tonnes in Guangxi region only (Zhou *et al*. 2021). The reasonable use of SEL through silage technology can solve the problem of food shortage of cattle and sheep in winter, reduce the cost of farming, and reduce the pressure of farmers' farming (Peng *et al*. 2020). Since crushed SEL is a loose elastic viscous material with low bulk density and large volume, crushed SEL takes up a lot of space in storage and transport (Zhang *et al.* 2023), which increases the storage and transport costs. Moreover, the creep characteristics of rolled bales of crushed SEL have a great influence on the density, and the phenomenon of strain increase with time leads to the decrease in the density of crushed SEL silage, which is prone to moulding. Therefore, the study of the compression creep characteristics of crushed sugarcane end-leaves can lead to better understanding of the deformation behaviour of silage during production, storage, and transportation, so as to optimize the production, storage and transportation schemes and reduce the deterioration and loss of feed.

There has been much research on the compression creep test of some crops. Ma *et al.* (2024) used an uniaxial creep test, with particle size and shape of corn stover particles as the independent variables. A six-level two-dimensional model was established using PFC 2D software, and the simulation parameters suitable for describing the creep characteristics of corn stover particles were obtained. Guo *et al.* (2021) used the four-element Burgers model to study the creep characteristics of potato residue. They obtained the change rule of strain with time and analysed the effect of different test conditions on the parameters of the creep characteristics obtained by fitting. Ma *et al.* (2023) studied the creep characteristics of corn stover and lignite mixture type coal to obtain the displacement *versus* time curves under different feeding amount and pressure conditions. They established the creep model and the intrinsic equation. Li (2011) performed an experimental study and theoretical analysis of open compression creep of kneaded corn stover, finding the distribution law and quantitative relationship of each parameter of creep. In a study on the mechanical properties of sugarcane, Duan *et al*. (2018) used uniaxial confined compression, uniaxial loading and unloading, and consolidation-drainage triaxial and direct shear tests to reveal the static mechanical properties of sugarcane milling mixtures. Lei *et al*. (2023) considered the stress relaxation characteristics of crushed SEL, to explore the changing law of different factors on the stress relaxation process of crushed SEL and to establish a five-component stress relaxation model with a higher coefficient of determination R^2. Luo *et al*. (2016a,b) tested the tensile, compressive and flexural mechanical properties of sugarcane stalks and found that the tensile and compressive strengths, flexural strengths, and flexural modulus of elasticity of sugarcane stalks decreased significantly from the center of the stalk towards the growth point of the stalk tip (Zheng *et al.* 2017). Shear tests were carried out on different positions of SEL and shear strength and shear modulus of SEL were obtained using applied statistical software.

In summary, the compression creep characteristics of crushed SEL have rarely been studied. Therefore, in this paper, the compression creep characteristics of crushed SEL under different influencing factors are investigated. The software product Matlab 2018b was used to write the generalised Vollert model program to analyse the creep characteristics of crushed SEL during compression, and the compression creep model of crushed SEL can be known after determining the number of Kelvin models n in the generalised Vollert model. The creep model of crushed SEL was fitted and analysed by the statistical software SPSS under different influencing conditions, and the creep parameters were obtained. The creep characteristic parameters under different influencing factors were compared, which provided basic physical parameters and theoretical research for the compression of crushed SEL silage for the production, storage, and transport of crushed silage.

EXPERIMENTAL

Materials and Equipment

The test material was from a healthy and mature sugarcane variety *Gui Sugar 42* produced on 25 October 2023 from Guangxi Academy of Agricultural Sciences, Guilin Branch (110°28′E, 25°28′N, altitude: 150 m). The SEL was kneaded or guillotined to a length of about 5 cm (hereinafter referred to as crushed SEL), and five groups of samples were randomly selected for the test. Measurement results showed that the average proportion of shredded SEL was 8.2% for the length of 4.7 to 4.9 cm, 83.9% for the length of 4.91 to 5.1 cm, and 7.8% for the length of 5.11 to 5.3 cm. The mean proportions of tail diameter, cane leaves, and impurities in the test samples were also measured as 46.2%, 51.1%, and 2.7% respectively. The moisture content was measured using an electronic scale and Model 101-1 electric convection dryer. In order to ensure the accuracy of the test, the crushed cane tail test samples were loaded flat into homemade compression cylinders for uniaxial compression test at room temperature. Efforts were made to ensure that the test conditions were basically the same each time. The convection drying oven and the crushed SEL test samples are shown in Figs. 1 and 2, respectively.

Fig. 1. Electrically heated convection drying oven

Fig. 2. Test samples of crushed SEL

The moisture content of crushed sugarcane end-leaf was processed according to (NYT1881. 2-2010 “Test Methods for Biomass Solid Molding Fuels Part 2: Total Moisture”) (IS-A, 2010), with an initial moisture content of 67.5% determined for the cane tails and 70.2% for the tailstock. The moisture content was proportioned according to the test requirements and by rehydration method to the test requirements, as far as possible the test was completed within one week. The formula for calculating moisture content was as follows:

$$p = 1 - \frac{m_1 - m_1 p_1}{m} \tag{1}$$

where:

p is the required moisture content of the test sample ,

p_1 is the initial moisture content of the test sample,

m_1 is the initial mass of the test sample (g),
m is the quality of the test sample after treatment (g).

The test was carried out on the WDW-100 micro-control electronic universal testing machine in No.116 laboratory, No.8 building, Guilin University of Science and Technology. The test was mainly carried out with a self-designed compression cylinder, in order to make the test closer to the actual production situation, the bottom of the compression cylinder and the wall of the cylinder randomly cloth with 5mm diameter exhaust holes, so as to break the SEL juices and air discharged during the compression process. Auxiliary equipment included electronic scales, measuring cups and vernier calipers. Electronic universal testing machine and compression cylinder shown in Fig. 3.

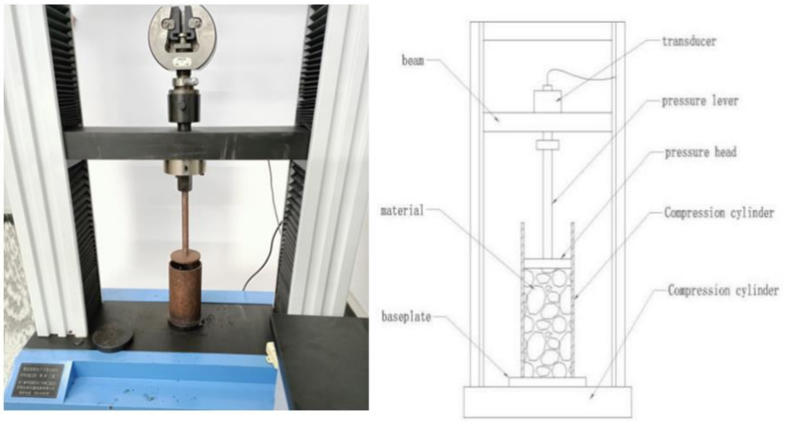


Fig. 3. Electronic universal experiment machine and compression device

Test Factors and Experimental Design

This experiment investigates the effect of moisture content, feed amount, and loading force on the compression creep characteristics of crushed SEL. The uniaxial compression test was carried out in the compression cylinder to ensure that the experiment was started when the piston head was lowered to just in contact with the test material. Test loading speed and unloading speed is set to 200mm/min, loading force to reach the preset loading force to stop loading, holding time for 100s, the test is repeated five times to take the average value, the test results into origin2020 to get the compression creep curve. The test results were analysed using rheological theory to establish the creep model. Then the creep experimental curves were fitted and analysed using SPSS data statistics software to obtain the parameters of creep characteristics of crushed SEL as the experimental indexes, and to analyse the effects of experimental factors on the creep characteristics of crushed cane end (Guo *et al.* 2021).The levels of the test were selected as shown below:

(1) Analysis of the effect of different moisture contents on the creep characteristics of crushed SEL: the moisture content of fresh SEL is about 70%, and the moisture content of crushed SEL is naturally reduced (Li *et al.* 2020). Different moisture contents of 55%, 65%, and 75% of crushed SEL were selected, and the loading force and feeding amount were kept at the same level, respectively.

(2) Analysis of the effect of different feeding amounts on the creep characteristics of crushed SEL: According to the commonly used feeding amount in the compression production process of agro-fibre materials and the actual production process, the initial density of the bale rolling machine feeding is 200-500 kg/m^3 (Liu *et al.* 2020). Therefore, taking the maximum creep as the evaluation standard of the measured data, this test selects

five feeding amounts of 150g/mm^3, 175g/mm^3, 200g/mm^3, 225g/mm^3, and 250 g/mm^3, and the moisture content and loading force were kept at the same level.

(3) Analysis of the effect of different loading force on the creep characteristics of crushed SEL: through the pre-experiment, it is known to make the density of crushed sugarcane silage products reach 400-500 kg/m^3, and select five constant loads of compression force of 5000, 5500, 6000, 6500, and 7000 N to carry out the compression, and the moisture content and the amount of feeding were kept at the same level.

RESULTS AND DISCUSSION

Analysis of Creep Curves

The study of creep characteristics of crushed SEL is deformation versus time when the loading force is loaded to a certain value at any course. Figures 4, 5, and 6 show different influencing factors test results creep curve, the first stage for the loading stage, that is, the test material began to creep, the loading force to overcome the material deformation and material gap. The loading stage of the material strain rate is very fast, the loading force with the superposition of time gradually increased, the material strain in the compression cylinder is a linear increase in the trend. The strain of the material in the loading stage is very fast, the loading force becomes gradually larger with the superposition of time, and the strain of the material in the compression cylinder tends to increase linearly. The demarcation point between the loading phase and the holding pressure phase for the crushed sugarcane tail leaves were both at the 24-27 sec inflection point. When the test reached the holding pressure stage, the loading force reached the constant value preset for the test and the loading stopped. The force in the holding pressure stage overcomes the friction in the cylinder and the degree of collapsing the cell wall tissue (Zhao 2009), the material maintains continued creep, the deformation rate changes slowly (Gao *et al.* 2017), the curve is close to the level.

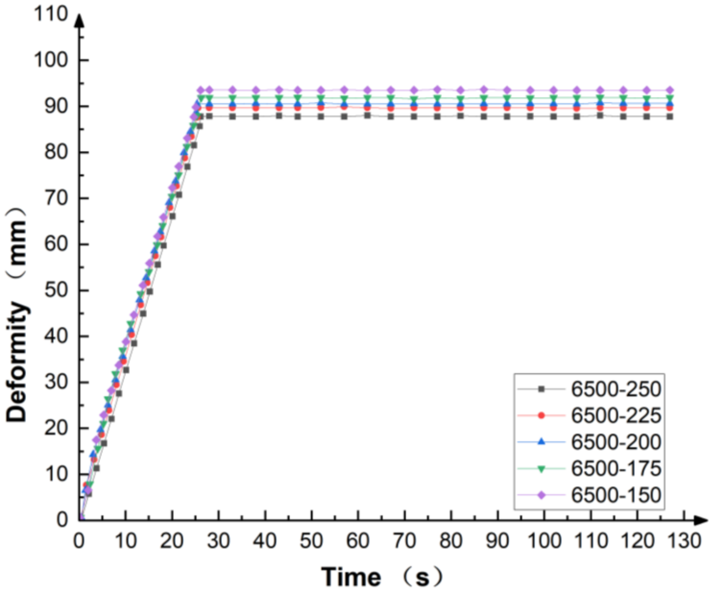


Fig. 4. Creep curve of each feeding amount with 65% moisture content and 6500N loading force

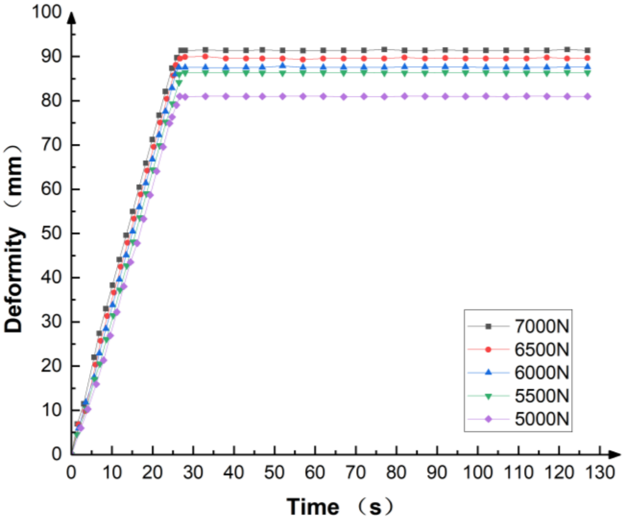


Fig. 5. Creep curves for each loading force for 55% moisture content and 200 g/mm^3 feed amount

As shown in Fig. 4, the deformation of the crushed SEL increases as the feeding amount decreases. This indicates that the feeding amount has some effect on the creep characteristics of crushed cane tail leaves. In Fig. 5, the experimental curves have a good regularity. The deformation of crushed SEL increases relatively with the increase of loading force when the remaining two factors are constant. In Fig. 6, the deformation of crushed SEL increases with the increase of moisture content under the condition of constant loading force and feeding amount.

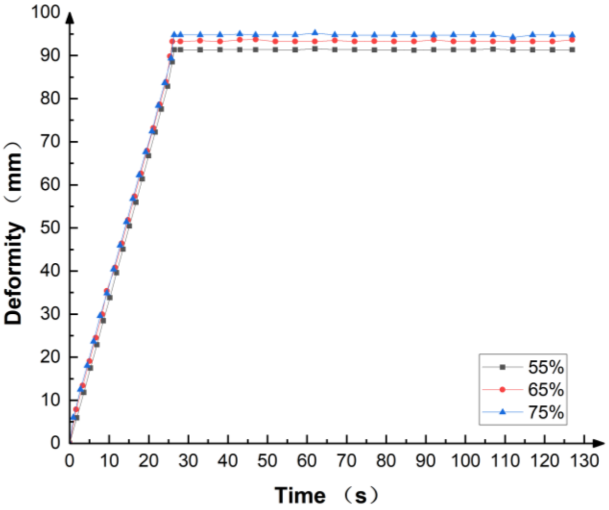


Fig. 6. Creep characteristic curves for different moisture contents with feeding amount 175g/mm^3 and loading force 7000N

Analysis of Test Results in Loading Phase

In the creep test process, the loading force is required to maintain a certain constant value, but it is not possible to make the loading force reach a certain constant value instantaneously during the test process, and the piston compresses the crushed SEL in the compression cylinder, and the deformation of the crushed SEL becomes larger with the increase of pressure on the piston. Therefore, the changing law of the loading stage of the crushed SEL can be analysed with the help of the Boltzmann superposition principle in the rheological theory (Lin and Meier 1996). It can be viewed as the superposition of m strains ε(i) generated when m stresses σ i act separately into the total strain ε. The expression for the sum of the strains generated by the loading process is:

$$\varepsilon\{\sum_{i=1}^{k}\sigma_i(t-t_i)\}=\varepsilon^{'}\{\sigma_1(t-t_1)\}+\varepsilon^{''}\{\sigma_2(t-t_2)\}+....\varepsilon^{(k)}\{\sigma_k(t-t_k)\} \quad (2)$$

where:

ε-total strain;

t_i-the i-th moment of action on the test material; s

σ_i-the ith stress acting on the test material at the moment of t_i, MPa;

ε(i)-represents the strain produced by the action of σ_i at the moment of t_i.

The strain response for the case of m stresses σ(t) acting can be deduced from Eq. 2,

$$\varepsilon\{\mathrm{m}\sigma(t)\}=\mathrm{m}\varepsilon\{\sigma(t)\} \quad (3)$$

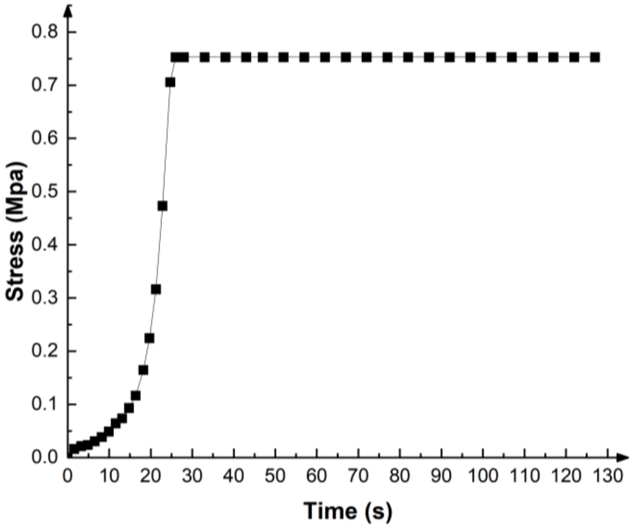


Fig. 7. Stress time course curves

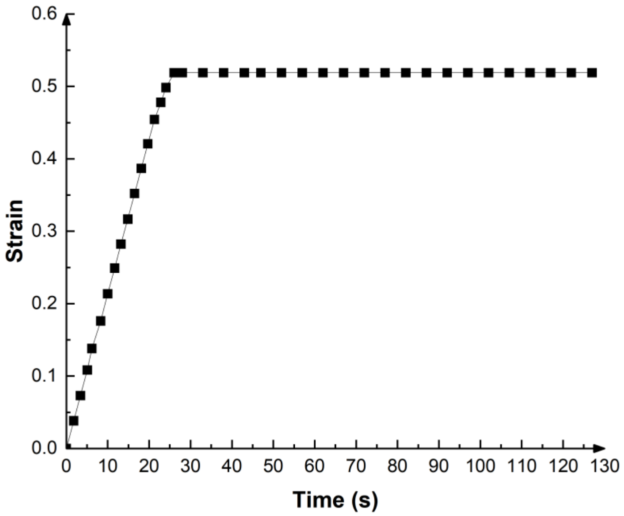


Fig. 8. Strain time course curves

Figures 7 and 8 show the stress-strain time course curves for 55% moisture content, loading force of 6000 N, and feeding amount of 150g/mm^3. From Fig. 7, it can be seen that the stress in the crushed SEL during compression is a function of m stresses σ as a function of time t, σ(t). Therefore, according to the Boltzmann superposition principle, it can be seen that the strain function ε(t) in Fig. 8 is the corresponding stress σ(t) is a superposition synthesis of m constant stresses σ_i at equal intervals in Fig. 7. The stress-strain relation is obtained as follows,

$$\varepsilon（\mathrm{t}）\approx \sum_{i=1}^{\mathrm{m}} \sigma(t_i) J(\mathrm{t}-t_i) \tag{4}$$

where ε(t) is the strain in loaded crushed cane tail, $\sigma(t_i)$ is the ith constant stress (N.mm^{-2}), and $J(t-t_i)$ is creep flexibility of the crushed cane tail (N.mm^{-2}).

From the principle of integration in higher mathematics, when n → ∞ and Δt_i is sufficiently small, Eq. 4 can be transformed into the integral form as follows:

$$\begin{aligned}\varepsilon（\mathrm{t}）&= \int_0^t J(t-\tau)\frac{d\sigma(\tau)}{d\tau}d\tau \\ &= \int_0^t \sigma^{'}(\tau)J(t-\tau)d\tau\end{aligned} \tag{5}$$

where τ is the intermediate variable of time (s).

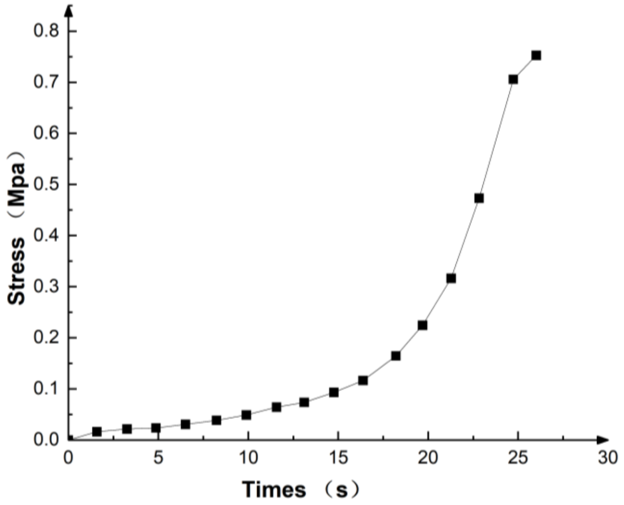


Fig. 9. Stress-time course curve of loading phase

Figure 9 shows the stress-time course curve for the loading stage with a moisture content of 55%, a loading force of 5000N and a feeding amount of 150g/mm^3. As can be seen from Fig. 9, a straight line can be taken between two points adjacent to the stress value, and the slope of the straight line can be calculated by superposition of the Eq. 5,

$$\sigma^{'}(\mathrm{t})=\begin{cases} b_1=\dfrac{\sigma_1-\sigma_0}{\Delta t_1} \\ b_2=\dfrac{\sigma_1-\sigma_0}{\Delta t_2} \\ \cdot \\ \cdot \\ b_m=\dfrac{\sigma_m-\sigma_{m-1}}{\Delta t_m} \end{cases} \tag{6}$$

According to the current national and international studies on the creep characteristics of agricultural materials and agrofibrous materials during compression (Lin and Meier 1996; Andrejko and Grochowicz 2007; Shukla and Joshi 2017), the generalised Volod model can be used to describe the creep pattern of crushed SEL during the compressive loading stage (Zhao, 2009). The creep flexibility calculation is shown in Eq. 7,

$$\begin{gathered} J(\mathrm{t})=\frac{1}{E_0}+\sum_{i=1}^{n}\frac{1}{E_i}\left(1-e^{-\frac{E_i}{\eta_i}.t}\right)+\frac{1}{\eta_0}\cdot t \\ J(\mathrm{t}-\tau)=\frac{1}{E_0}+\sum_{i=1}^{n}\frac{1}{E_i}\left(1-e^{-\frac{E_i}{\eta_i}.(\mathrm{t}-\tau)}\right)+\frac{1}{\eta_0}\cdot(\mathrm{t}-\tau) \end{gathered} \tag{7}$$

where:

E_0, E_i-modulus of elasticity, N.m^{-2} ;

η_1, η_i-the ith coefficient of viscosity, N.S.mm^{-2} ;

n-Number of Kelvin models.

Substituting Eqs. 6 and 7 into Eq. 5, solving the equation and solving to obtain the creep constitutive equation in the loading stage, because E_0, E_i, η_i and η_0 in the equation are unknown parameters, and the value of strain value ε(t) should be determined by determining the value of each of the pending parameters in the equation first. The creep eigenstructure equation can be simplified into the following form from the stress and strain time course values of the creep loading stage of crushed SEL:

$$\varepsilon(\mathrm{t})=A+\sum_{i=1}^{n}B_i-\sum_{i=1}^{n}\left[b_m\cdot e^{-C_i(t-t_m)}+\sum_{m-1}^{m-1}(b_{k+1}-b_k)\times e^{-C_i(t-t_m)}+b_1\cdot e^{-C_i\cdot t}\right]\cdot\frac{B}{C_i\cdot M}+[t\cdot M-N]\cdot D$$

$$\begin{cases} A=\dfrac{M}{E_0} \\ B_i=\dfrac{M}{E_\mathrm{i}} \quad (i=1,2,\ldots n) \\ C_i=\dfrac{E_\mathrm{i}}{\eta_i} \quad (i=1,2,\ldots n) \\ D=\dfrac{1}{\eta_0} \end{cases} \begin{cases} M=b_m\cdot t_m-\sum\limits_{k=1}^{m-1}(b_{k+1}-b_k)\cdot t_k \\ N=b_m\cdot\dfrac{t_m^2}{2}-\sum\limits_{k=1}^{m-1}(b_{k+1}-b_k)\cdot\dfrac{t_k^2}{2} \end{cases} \Rightarrow \text{All are Constants} \tag{8}$$

After calculating A, B_i, C_i, and D, the corresponding parameter values of E_0, E_i, η_0, and η_i can be derived. Because there is a total of 2n+2 unknowns in Eq. (8), a nonlinear equation consisting of 2n+2 equations can be obtained, but the obtained system of nonlinear equations cannot be solved for all the parameter values to be determined. Therefore, each unknown parameter A, B_i, C_i, and D are first given initial values $A^{(0)}$, $B_i^{(0)}$,

$C_i^{(0)}$, and $D^{(0)}$, respectively, which are converted into a system of linear equations to solve $h_{i(i=1,2,3,\ldots.2n+2)}$ problem and determine hi by least squares method to obtain the following system of equations:

$$\begin{cases} F_{11}h_1 + F_{12}h_2 + \cdots + F_{1n}h_n + F_{1n+1}h_{n+1} + F_{1n+2}h_{n+2} + \cdots + F_{12n+2}h_{2n} + F_{12n+2}h_{2n+2} = F_{1y} \\ F_{21}h_1 + F_{22}h_2 + \cdots + F_{2n}h_n + F_{2n+1}h_{n+1} + F_{2n+2}h_{n+2} + \cdots + F_{22n+2}h_{2n} + F_{22n+2}h_{2n+2} = F_{2y} \\ \vdots \\ F_{2n+21}h_1 + F_{2n+22}h_2 + \cdots + F_{2n+2n}h_n + F_{2n+2n+1}h_{n+1} + F_{2n+2n+2}h_{n+2} + \cdots + F_{2n+22n+2}h_{2n+2} = F_{2n+2y} \end{cases} \tag{9}$$

According to the pre-selected initial values of all h_1, h_{1+i}, h_{n+1+i}, $h_{2n+n\ (i=1,2,3,\ldots n)}$ in the system of equations (9), and then from the equation (8) to find out the corresponding A, B_i, C_i, D, if h_1, h_{1+i}, h_{n+1+i}, $h_{2n+n\ (i=1,2,3,\ldots n)}$ is larger, and the current calculated value to replace $A^{(0)}$, $B_i^{(0)}$, $C_i^{(0)}$, $D^{(0)}$ again with the current value of the pre-selected initial values of $A^{(0)}$, $B_i^{(0)}$, $C_i^{(0)}$, $D^{(0)}$ is larger, the current calculated value is used to replace the pre-selected initial values $A^{(0)}$, $B_i^{(0)}$, $C_i^{(0)}$, $D^{(0)}$, and repeat the above calculation process, so as to obtain the new A, B_i, C_i, D, and so on repeatedly iterated until $|\ h\ |_{\max}$ to achieve the required accuracy, stop iterating, then $A^{(0)}$, $B_i^{(0)}$, $C_i^{(0)}$, $D^{(0)}$, and so on. $A^{(0)}$, $B_i^{(0)}$, $C_i^{(0)}$, $D^{(0)}$ is the value of each parameter to be determined.

Table 1. Parameter Values of Creep Kneading Equation for Crushed STL at 6500N, 55% Moisture Content, and Various Feed Amounts During Loading Stage

Feed Amount (g/mm³)	E_0 (N/mm²)	E_1 (N/mm²)	t (s)	η_0 (N·s/mm²)	η_1 (N·s/mm²)	R^2
150	0.62	70.12	18.32	11.20	1284.60	0.95
175	0.83	89.70	42.91	14.60	3849.03	0.93
200	1.13	189.26	70.41	18.50	13325.80	0.94
225	1.37	299.38	43.56	24.49	13040.99	0.92
250	1.81	354.32	63.05	30.99	22339.88	0.92

where:

E_0:Instantaneous elasticity coefficient, $N\cdot mm^{-2}$;
E_1:Delayed elasticity coefficient,$N\cdot mm^{-2}$;
$\tau=\eta_1/E_1$:The delay time, s;
η_0,η_1:Viscous coefficient, $N.s.mm^{-2}$;

Based on the generalised Vollert model, a Matlab program was written to calculate the parameters E_0, E_1, η_1, η_0 of the creep eigenstructure equation of crushed SEL during compression (Zhao 2009). The Matlab program was used to calculate and analyse the creep results under the influence of different moisture content, different feeding amounts and different loading forces, and the number of Kelvin models in the generalized Voltaic model n was selected at most 3,When n is 1, the curve fit is good and the correlation coefficient R^2 reaches above 0.90. The parameter values of the creep kneading equation for the loading stage of crushed SEL at 6500N, 55% moisture content, and loading at each feed amount are shown in Table 1.

The four-element Burgers model can accurately describe the creep characteristics of the crushed cane end-leaf describing the crushed SEL when n=1. The four-element Burgers model is shown in Fig. 10, in which the spring at E_0 is an elastic element, which is related to the instantaneous deformation of the creep characteristic; the damper element at η_0 is a viscous kettle Newtonian body, which is mainly related to the permanent deformation of the creep characteristic; E_0 and η_0 are connected in series to form a Maxwell's body; the viscous-elastic parallel element at E_1 and η_1 is a Kelvin's body, which is mainly related to the delayed deformation of the compression creep characteristic.

The spring at E_0 immediately deforms under the loading force; at the same time, the damper $\eta 1$ and the spring E_1 in the Kelvin model slowly deform under the loading force; the damper element at η_0 displacements at a certain level of loading. After the loading force is unloaded, the elastic deformation of the spring E_0 in Maxwell's model can be quickly recovered to the initial state, so the larger the value of E_0 the larger the recovery, resulting in a waste of compression work. The Kelvin model consists of a spring E_1 and a damper η_1 in parallel, resulting in a portion of the inelastic deformation recovering slowly with time under the effect of delayed elasticity. This means that part of the energy is stored in the spring E_1 and will be released gradually over time, allowing the material deformation to recover gradually, so the smaller the value of delayed elasticity E_1, the greater the final density of the silage product. The permanent deformation of the damper at η_0 is exactly what is needed for the silage compression production and processing process. The smaller the η_0, the greater the permanent deformation the more favourable it is for the production and processing.

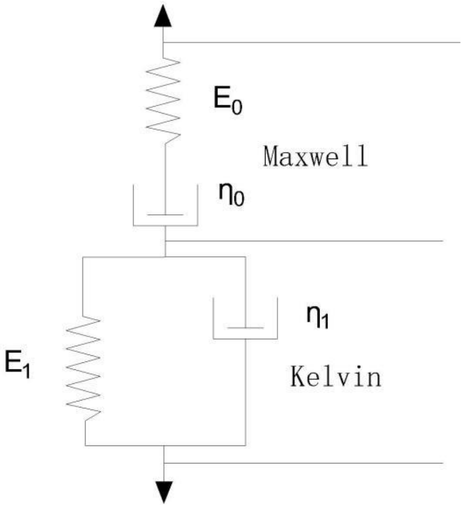


Fig. 10. Four-element Burgers model

Selection of Creep Model For Holding Pressure Stage

Due to the above analysis of the creep characteristics of crushed SEL during the loading stage, it is known that the compression process of crushed SEL can be analysed by the four-element Burgers model. The deformation curve in the holding stage is close to horizontal,and this theory is in line with the creep law of certain density silage. Therefore,the four-component Burgers model was also chosen to analyse the creep characteristics of the crushed cane tail leaves during the holding pressure stage (Tang *et al.* 2021). The relationship equation for the variation of creep history of crushed SEL during holding pressure stage is:

$$\varepsilon(t)=\frac{\sigma_0}{E_0}+\frac{\sigma_0}{E_1}\left(1-e^{\frac{-t}{\tau}}\right)+\frac{\sigma_0}{\eta_0}t \qquad (10)$$

Table 2. Parameter Values of Creep Characteristics of Crushed STL at 65% Moisture Content, Loading Force 5500N and Various Feed Amounts at Holding Pressure Stage

Feed Amount (g/mm^3)	E_0 ($N \cdot mm^{-2}$)	E_1 ($N \cdot mm^{-2}$)	τ (s)	η_0 ($N \cdot s \cdot mm^{-2}$)	η_1 ($N \cdot s \cdot mm^{-2}$)	R^2
150	1.36	18.22	0.083	89086.77	1.51	0.99
175	1.38	21.80	0.066	80589.65	1.44	0.98
200	1.33	40.98	0.188	56546.32	7.70	0.99
225	1.32	70.77	0.143	37575.35	10.12	0.98
250	1.333	65.82	0.252	26235.14	16.59	0.97

Using mathematical statistical analysis software SPSS to fit and regression analysis of the creep curve of the holding pressure stage of crushed SEL under different influencing factors, we obtained the creep characteristic parameters under the conditions of different influencing factors. According to Table 2, the fitted correlation coefficient should be $R^2 \geq 0.97$.Comparison and analysis of the creep parameters of the holding pressure stage of the crushed SEL under the conditions of different influencing factors can help us to more intuitively understand the degree of influence of these factors on it. The following is a comparative analysis of the creep parameters of crushed cane tails under the conditions of different influencing factors in the holding pressure stage.

Analysis of the Effect of Different Influencing Factors on the Parameters of Creep Properties in the Holding Pressure Stage

Influence of instantaneous elasticity E_0 value

As shown in Fig. 11, the value of instantaneous elasticity coefficient E_0 appears to change slowly with the increase of feeding amount in the case of the same loading force and moisture content; in the case of the same feeding amount and loading force, the change of moisture content has no obvious effect on the change of instantaneous elasticity E_0 value; however, the instantaneous elasticity coefficient E_0 increases gradually with the increase of loading force in the case of the same loading amount and moisture content.

From the theoretical conjecture reasoning, at the zero moment, from the deformation of the formula (10): $E_0 = \sigma_0/\varepsilon$, from the $E_0 = \sigma_0/\varepsilon$ formula can be seen, in the case of the feeding amount is unchanged, the strain ε tends to be close to the smooth state, the instantaneous elasticity E_0 value is a constant value, so the instantaneous elasticity E_0 value is positively correlated with the loading force σ_0, and the conclusion is in line with the results of the actual test. However, it can be seen from Fig.11 that there is a slow change in the instantaneous elasticity value E_0. There are two reasons for the slow change of the instantaneous elasticity value E_0 as follows:

1) The material of crushed SEL belongs to non-rigid material, and the density of each level randomly laid flat in the cylinder is different, coupled with the fact that the crushed SEL itself is not isotropic, resulting in different friction and relative displacement of each cross-section of the cylinder;
2) The compression force transfer process is a non-linear transfer, resulting in different instantaneous elasticity of the creep characteristics.

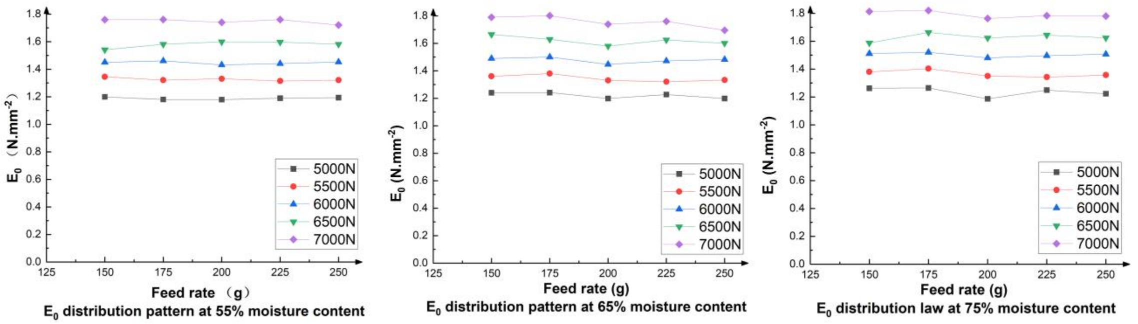


Fig. 11. Delayed elasticity E_0 distribution law in holding pressure stage

Influence of delayed elasticity E_1 value

The transient elastic deformation of crushed SEL was almost constant during the holding pressure stage, and the deformation mainly consisted of two parts of deformation: delayed elastic deformation and viscous deformation. From Fig.12, it can be seen that the change of loading force cannot change the physical properties of the test materials under the same feeding amount and moisture content. Therefore, the effect of loading force on delayed elasticity coefficient E_1 is not significant. Because the frictional resistance in the cylinder shows anisotropy and the compression force is also transferred non-linearly, which leads to the non-uniform density of the experimental material cross-section and the difference in the relative displacement of the material mass points. Therefore, there is no regularity in the delayed elasticity E_1 coefficient when the loading force changes. However, for the same loading force and moisture content, the value of delayed elasticity coefficient E_1 increases with the increase of feeding amount, and the larger the value of E_1, the more serious is the waste of compression work. There is a negative correlation between moisture content and delayed elasticity coefficient E_1 value, that is to say, the delayed elasticity coefficient E_1 value of crushed SEL with high moisture content is smaller than that with low moisture content.

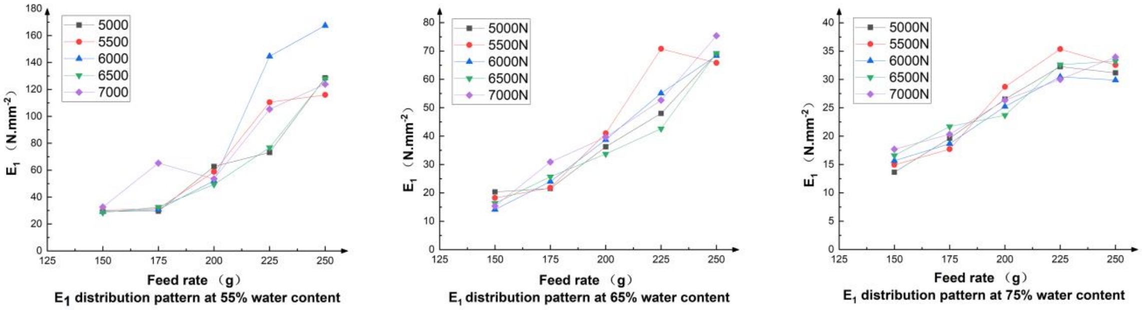
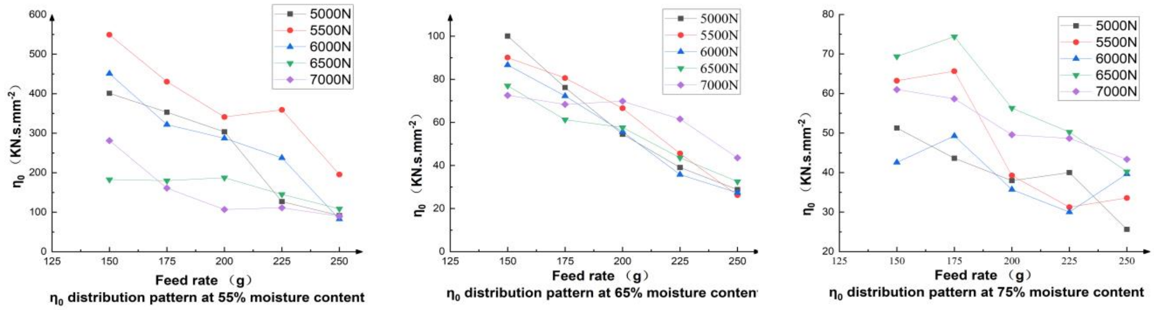


Fig.12. Delayed elasticity E_1 distribution law in holding pressure stage

Influence of the value of the coefficient of adhesion η_0

Viscous deformation is an important component of compression creep deformation, as shown in Fig.13, in the case of the same loading force and moisture content, because of the increase of the feeding amount, the gap between the test materials decreases, the adhesion increases, and the value of the coefficient of adhesion η_0 decreases accordingly. In the case of the same feeding amount and loading force, the moisture content of the crushed SEL test material has the same effect on the value of the coefficient of adhesion η_0 as it does on the value of the coefficient of delayed elasticity E_1. This indicates that the permanent deformation of crushed SEL with high moisture content is greater than that of crushed SEL with low moisture content.



η_0 distribution pattern at 55% moisture content

η_0 distribution pattern at 65% moisture conten

η_0 distribution pattern at 75% moisture content

Fig.13. Delayed elasticity η_0 distribution law at holding pressure stage

CONCLUSIONS

1. The change of loading force could not change the physical properties of crushed SEL. The higher the loading force when crushed SEL is compressed to the holding stage, the higher the strain, and the higher the tightness and density of the material, resulting in a higher instantaneous elasticity value E_0.
2. The increase in the amount of feeding does not have a significant effect on the value of instantaneous elasticity, E_0, and the adhesion between the test materials becomes larger and the delayed elastic deformation increases, resulting in an increase in the delayed elasticity coefficient, E_1, and a decrease in the value of the cohesion coefficient, η_0.
3. The effect on the instantaneous elasticity value E_0 value was not significant at higher moisture content, and the delayed elasticity coefficient E_1 value and the coefficient of viscosity η_0 decreased.

To analyze the effect of different loading force, different moisture content and different feeding amount on the compression creep characteristics of crushed SEL under different test conditions. This can provide a reference for how much loading force, moisture content of crushed SEL and each feeding amount are needed for the production of crushed sugarcane silage baling. In this way to reduce the delayed deformation of the material and increase the irreversible deformation of the material, so as to improve the firmness and density of the silage at the highest level, which is more conducive to the anaerobic fermentation of the silage and reduce the mold rate. At the same time reduce the volume of crushed SEL silage, thus reducing transportation costs.

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