

Research Article

Effect of Recycled Bagasse on Cracking Behavior of Clay Materials

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Bagasse is the residue after juicing sugarcane, and bagasse is a recyclable biological resource that can be used in many ways. Under arid climatic conditions, the clay material shrinks and loses water. Many crisscross drying shrinkage cracks formed on the surface and inside the soil will affect the stability of the soil. In this article, the cracking characteristics of clays with different bagasse contents during the evaporation process have been studied. The cracks were extracted and calculated by digital image processing technology, and the crack characteristics of samples with different bagasse contents were studied by fractal dimension and crack entropy. The results show that when moisture content maintains 34%, the clay material forms only one main crack without bagasse, forms no crack with bagasse content of 9%, and forms a crack network with the bagasse content of 3%. Adding bagasse to the clay can advance the cracking time of the clay, and different contents of bagasse have different effects on the cracking time of the clay. Among these five experimental groups, the clay was affected the most with 3% bagasse content, while the least effect happened with 6% bagasse content. The time can be advanced when the clay crack entropy appears and increases the size of the crack entropy.

1. Introduction

Sugarcane is a kind of sugar cash crop. As a renewable biological resource, bagasse is the residue of sugarcane juice, which is mainly composed of cellulose, hemicellulose, and lignin [1, 2]. Hemicellulose is bound between cellulose. As a molecular adhesive, lignin has a network structure, which surrounds and strengthens cellulose and hemicellulose as a supporting framework [3]. After bagasse is recycled, it can be mixed with urea, fermented, dried, and ground into powder, which can be used as feed for cattle, sheep, pigs, etc. Bagasse contains high sugar and nutrients. The cellulose in bagasse can be converted into sugar, which can be used as alcohol and fuel. As the raw material for making paper cups, mulching films, and paper tableware, wood can be replaced by bagasse to reduce tree felling and protect the environment. It can also make disposable tableware green.

Bagasse used to improve soil is often processed into biochar first. Biochar is a carbon-rich material formed by pyrolysis and carbonization of biomass under the conditions of low oxygen, hypoxia, and relatively low temperature [4]. The biochar is generally alkaline, with large porosity and specific surface area, and rich in ash, which can improve soil

pH, improve soil structure, and increase soil nutrient content. Therefore, biochar is often used as a soil improvement material [5, 6]. But converting bagasse into biochar requires additional energy. Bagasse is widely used in concrete building materials. The characteristics of concrete produced with bagasse ash as a substitute by substituting bagasse ash for some components of concrete mixtures, such as cement and pozzolan materials, have been analyzed by many scholars [7, 8]. By summarizing the articles about replacing cement with bagasse ash in the Scopus database from 2007 to 2021, it is found that replacing cement with bagasse ash in cement composites is a sustainable method [9].

In recent years, as a new type of slope protection and treatment technology, vegetation slope protection and greening technology have been widely used in engineering practice. It can not only improve the stability of the slope to a certain extent and prevent geological disasters, but also improve the ecological environment and promote green development [10, 11]. As major slope protection and greening technology in China, the main soil base material (clay) is prone to water loss and cracking under dry climate conditions, which has a serious impact on the protection effect of actual slope engineering [12]. The crack

characteristics of soil are related to a series of processes such as soil structure, permeability, and water evaporation. The existence of cracks destroys the integrity of soil, makes the cementation between soil particles loose, reduces the cohesion and internal friction angle of soil, reduces the strength of soil, and thus causes a series of engineering problems. Geological disasters caused by soil shrinkage cracking and other problems continue to occur, posing a great threat to human living environment and property safety [13–15]. At present, domestic and foreign scholars have conducted a lot of research on the influencing factors of cohesive soil cracking and quantitative analysis of crack networks [16, 17]. In the process of soil shrinkage and expansion, the content of water and clay has a very important impact on cracks, and wind speed has the greatest impact on the evaporation of cracked soil [18–20].

Cracked clay is a geological body with multiple cracks and significant expansion and contraction produced during the formation of natural geology. Its main components are strongly hydrophilic minerals like montmorillonite, illite, and their mixed-layer clay minerals [21]. In an arid climate, the soil loses water due to dry shrinkage. Crisscross dry shrinkage cracks will develop on the surface and inside the soil. This phenomenon is particularly common and typical in expansive soils with high clay content [22, 23]. Clay shrinkage cracks are a common phenomenon in nature. The crack will accelerate the evaporation of water in the soil, greatly change the movement of nutrients, water and microorganisms in the soil, affect the development of crop roots, and even lead to yield reduction [24]. It not only destroys the integrity of soil, but also provides a good channel for rainfall infiltration, thus reducing the strength of soil, which is an important factor affecting the engineering properties of clay [25, 26]. Cracks will also increase the weathering depth of soil mass, aggravate soil erosion on slope surfaces, and damage the ecological environment. The dry-wet cycle will lengthen the cracks on the surface of the weak argillaceous interlayer, and the dry-wet cycle will increase the crack degree of the weak argillaceous interlayer and reduce the shear strength [27].

In this article, bagasse was recovered and crushed. The cracking characteristics of clay with different bagasse content during evaporation were investigated by an evaporation drying test. The change of water content in the process of evaporation cracking of different samples was monitored, and the development characteristics of cracks of samples in the process of evaporation cracking were recorded by a digital camera. The crack was extracted and calculated by digital image processing technology, and the complexity of cracking was studied by fractal dimension. We observe the degree of chaos in the direction of crack development is determined by the crack entropy.

2. Materials and Testing Methods

2.1. Materials. The clay used in the experiment is mainly from Xuchang City, Henan Province, China. The weather here is a typical temperate monsoon climate. The annual sunshine duration is about 2280 hours, with sufficient

sunshine and abundant heat resources. Xuchang is mainly affected by seasonal climate, with less precipitation and dry weather in spring. Summer is the season with the most precipitation in a year, and the weather is hot. Normal rainfall in autumn is mild and comfortable. Winter is cold with less rain and snow. The average annual precipitation can generally reach 650 mm. The annual average temperature is 13°C–16°C, and the average temperature in January is about 0.7°C. The average temperature in July is about 27.5°C. The physical and mechanical properties of clay samples are listed in Table 1.

In the past five years, the global sugarcane planting industry has developed steadily. Due to its strong adaptability, sugarcane has been planted in most parts of the world. Therefore, the global sugarcane resources can be said to be very rich. However, our utilization of sugarcane only stays at its sugar-making value and edible value. There are two kinds of sugarcane produced in the world, most of which are used to make sugar and most of which are used for our daily consumption. According to my investigation and research, 80% of the raw materials of sugar in the world are cane sugar and 20% is beet sugar, as shown in Figure 1. According to the experimental results, it is found that both the sugarcane used for sugar production and the fruit cane we eat daily contain rich lignocellulose in the remaining bagasse after use. Lignocellulose can not only improve the strength, stiffness, and ductility of the soil, but also play a good role in strengthening the soil. It can also reduce the crack width of the clay, delay the cracking time of the clay, and improve the drying shrinkage of the clay to a certain extent. Therefore, if we can recycle the unused bagasse, we can not only increase the utilization rate of natural resources, but also promote the development of the sugarcane industry chain to a certain extent, so that we can promote common economic progress while making green development. The bagasse used in this experiment is 5 mm bagasse particles dried and screened after mixing the bagasse collected from the sugar factory with the bagasse after juice extraction and consumption. The sugarcane treatment process is shown in Figure 2. The purpose of adding bagasse to the soil is to explore the influence of bagasse as a micro-additive on the drying shrinkage of the clay. The content of chemical components in bagasse is listed in Table 2, and the comparison of mechanical properties between bagasse and other fibrous materials is listed in Table 3. In this article, the experimental results were obtained by comparing the evaporation rate of water and the rupture rate and rupture morphology of soil between normal clay and clay with bagasse in a controlled laboratory environment.

2.2. Methods

2.2.1. Sample Preparation and Experimental Procedures. After obtaining soil samples from the surrounding areas of Xuchang, the retrieved original soil was dried, crushed with a wooden hammer, and screened to remove large particles in the soil through a 2 mm sieve. The screened small granular soil was poured into 15 open round glassware with a

TABLE 1: Physical and mechanical properties of clay samples.

Density ($\text{g}\cdot\text{cm}^{-3}$)	Liquid limit (%)	Plastic limit (%)	Plasticity index	Cohesion	Internal friction angle ($^{\circ}$)	Compression factor
1.88	60.34	37.71	22.63	58.13	23.31	0.223

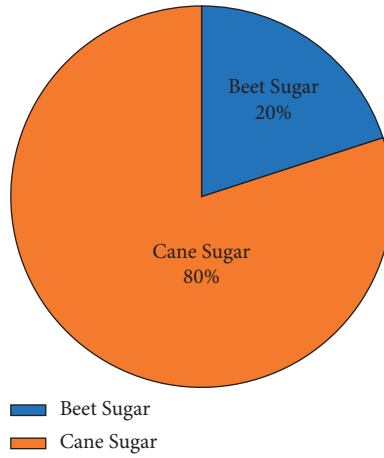


FIGURE 1: Composition of global sugar raw materials.

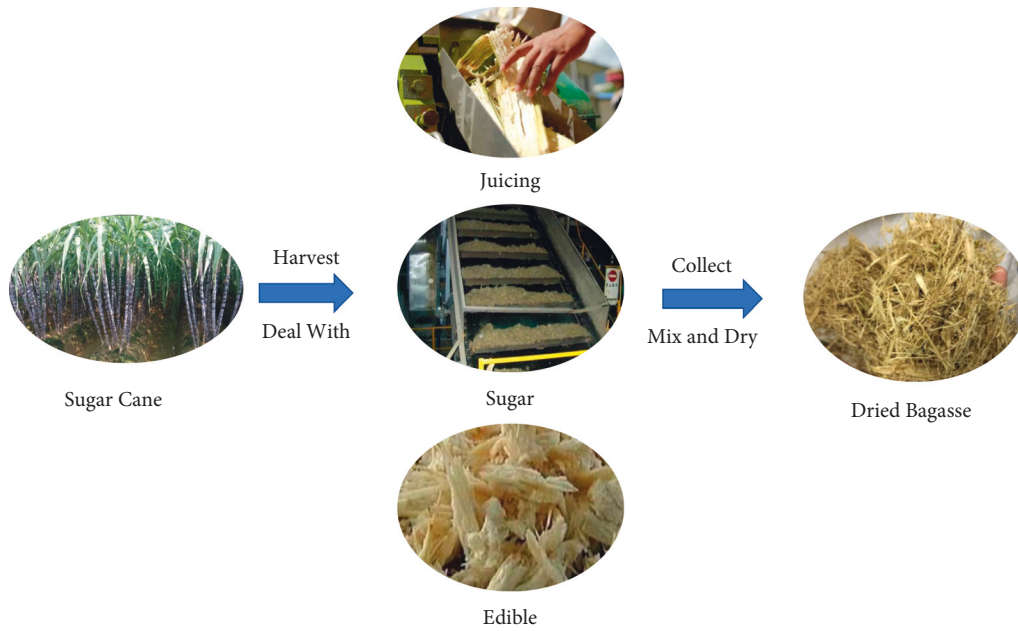


FIGURE 2: Sugarcane treatment process.

TABLE 2: Contents of chemical components in bagasse.

Ingredient name	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	Wax (%)
Composition ratio	49	24	23.6	2.8	0.6

TABLE 3: Comparison of mechanical properties between bagasse and other fibrous materials.

Type of material	Density ($\text{g}\cdot\text{cm}^{-3}$)	Elastic modulus (GPa)	Tensile strength (MPa)
Bagasse	1.5	6.38	92

diameter of 18 cm and a height of 5 cm. Each glassware contained 150 g of dry soil and different contents of bagasse of different contents, which were mixed evenly. Then, water was added to the material to make it reach the saturation state. After the material reaches the saturation state, it can be observed that the material changes from solid state to slurry state. The treated slurry sample was sealed, placed at a constant temperature and humidity box with a constant temperature of 30°C and relative humidity of 40%, and solidified for 170 h under the condition of weight. In the process of weight consolidation, in order to ensure the accuracy of the test results, the test samples should be strictly controlled in a constant temperature and humidity environment of 30°C and 40% relative humidity, and an electronic balance with an accuracy of 0.01 g should be used to record the real-time weight changes of the test samples. The specific operation steps are shown in Figure 3. A total of 15 samples with the same initial thickness were prepared for the test, including 5 bagasse test samples with different proportions. Three samples were set for each test sample to avoid special data in the test, and to ensure the accuracy of the test results.

2.2.2. Image Processing of Drying Experiment. The development of cracks in clay with or without bagasse was monitored with a digital camera. First, a fixed platform was selected and the platform was connected to the computer through the wireless network. The digital camera was installed on the fixed platform selected, with the orientation directly above the test sample and 75 cm away from the test sample. The lens direction of the digital camera was adjusted perpendicular to the surface of the glass container of the test sample. The electronic balance was placed for measuring the weight of the test sample under the circular glass container containing the test sample and the projection range of the camera lens was adjusted to 200 mm × 200 mm, making it the same size as the electronic scale. After adjustment, in the process of test monitoring, we can directly observe the changes of test samples in each round glass container by observing the imaging of the projection center of the digital camera. In order to observe the center change of the image more intuitively and eliminate the influence of the boundary, the image collected by the digital camera is cropped to 15 cm × 15 cm, and then the cropped image is processed according to the process in Figure 4. First, all the collected images are color images in RGB mode, as shown in Figure 4(a). The gamma correction graying method can be used to process the image after we remove the noise, as shown in Figure 4(b). The principle is as follows:

$$\text{Gray} = \sqrt[2.2]{\frac{R^{2.2} + (1.5G)^{2.2} + (0.6B)^{2.2}}{1 + 1.5^{2.2} + 0.6^{2.2}}}. \quad (1)$$

Second, the binary image which can clearly reflect the local and overall characteristics of the image is obtained by selecting the appropriate binary threshold for the gray image with 256 brightness levels after processing. After calculating the binarization threshold of different gray values in the gray

histogram, the gray image can be divided into two parts: crack and clay. The binary image after the assignment is shown in Figure 4(c).

Finally, the image without past noise processing is very blurred, and even isolated pixel points or pixel blocks will be formed. There are some denoising methods: mean filter, median filter, and Gaussian filter. Because the mean filter can easily lead to the blurring of image edges, and since the premise of using the median filter is to select an appropriate sliding window, a Gaussian filter is used to remove noise in this experiment. The denoised image is shown in Figure 4(d).

2.2.3. Calculation of Crack Fractal Dimension and Crack Entropy. In order to better analyze the length, shape, crack length, and other characteristics of clay cracks, fractal dimension is used to quantify the sample crack network. The commonly used fractal dimension algorithms mainly include the size method, the island method, and the box-counting dimension method. The sizing method is often used to measure the tortuosity of a curve. It mainly uses a selected size r to measure along the measured curve by dividing rules. The precondition for the use of the island method is the closed curve. The crack change map extracted is the closed curve, which meets the requirements. However, because it is not a regular figure, it cannot be calculated by assuming that the perimeter is directly proportional to the power of the measurement unit, and the area is directly proportional to the power of the measurement unit. The original smooth perimeter was replaced by the fractal perimeter curve according to the calculation method of the fractal dimension of irregular graphics, which was proposed by Blumen and Mandelbort [28]. The box-counting dimension method covers the fractal curve by taking a small box with side length l and uses the least square method to fit the curve in the double logarithmic coordinates through the number of boxes $N(l)$. The slope of the curve is the fractal dimension, as shown in the following formula:

$$D = -\lim_{l \rightarrow 0} \frac{\log N(l)}{\log (1/l)}, \quad (2)$$

where D is the fractal dimension. The box-counting dimension method is similar to the size method, which is suitable for fractal dimension calculation in this test.

Information entropy is related to the number of possible results of events. Under the condition of equal probability, the more possibilities exist, the greater the information entropy, that is, the greater the uncertainty of events. Information entropy is related to the probability distribution of events. The more uniform the probability distribution, the greater the information entropy [29]. When all probabilities are equal, the larger the information entropy is. Based on the information entropy, the probability entropy of a crack can be constructed. The larger the crack entropy is, the more uniform the crack distribution is.

$$K_c = -\sum_{i=1}^n p_i \log p_i, \quad (3)$$

where K_c is the fractal dimension and p_i is the probability of crack occurrence in a certain direction.

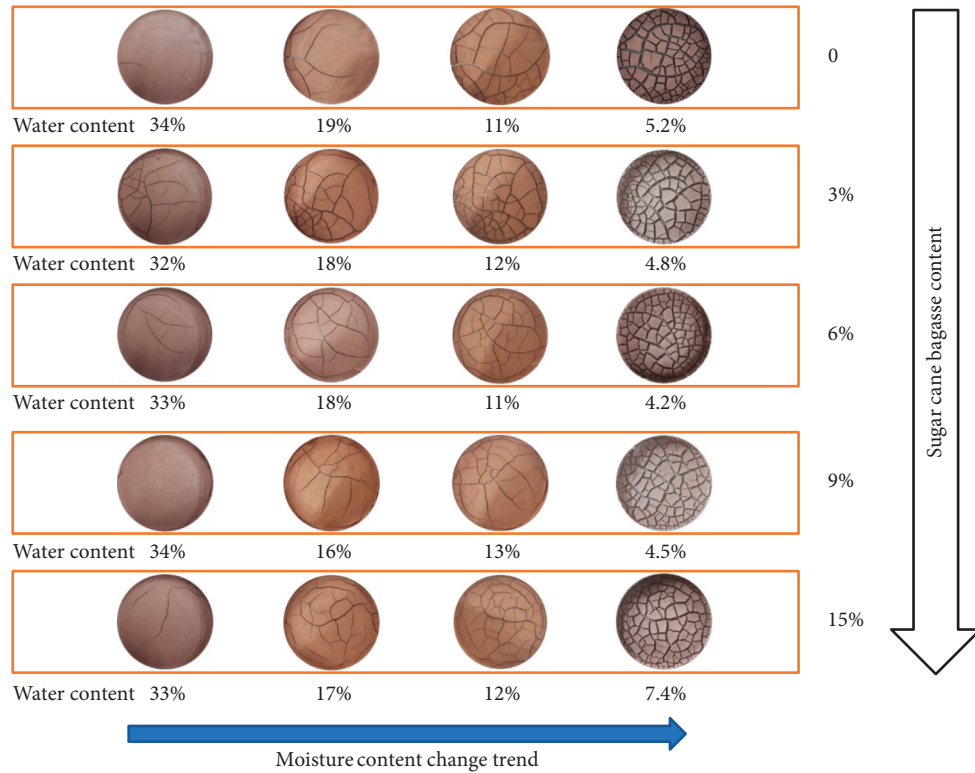


FIGURE 3: Change image of clay crack network with different bagasse content.

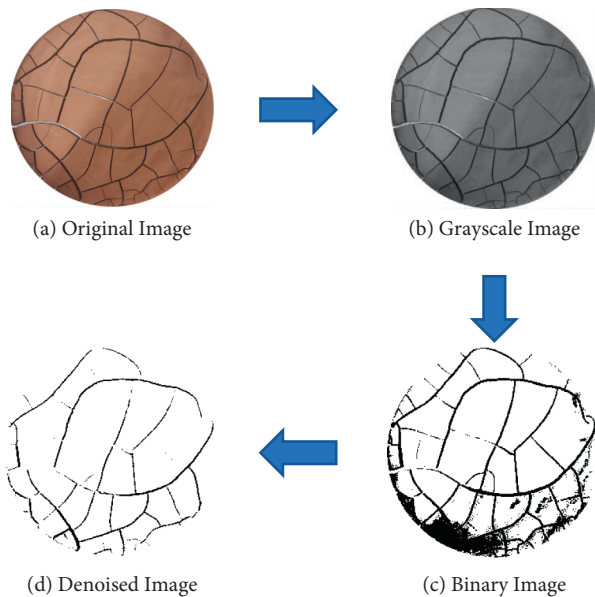


FIGURE 4: Image processing process.

3. Result

3.1. Fractal Characteristics of Crack Network. By observing the changing image of the clay crack network with different bagasse content in Figure 3, it can be found that the cracking degree of clay increases with the decrease of water content when the bagasse content is 0, 3%, 6%, 9%, and 15%, but the

cracking degree of bagasse clay with similar water content is different under different bagasse content. There is only one main crack in the clay without bagasse when the water content is 34%, and there is no crack in the clay with bagasse content of 9% when the water content is 34%. However, secondary cracks appear in the clay with a bagasse content of 3%, 6%, and 15% when the water content is approximately 33%, and the clay with bagasse content of 3% has initially formed a crack network. The clay with a bagasse content of 6% and 15% initially formed its crack network when the water content was about 18%, while the clay without bagasse and with a bagasse content of 9% initially formed its crack network when the water content was about 12%. When the water content is 5.2%, the clay without bagasse is completely cracked. When the clay with bagasse content of 3%, 4.2%, 6%, 9%, and 15% is completely cracked, the water content is 4.8%, 4.2%, 4.5%, and 7.4%, respectively. Through simple data analysis, we can find that different bagasse content can affect the cracking degree of clay under the same water content.

As shown in Figure 5, the change characteristics of the fractal dimension of clay crack with different bagasse content, the lines with different colors represent the clay with different bagasse content, and the starting points of the lines represent the occurrence time and stability time of the fractal dimension of the clay with different bagasse content. The slope of the line represents the relationship between the fractal dimension of clay with different bagasse content and time. The observation shows that when the bagasse content of clay is 3%, its fractal dimension begins to increase at 112 h,

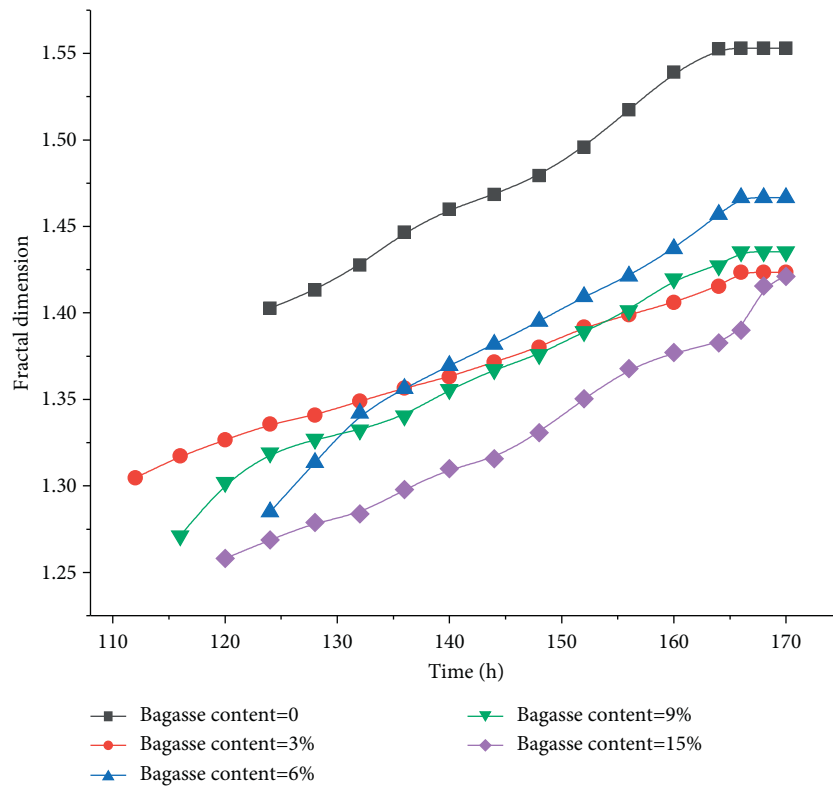


FIGURE 5: Change characteristics of clay crack fractal dimension with different bagasse content.

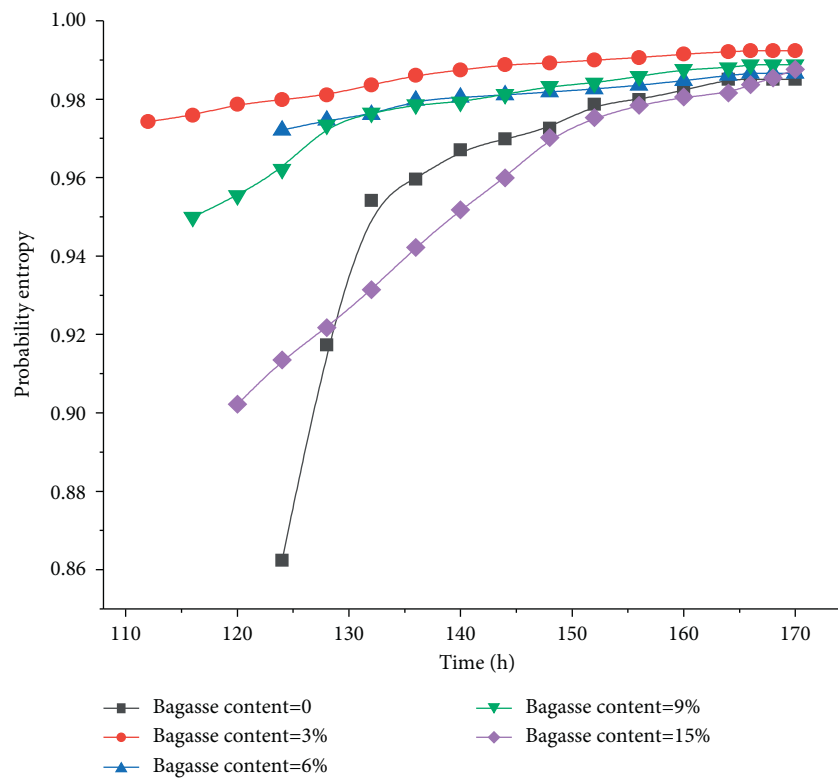


FIGURE 6: Change characteristics of clay crack entropy with different bagasse content.

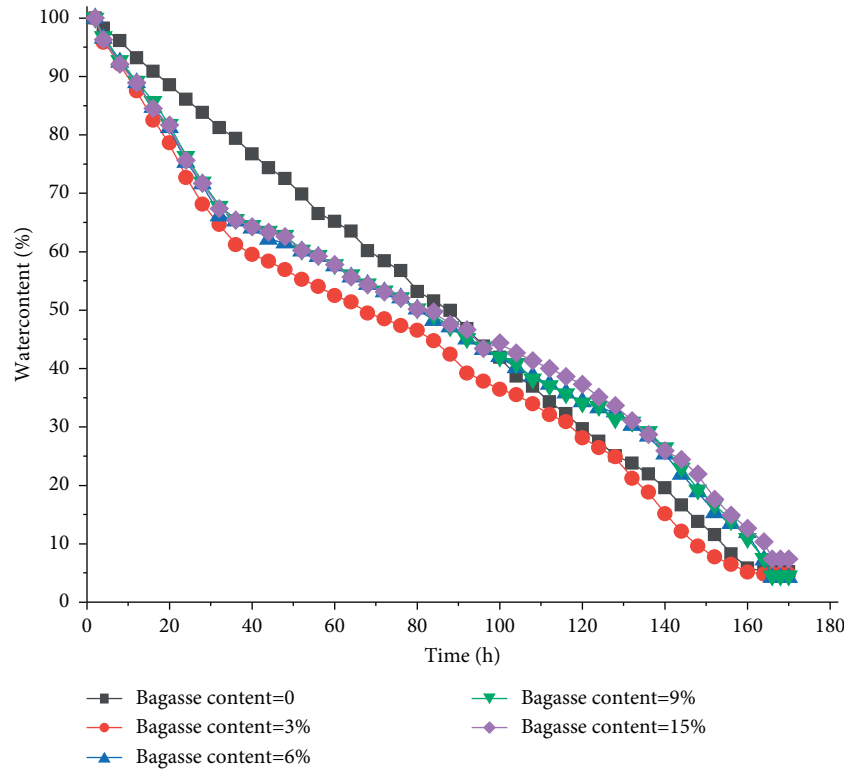


FIGURE 7: Variation characteristics of clay water content with different bagasse content.

indicating that the clay with a bagasse content of 3% cracks first and its fractal dimension is 1.304. Then, the fractal dimension of clay with a bagasse content of 9% was 1.271 at 116 h. The fractal dimension of clay with 15% bagasse is 1.258 at 120 h. The fractal dimension values of clay with bagasse content of 6% and clay without bagasse at 124 h are 1.285 and 1.402, respectively. The cracking time of clay varies with the different contents of bagasse. Adding bagasse to the clay can advance the cracking time of the clay, and different bagasse contents have different effects on the cracking time of the clay. Among our five experimental groups, the clay with 3% bagasse content has the greatest impact, and the clay with 6% bagasse content has the least impact. We can advance the cracking of clay by adding different content of bagasse to the clay.

As shown in Figure 6, the change characteristics of clay crack entropy with different bagasse content, different bagasse content in clay will change the time and size of clay crack entropy. By observing the data changes in the figure, the crack entropy of clay with a bagasse content of 3% first appeared at 112 h, with a size of 0.974. Compared with the clay with a bagasse content of 9% and a bagasse entropy of 0.950 at 116 h, the clay with a bagasse content of 3% obviously cracks earlier and has a greater impact on the clay crack entropy than the clay with a bagasse content of 9%. By observing the change curves of the other three contents, the earliest crack entropy of the clay with a bagasse content of 15% has first appeared at 120 h, and the size of the crack entropy is 0.902. The clay without bagasse and the clay with bagasse content of 6% both appeared at 124 h, but the clay without bagasse had a crack entropy of 0.862 at 124 h, and

the clay with bagasse content of 6% had a crack entropy of 0.972 at 124 h. Finally, the crack entropy of the clay with and without bagasse tends to be about 0.980 at 170 h. The crack entropy of clay with bagasse appeared earlier than the clay without bagasse, and the value is large. The effect of bagasse with different content on the change characteristics of clay crack entropy is also different. The addition of bagasse to the clay can advance the time of clay crack entropy and increase the current size of crack entropy.

Variation characteristics of clay water content with different bagasse content are shown in Figure 7. The variation characteristics of clay water content with and without bagasse are different. The water content of the clay without bagasse decreased from 100% to 5.2% in 170 h, and the water content basically showed a linear change with time. The water content of the clay with different content of bagasse decreased from 100% to about 65% in 0–30 h, while the water content of the clay without bagasse decreased from 100% to about 80% in 0–30 h, indicating that the addition of bagasse can make the water content of the clay decrease rapidly in the early stage. The water content of clay with different content of bagasse slows down at 30–170 h. The water content of clay with different content of bagasse is basically the same as that of clay without bagasse at about 100 h. The water content of clay with 6%, 9%, and 15% bagasse at 100–170 h is greater than that of clay without bagasse. Only the water content of clay with 3% bagasse is less than that of clay without bagasse at 100–170 h. Finally, at 164 h, the water content of the clay without bagasse and the clay with bagasse content of 3% completely cracked did not change and decreased to 5.2% and 4.8%, respectively. The

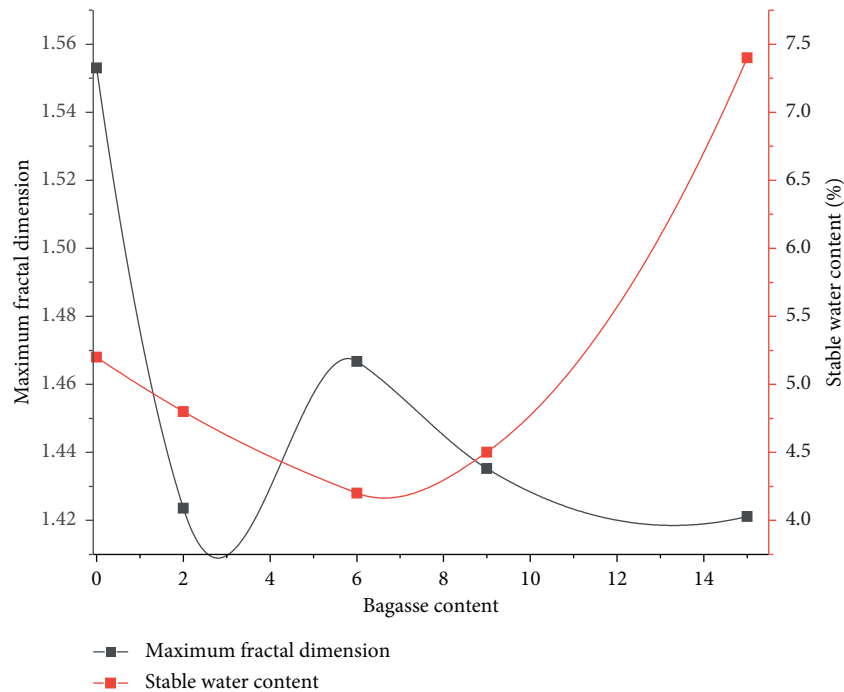


FIGURE 8: Relationship between water content and crack fractal dimension of clay with different bagasse content.

clay with a bagasse content of 6%, 9%, and 15% completely cracked at 166 h, and the water content decreased to 4.2%, 4.5%, and 7.4%, respectively. It shows that the appropriate addition of bagasse to the clay can make the water content of the clay with bagasse higher than that of the clay without bagasse at the same time in the later stage, and enhance the water retention capacity of the clay in the later stage.

4. Discussion

Bagasse fiber contains many polar hydroxyl groups, and its compatibility with hydrophobic polymer matrix is very poor; at the same time, hydroxyl groups generate strong hydrogen bonds between bagasse fibers, which makes bagasse easy to agglomerate in the polymer matrix, and the dispersion is not ideal. As shown in Figure 8, for the sample without bagasse, the final fractal dimension of the sample crack network is the largest, with a value of 1.553. The final fractal dimension of the sample crack network decreases with the addition of bagasse. The final fractal dimension of the sample with 15% bagasse content is the smallest, which is 1.421, which is decreased by 8.4% compared with the sample without bagasse. The final fractal dimension of the sample with bagasse content of 3% was 1.423, which decreased by 8.3% compared with the sample without bagasse. The final fractal dimension of the crack network of the sample with bagasse content of 6% was 1.466, which decreased by 5.6% compared with the sample without bagasse. The final fractal dimension of the crack network of the samples with bagasse content of 9% was 1.435, which decreased by 7.5% compared with the samples without bagasse. The stable water content of the sample decreased first and then increased with the addition of different amount of bagasse. For the sample without bagasse, the

stable water content of the sample is 5.2%. The stable water content of the sample with bagasse content of 3% was 4.8%, which decreased by 7.6% compared with the sample without bagasse. The sample with a bagasse content of 6% had the lowest stable water content, which was 4.2%, and decreased by 19.2% compared with the sample without bagasse. For the samples with a bagasse content of 9%, the stable water content of the samples began to rise, and the value was 4.5%. However, compared with the samples without bagasse, the stable water content of the samples still decreased, with a decreasing percentage of 13.4%. The stable water content of the sample with 15% bagasse was the highest, which was 7.4%, and increased by 42.3% compared with the sample without bagasse.

5. Conclusions

There are many polar hydroxyl groups in the bagasse fiber, and its compatibility with the hydrophobic polymer matrix is very poor. In this article, the cracking characteristics of clay materials with different bagasse contents during evaporation were studied by recycling bagasse. The digital image processing technology is used to extract and calculate the crack. The fractal dimension and entropy of cracks are used to quantitatively analyze the crack characteristics of the samples.

When the content of bagasse in the clay is different, the cracking time of the clay is also different. The clay with a bagasse content of 9% has no cracks when the water content is 34%, and the clay with a bagasse content of 3% has initially formed a crack network.

The clay with 3% bagasse content has the greatest impact, and the clay with 6% bagasse content has the least impact. By adding a certain amount of bagasse to the clay, the time of

clay crack entropy and the size of clay crack entropy can be increased.

The final fractal dimension of the sample crack network decreases with the addition of bagasse. The final fractal dimension of the sample with 15% bagasse content is the smallest, which is 1.421, which is decreased by 8.4% compared with the sample without bagasse.

Data Availability

The datasets generated during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

No conflicts of interest exist in the submission of this manuscript.

Authors' Contributions

All authors approved the manuscript for publication.

Acknowledgments

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