Study on the Variation of Mechanical Properties of Residual Plastic Film Over Time

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Abstract. The mechanical properties of residual plastic film determine the recovery rate of residual film. The mechanical properties of residual film with a thickness of 0.01mm commonly used in the semi-arid region of northeastern China were tested at different laying times. The experimental results show that the tensile strength of residual film is inversely proportional to the laying time. After crop harvesting, the longer the residual film is exposed in the field, the more significant the decrease in its mechanical properties. From the first autumn harvest to the second spring sowing, the reduction coefficient of the tensile strength of residual film is 0.35. The concept of residual film tensile strength coefficient k has been proposed, and experimental data shows that the minimum value of residual film tensile strength coefficient is 65% of the maximum value. The residual film tensile strength coefficient has a significant impact on the picking rate of residual film pickups. This study can provide reference for the design, structural improvement, and optimization of operating parameters of residual film recycling machines.

1 Introduction

In the 1950s, many developed countries began to use plastic film planting technology. China began to introduce plastic film planting technology in the 1970s [1-2]. After half a century of development, plastic film planting technology has become mature in the cultivation and planting of crops such as grain, cotton, vegetables, and fruits [3-4]. But with the widespread promotion of agricultural film planting technology, the "white pollution" caused by agricultural film residue is becoming increasingly serious. At present, mechanical picking is the main means of treating residual film pollution. The common picking machines on the market mostly pick up along the direction of plastic film laying, and the picking rate is generally below 85%. It is difficult to improve the picking rate through the improvement of the picking mechanism [5].

From the actual investigation results, it can be seen that the mechanical properties of residual film have a significant impact on the picking rate of residual film pickers. During the process of picking up residual film, it was found that the mechanical properties of the residual film in various directions are different, and the mechanical properties of the residual film also undergo significant changes over time. The mechanical properties that affect the picking up of residual film are mainly tensile and tear properties. Due to the large number of small cracks generated during the use of plastic film, the direction of crack generation is highly random, and the tearing direction of residual film will tear along the crack direction. Therefore, the tearing performance of residual film has lost statistical significance on the picking rate of residual film. The tensile performance of residual film is the main mechanical property that affects the picking rate of residual film. The tensile performance of residual film is affected by the picking direction, the angle between the residual film laying, and the laying time. Studying the mechanical properties of non ridge residual film is of great significance for improving the picking rate, and its research results will provide theoretical basis for the design, structural improvement, and optimization of operating parameters of residual film picking machines [6-7].

2 Selection of experimental materials and test results

2.1 Material selection

The climate changes in spring, autumn, and winter in the central and eastern parts of Inner Mongolia are significant, which has a significant impact on the tensile mechanical properties of residual films. When using mechanical picking, there is a significant difference in picking rate at different operating times.

According to the crop planting climate of the experimental site, the laying time in spring is at the end of April, and the harvesting time in autumn is at the

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beginning of October, with samples taken in chronological order. The experimental field is located in Yikenzhong Township, Ningcheng County, Chifeng City. It selects an area with a large area of intact plastic film and no obvious sudden external impact, and entrusts villagers to protect it to prevent livestock from trampling. The harvest date of the experimental field is October 10, 2022, and the sample selection is shown in Table 1 according to the sampling time:

Table 1. Sampling time for residual film tensile strength test.

Time Type	Sample Time						
Sampling Date	10.24	11.21	12.19	1.16	2.20	3.20	4.24
Post harvest time of crops(day)	14	42	70	98	133	161	196

According to the fitting model of mechanical performance tests at different angles between the residual film and the ridge direction, it can be seen that the tensile strength of the residual film is the highest at an angle of 40.6 °. Therefore, the mechanical performance test of the residual film is based on time, and the sample with an angle of 40.6 ° between the residual film and the ridge direction is selected for the test. Due to strict sampling requirements, complex working conditions, and uncontrollable factors, six repeated tests were selected for each level.

2.2 Experimental Results

The experimental results of mechanical properties of residual film at different laying times after crop harvest are shown in Fig. 1.

The tensile strength and elongation of residual plastic film at different laying times after crop harvest are shown in Tables 2 and 3.
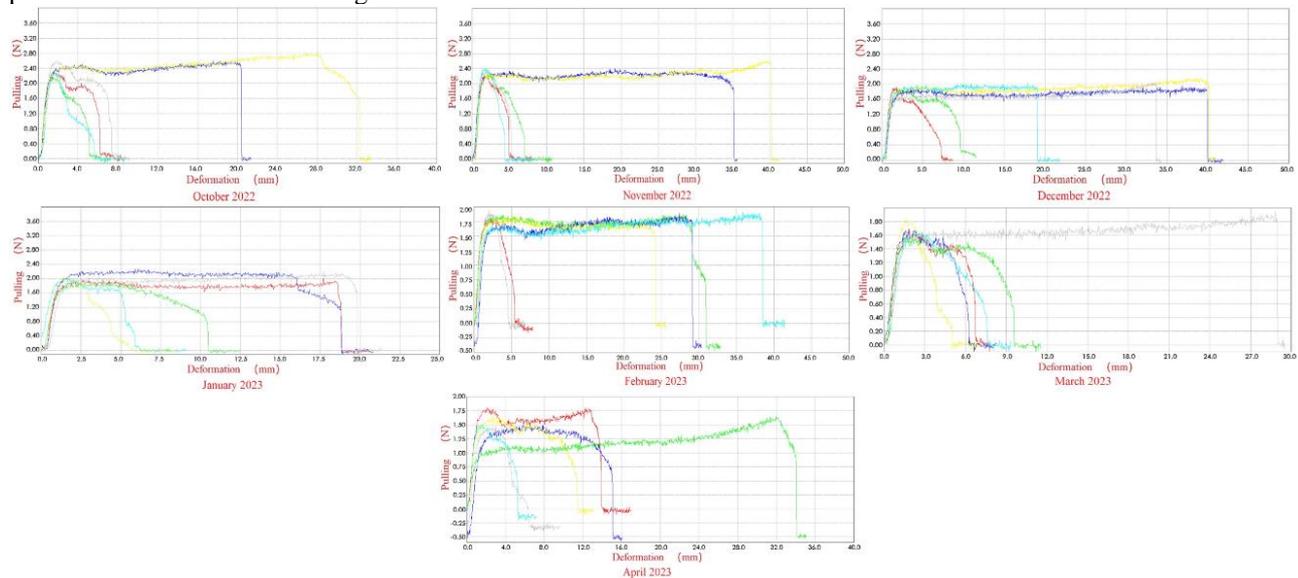

Fig. 1. Experimental results of mechanical properties of residual plastic film at different laying times after crop harvest.

Table 2. Tensile strength of residual plastic film at different laying times after crop harvest.

different laying times after crop harvest(day)	Tensile strength (MPa)						Average (MPa)
14	11.4	10.8	12.9	14.2	13	11.5	12.30
42	11.2	11.6	12.1	13	11.7	12.1	11.95
70	9.7	9.3	9.8	10.8	10.3	10.2	10.02
98	10.0	9.6	11.4	10.3	11	10.1	10.40
133	9.1	9.4	9.5	9.5	9.7	9.5	9.45
161	8.5	8.0	8.4	9.2	9.7	8.3	8.68
196	9.0	8.2	7.6	8.2	7.4	7.5	7.98

Table 3. Elongation rate of residual plastic film at different laying times after crop harves.

different laying times after crop harvest(day)	Elongation rate (%)						Average (%)
14	8.7	7.2	21.3	33.4	9.2	8.7	14.75
42	8.0	10.7	35.6	41.2	8.0	8.6	18.68
70	8.6	11.5	41.9	40.9	34.2	21.8	26.48
98	20.5	12.5	20.8	8.3	21.4	9.1	15.43
133	7.8	32.8	30.3	25.7	6.8	41.4	24.13
161	7.8	11.5	8.3	6.9	29.5	9.3	12.22
196	16.9	35.1	16.0	13	9.6	7.2	16.30

3 Analysis of Experimental Results

The analysis of the mechanical properties of the 0.01mm thick residual film in the central and eastern parts of Inner Mongolia at different laying times after crop harvest is shown in Table 4. The tensile strength of the residual film at different laying times is considered to have significant statistical differences with P<0.05; However, the P-value of the elongation test of the residual film at different laying times was 0.3406, with a P-value greater than 0.05, indicating no significant effect.

Table 4. Statistical analysis of mechanical performance experimental results of residual plastic film at different laying times after crop harvest.

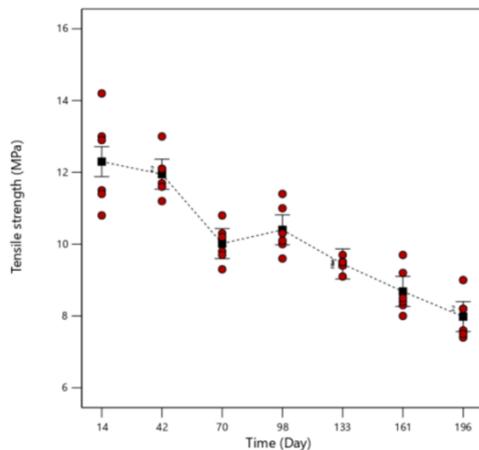| Dependents	Sum of Squares	df	Mean Square	F-value	P-value	
Tensile strength	91.61	6	15.27	30.06	< 0.0001	significan
Elongation rate	977.80	6	162.97	1.18	0.3406	Not significant

Fig. 2. Tensile strength test results of residual plastic film at different laying times after crop harvest.

The tensile strength test results of residual plastic film at different laying times after crop harvest are shown in Fig. 2. As crops harvest, the tensile strength of residual plastic film is inversely proportional to the laying time.
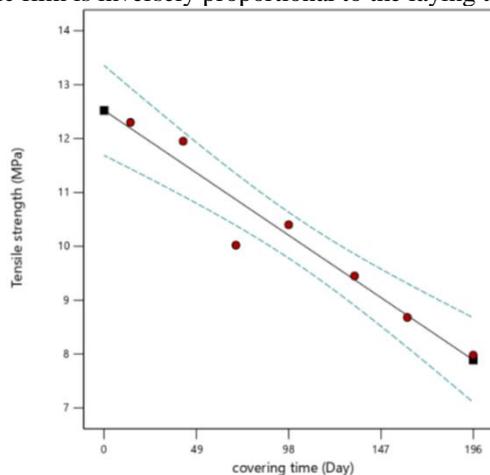

Fig. 3. Fitting curve of the mean tensile strength of residual plastic film at different laying times after crop harvest.

The fitting curve of the average tensile strength test results of residual plastic film at different laying times after crop harvest is shown in Fig. 3 The tensile strength of residual plastic film varies linearly with the length of laying time after crop harvest. The longer the residual film is laid after crop harvest, the lower its tensile strength value.

When the angle between residual plastic film and ridge planting is 40.6 °, the fitting equation for the tensile strength of residual plastic film at different laying times after crop harvest is shown in Equation (1).

$$\sigma_t = 12.52 - 0.024t \qquad (1)$$

Where σ_t is the laying time of residual plastic film after crop harvest; t is the tensile strength of residual plastic film at different laying times after crop harvest.

4 Tensile strength coefficient of residual film

From the analysis of experimental results, it can be concluded that the mechanical properties of residual plastic film are closely related to the forces it receives when laid in spring. During the laying process, the plastic film is installed at the back of the seeder. As the seeder moves forward, the plastic film slowly unfolds under the action of tension and the drum to complete the laying of the plastic film. During the laying process, the plastic film is subjected to a force consistent with the direction of ridge cultivation, resulting in a force in the direction of ridge cultivation. At the same time, in order to prevent both sides of the plastic film from tipping over due to wind force, the seeder comes with a soil compaction device to compact both sides of the plastic film. During this process, the plastic film was subjected to a force perpendicular to the direction of ridge cultivation. The angle between the pulling force direction of the plastic film and the ridge planting direction during sowing is influenced by various factors such as the sowing speed of the plastic film seeder, the force of the mold wheel on the plastic film, the shape of the cover plate, the inclination angle of the cover plate, and the physical characteristics of the cultivated soil.

The concept of residual film tensile strength coefficient was proposed to describe the mechanical properties of residual film. The mechanical properties of residual plastic film can directly affect the picking rate of residual plastic film. The tensile strength coefficient of residual plastic film is the main measure of its mechanical properties and serves as a theoretical reference for the design of residual plastic film picking machines. The calculation of residual plastic film tensile strength coefficient is shown in Equation (2):

$$k_\alpha = k_{\alpha t} k_{\alpha \omega} \qquad (2)$$

Where k_α is the tensile strength coefficient of residual plastic film; $k_{\alpha t}$ is the tensile strength

coefficient of residual plastic film laying time; $k_{\alpha\omega}$ is the tensile strength coefficient of the angle between residual plastic film and ridge planting direction.

The tensile strength coefficient of residual plastic film laying time is:

$$k_{\alpha t} = \frac{\overline{\sigma_{\alpha t}}}{\overline{\sigma_{\alpha 1}}} \qquad (3)$$

Where $\overline{\sigma_{\alpha t}}$ is the average tensile strength of residual plastic film after t days of crop harvest; $\overline{\sigma_{\alpha 1}}$ is the average tensile strength of residual plastic film within 15 days after crop harvest;

The tensile strength coefficient of the angle between residual plastic film and ridge planting direction is:

$$k_{\alpha} = \frac{\overline{\sigma_{\alpha}}}{\overline{\sigma_0}} \qquad (4)$$

Where $\overline{\sigma_{\alpha}}$ The direction of residual plastic film and ridge cultivation is θ The average tensile strength of residual plastic film at the corner; $\overline{\sigma_0}$ is the average tensile strength of residual plastic film when it is in the same direction as ridge cultivation;

The tensile strength coefficient of residual plastic film has an important impact on the picking rate of residual plastic film. According to experimental data and the formula for the tensile strength coefficient of residual plastic film, when the picking direction of residual plastic film is 40.6 ° from the ridge planting direction, the tensile strength coefficient of residual plastic film is 1.18 after 14 days of crop harvest; When crops are harvested for 196 days, the tensile strength coefficient of residual plastic film is 0.766, and the minimum tensile strength value of residual plastic film is 65% of the maximum value. The smaller the tensile strength coefficient value of residual plastic film, the more fragile and difficult it is to pick up, which will have a significant impact on the efficiency of residual plastic film picking up.

5 Conclusion

The residual film with a thickness of 0.01mm commonly used in the central and eastern parts of Inner Mongolia shows a more significant decrease in mechanical properties as it is exposed to the field for a longer period of time after crop harvesting. Under the conditions of this experiment, from the first autumn harvest to the second spring sowing, the reduction factor of the tensile strength of the residual plastic film is 0.35. The selection of residual film picking time should be carried out as early as possible after crop harvesting and straw sorting and transportation, which can effectively improve the residual film picking rate. The article also proposes the concept of residual film tensile strength coefficient, providing theoretical guidance for the design, structural improvement, and operational parameter optimization of residual film picking machines. In addition, the relationship between the maximum tensile strength of residual film and the angle between the ridge planting direction under different climatic conditions and using different mulching sowing machinery; Further research is needed on the quantitative impact of changes in the tensile strength coefficient of residual film on the efficiency of residual film collection.

Acknowledgements

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