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Study on mechanical properties of apple picking damage

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Abstract. In order to reduce the apple damage of extrusion and collision caused by machine during apple picking, study law of apple damage is necessary. A compressive test is carried out on precision micro controlled electronic universal testing machine, red apple of Fuji type at mature state as the test material. Through analyzing mechanical characteristics of apple compression, the mechanical model is established. By calculating, obtained compressive elastic modulus of apple is 2.091MPa, the maximum elastic limit is 0.130MPa, and the elastic modulus of compression remained at the scope of 5~7MPa. When the stress value of Apple reaches its yield limit 0.125MPa, the deformation of apple is accelerated. This study can be used to make a reasonable prediction of mechanical damage of apple.

Introduction

Apple is a common fruit, rich in nutrients. Usually has round shape, and yellow or red color.Apple picking mode is manual in the past. This mode is time-consuming and inefficient. Apple picking machine can solve the disadvantages of manual picking, it can liberate labor force, save time, and has high efficiency [1]. But everything has two sides, if imprecise force loaded on the apple surface, may effects not only the apple's storage, but also processing and sales, and ultimately effect apple's market benefits [2]. In order to reduce apple loss and improve apple quality, it is necessary to control their mechanical damage[3]. In recent years, the research of mechanical damage and mechanical properties of fruits has been paid more and more attention by researchers both at home and abroad. The researchers used the finite element method and the theory of hertz to explore the mechanism of fruit mechanical damage, and great process has been made [4-10]. But no paper has carried out the analyses of mechanical properties of apples when picking. Therefore, it is particularly important to study the stress characteristics of apple picking process, to obtain compression stress and strain, and then get apple’s mechanical properties. The conclusion may provide structure design and operation method of apple picking robot.

Materials and methods

Test sample selection

Red apple of Fuji type is selected as the samples. Its longitudinal diameter average is about 73.67mm, and the transverse diameter average is about 81.25mm. In order to carry out the compression test, a rectangular specimen with a certain size was taken out from the apple as the test sample. The apple samples must guarantee has no wormhole and no breakage.

Fig.1 The Apple sample

Fig.2 CMT6502 series microcomputer electronic universal testing machine

Experiment

Experiment machine

Fig.2 is a CTM6502 type precision micro control electronic universal testing machine, equipped with force and displacement sensors. In this experiment, a force sensor with a range of 500N, a resolution of 1/120000 and a numerical accuracy of 0.5% is selected. A displacement sensor with a precision of 0.3% and resolving power is selected. CTM6502 type precision micro controlled electronic universal testing machine. The relative error of displacement value for large deformation measurement range is $10 \sim 800\,mm$, the relative error of indication for large deformation is $\pm 0.05\%$.

In this experiment, the loading exert rate is 3mm/min, and the data sampling obtained frequency is 2/s. The environment temperature is $23°C$, moisture is 51.3% in the test.A vernier caliper with a test accuracy of 0.02mm is also needed.

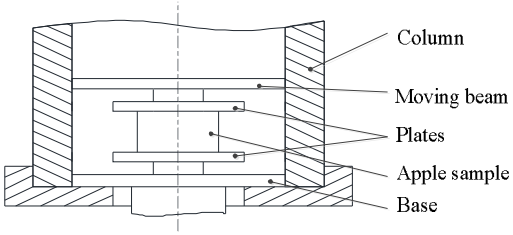


Fig. 3 The compression experiment of apple

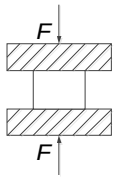


Fig.4 The force analysis of the apple

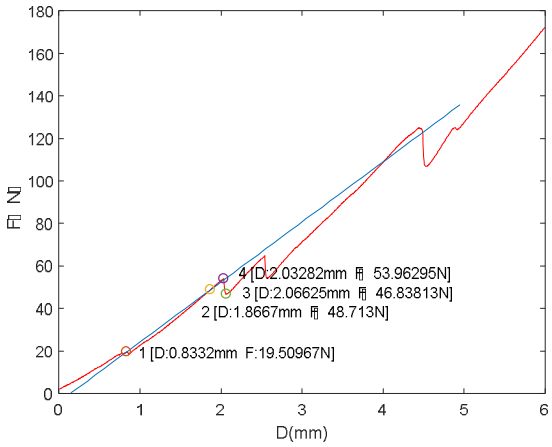
Experiment process

Size measuring of apple samples. Cut the apple with cubes shape, and use the vernier caliper to measure the length, width, and high of the apple block.

Apple block placement. Start the universal testing machine, using the column adjust the moving beam with "up" or "down" button at right side of the machine roughly, and then tune fine the button at left side, the specimen is placed in the middle position on the two plates.

Adjustment experiment machine and exert load on apple sample. Adjust the peak load, initial displacement and deformation, zero point of original test time in the software of SANS; press the "start" button on computer display, applied axial load to the apple sample with box shape, as shown in Fig.4. in the process of force apply, pay attention to the changes of yield load all the time, recorded the yield load.

Observe the shape of apple block sample after compression, and draw the force and displacement curve diagram of apple block sample (Fig.5).



1_initiation point of elastic segment. 2_ end point elastic of elastic segment. 3_ lower yield point. 4_upper yield point. D_Displacement. F_Force.

Fig.5 The force-displacement curve of the apple sample

Analysis of apple compression experiment results

Elastic stage analysis of compression experiment of apple sample

First reset the machine's load value to zero, then exert slow and uniform load on apple. Draw the force displacement curve, where the force as the ordinate and the displacement as the abscissa. As shown in Fig. 5, compression displacement of the apple sample increases with the load. It can be seen from the curve that at the beginning of the compression experiment, the force- displacement curve of the apple sample exhibits a certain nonlinear characteristic, which is the characteristic of the specimen itself. At this stage, apple specimen deformation is elastic, if loading removed at this stage, the sample can still be restored to its original size, the sample, that is to say the specimen without any residual deformation.

The relation between stress and strain is satisfied:

$$d_0 = E_y e_0 \quad (1)$$

The above relation is Hooke's law. E_Y is the modulus of elasticity of apple specimen, unit is MPa.

Combined with the lower formula:

$$F_y = K\Delta L_b \quad (2)$$

Obtained compressive elastic modulus of apple as following:

$$E_y = \frac{F_y H}{\Delta l_b S_y} = 2.091\text{MP} \quad (3$$

(4))

In the formula:

F_y_the force corresponding to the compression stage of the apple specimen, N.

ΔL_b _Elastic deformation of apple specimen under compression elastic stage, mm.

K_The slope of line connecting the starting point and the end of the curve.

H _Apple ample height, mm.

S_y_The area of apple sample, mm^2.

With the above formula(3), the compressive modulus of elasticity of the apple specimen can be calculated. Using Matlab statistical software draw the variation of elastic modulus of apple sample at different pressure stages (Fig.6). It can be seen from Fig. 6, with the displacement of the apple specimen increased, compressive elastic modulus in addition to several special points, remained at 5-7MPa.

When picking apples, the stress value of apples may reach the elastic stage maximum stress d_{max}. If the apples bear the stress $d_0 \geq d_{max}$, the apple peel will suffer serious damage. So, it is very necessary to study the maximum elastic compressive stress value d_{max} of apple.

$$d_{\max} = F_{\max} / S_y = 0.13MPa$$

In the formula:

d_{max}_the maximum elastic stress of apple compression, MPa.

F_{max}_the maximum elastic compression force of apple compression, N.

Considering the damage of apple, in the process of apple picking or transporting, much attention must be paid to the apple.

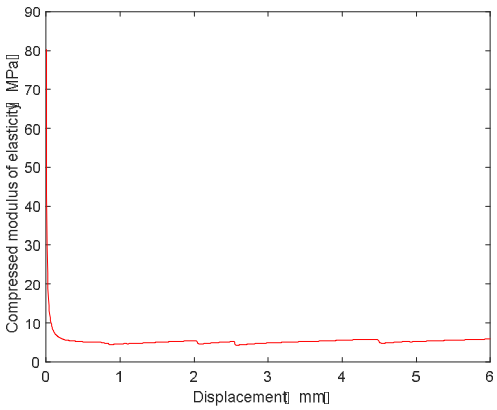


Fig.6 The change of compression modulus of apple

Analysis of yield stage for apple specimen compression

It can be seen from the Fig. 5 that the yield stage of the apple specimen is different from that of the metal material. When the metal material is compressed, first stress and strain will be increased to a certain value, then the stress-strain curve will appear level (there may be slight fluctuations) in this stage, next the value of constant stress and deformation of plastic material rapid growth.

In the yield stage, up yield point of apple samples is at the place of 2.0328mm, 53.9629N, the lower yield point apple samples is at the place of 2.0662mm, 46.8381N. These two yield points exactly prove the stress strain characteristics of the apple specimen being compressed at the yielding stage. After the lower yield point, it can be seen from the Fig.5 that the compression curve of the apple will continue to appear the curve of the yield stage of the compression test of the apple sample.

The yield point is defined as the yield limit of the compression experiment of the apple specimen, and the yield limit is the sign that the apple begins to enter the plasticity. The yield limit is very important for the study of apple pressure characteristics.

$$d_L = F_L / S_y = 0.125MPa$$

In the formula:

d_L _ower yield stress, MPa.

F_L –Lower yield load, N.

Therefore, in order to avoid apple damage in picking, transportation and other processes, apple should be avoided to reach yield limit stress.

Conclusions

The mechanical properties of apples under compression are analyzed and studied, and the curves of elastic modulus of apple are drawn.When the stress value reaches the maximum elastic limit 0.13MPa when apple compressed, apple will be damaged. Therefore, when picking apples, the harvesting machine should reduce the pressure stress value lower than 0.13MPa.

The mechanical properties of apple elastic stage and yield stage analyzed and calculated. The results show that the compressive modulus of elasticity of apple is 2.091MPa. The lower yield limit of apple is 0.125MPa, and when the stress of apple is above the value, and the deformation of apple is accelerated.

Acknowledgement

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