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Theoretical Analysis of Deflection in Deformed Silicone Components for Dried Longan Peeling

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ABSTRACT

In traditional manual processing of dried longan, the fruit is typically peeled by cutting from the stem end with a knife and tearing along the seed axis to separate the flesh. However, to enhance operational efficiency and realize production automation, the development of dried longan processing machinery with automatic peeling capabilities has become an inevitable trend in the industry. The most critical component of such machines is the peeling module, whose geometry and dimensions directly influence the success rate of the peeling process. In the peeling machine developed by our research team, silicone plates are employed as the primary peeling elements. However, during operation, excessive deformation of the silicone plates often results in peeling failure or material damage. Therefore, controlling the deflection of these components is a key challenge in the design process. This study focuses on the deflection behavior of circular silicone plates under loading and develops an analytical model along with parameterized formulas to estimate their deformation. The results serve as a theoretical foundation for the design and evaluation of the peeling components.

Keywords: dried longan, deflection analysis, silicone component

INTRODUCTION

Longan is a tropical fruit with rich nutritional content and high economic value, widely distributed throughout tropical Asia and regarded as a commercially important crop (Jiang et al., 2002; Rangkadilok et al., 2005; Chen et al., 2020). The production season of longan is mainly concentrated in summer; however, because harvested fruit is typically exposed to hot and humid conditions, the shelf life of fresh longan is very short, and the fruit readily spoils. Consequently, drying fresh longan to produce dried longan is a common processing method to extend its shelf life and storage stability. Currently, pulp peeling for dried longan is still performed manually on a fruit-by-fruit basis, which is labor-intensive and raises concerns regarding food hygiene and safety. To address food-safety issues, improve operational efficiency, and enable process automation, we developed an automated dried-longan pulp peeling machine that uses silicone plates as the peeling element; however, excessive deformation of the silicone plate during operation can lead to peeling failure or component damage, it can be seen that effectively controlling plate deformation is a key technology. Based on plate-deflection theory, this study derives an analytical formula for estimating the deformation of the silicone plate.

MATERIALS AND METHODS

Deflection Theory of Circular Plate

To obtain the pulp from dried longan by squeezing, the flesh is first incised; a silicone plate is then used to squeeze at the incision, separating the pulp from the pit. (In this study, “pulp peeling” refers to separating the pulp from the pit.) The amount of deformation of the silicone plate during squeezing affects the pulp-peeling success rate; therefore, this study derives a formula to estimate plate deflection using plate-deflection theory *(Timoshenko and Woinowsky-Krieger, 1959)*. The squeezing region of the pulp-peeling component is a circular plate with a central through-hole, as shown in Fig. 1.

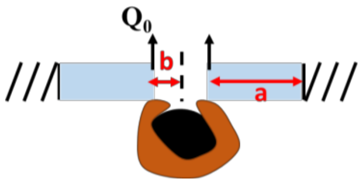

Fig.1 Schematic of the dried-longan pulp-peeling silicone plate, showing a central circular hole plate and a clamped (fixed) outer edge.

Under an applied compressive load during squeezing, the general solution for its deflection is:

$$w = \frac{Pr^2}{8\pi D}\left(\ln\frac{r}{a} - 1\right) - \frac{C_1 r^2}{4} - C_2 \ln\frac{r}{a} + C_3 \tag{1}$$

During squeezing, the plate’s outer edge is fixed (clamped), and a uniformly distributed shear force is applied along the inner edge. Accordingly, the boundary conditions used in Eq. (1) are specified as follows:

$$w_{r=a} = 0,\ w'_{r=a} = 0,\ (M_r)_{r=b} = 0$$

From the boundary conditions, the integration constants C_1, C_2, and C_3 in the general solution (Eq. (1)) are determined. Substituting these into Eq. (1) gives the maximum deflection w_{max}, as follows:

$$(w_{r=b})_{max} = \frac{Pa^2}{D}\left\{\frac{c^2}{8\pi}(ln(c) - 1) - \frac{c^2}{32\pi}\left[-2 + \left((1+\nu)\cdot 2\,ln(c) + 2\right)\cdot\left(\frac{c^2}{(1-c^2+(1+c^2)\nu)}\right)\right] + \frac{1}{8\pi} + \frac{1}{32\pi}\left[-2 + \left((1+\nu)\cdot 2\,ln(c) + 2\right)\cdot\left(\frac{c^2}{(1-c^2+(1+c^2)\nu)}\right)\right] + \frac{ln(c)}{8\pi}\left[\left((1+\nu)\cdot 2\,ln(c) + 2\right)\cdot\left(\frac{c^2}{(1-c^2+(1+c^2)\nu)}\right)\right]\right\} \tag{2}$$

where $c = b/a$.

$$w_{max} = k\frac{Pa^2}{Eh^3} = k\frac{Pa^2}{D\cdot 12\cdot(1-\nu^2)} = \frac{pa^2}{D}K \tag{3}$$

where $E = \frac{12D(1-\nu^2)}{h^3}$, $K = \frac{k}{12(1-\nu^2)}$, (equivalently, $k = 12(1-\nu^2)\cdot K$). E is the Young’s modulus; D is the plate’s flexural rigidity (bending stiffness). The Poisson’s ratio of the pulp-peeling silicone plate is set to $\nu = 0.48$. h denotes the plate thickness, and k is the deflection coefficient. Using Eqs. (2) and (3), the deflection coefficient k for different geometric parameters can be obtained, as in Table 1.

Table 1 Deflection coefficient k for the dried-longan pulp-peeling component.

$a/b =$	2.0	3.0	3.4	4.0	5.0	5.5	5.8
k	0.076	0.150	0.164	0.179	0.191	0.194	0.195

RESULTS & DISCUSSION

According to the circular-plate deflection theory, a circular plate develops deflection when its outer edge is clamped and a shear force acts along the boundary of the central through-hole. For the configuration in Fig. 1 ($a = 38$ mm, central through-hole $b = 6.5$ mm, $a/b = 5.8$), the deflection coefficient is $k = 0.195$ (see Table 1), and the maximum deflection computed from Eq. (3) is about 8 mm, which agrees with the measured deformation during squeezing. With $a = 38$ mm, the excessive deflection leads to two unfavorable outcomes: (i) pulp remaining on the pit surface, and (ii) the dried longan passing directly through the 6.5 mm through-hole, making it ineffective for peeling the pulp from the pit edge. When a is reduced to 22 mm, the ratio decreases to $a/b = 3.4$, k drops to 0.164, and the calculated deflection reduces to approximately 4.6 mm, close to the experimental value; the smaller deflection enables the 6.5-mm through-hole to peel the pulp effectively from the pit surface, but a larger squeezing force is required for the fruit to pass through the hole.

CONCLUSIONS

In summary, this study establishes a deformation-estimation formula for the silicone circular plate used in the dried-longan pulp-peeling component and verifies its accuracy against measured deformations. The geometric-parameter analysis shows that narrowing the squeezing region reduces the deflection coefficient k and the maximum deflection w_{max}, thereby improving the pulp-peeling success rate; however, a higher squeezing force is required. Accordingly, the design should balance pulp-peeling success rate against the available actuation force to optimize overall performance.

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