Mechanical and physical properties of sugarloaf

Habib Hashemifard, Mohammad Mehranzadeh, Mohammad Chenari

Department of Agricultural Machinery, Dezful Branch, Islamic Azad University, Dezful, Iran.

ABSTRACT

Knowledge of the mechanical properties of Sugarloaf is considered to be necessary to design cracking and other processing machines. Although there are a large published works on the mechanical properties of agricultural products, information on the mechanical properties of Sugarloaf is not available. In this study, rupture force, rupture energy and power, toughness, firmness and modulus of elasticity of Sugarloaf under uniaxial compression were studied. Test were conducted on beam specimens (with dimension 5 × 5 × 20 mm) of Sugarloaf. The beam samples were prepared by using a pneumatic motor driving a jeweler’s saw 60 mm in diameter and 0.2 mm thick. The effect of loading velocity (at 1.24, 50 and 100 mm/min), types of Sugarloaf (soft and hard), and position of sampling the beam specimens (top, middle and bottom of Sugarloaf) were studied. The results showed that all the mentioned above parameters had significant effect on the measured mechanical properties (P = 0.01). The variation range of rupture force, energy, toughness, firmness and modulus of elasticity for soft Sugarloaf samples were 79.6-295.5 (N), 14.7-61.9 (mj), 0.029-0.123 (mj/mm³), 139.2-1154.1 (N/mm) and 24.6-92.7 (Mpa), respectively. Corresponding values for hard samples were 131.2-308.3 (N), 20.8-83.6 (mj), 0.0416-0.168 (mj/mm³), 428.2-624.4 (N/mm) and 34.4-108.1 (Mpa), respectively. The toughness and firmness increased from bottom to top of the sugarloaf. With increasing the loading velocity, from 1.24 to 100 mm/min, the mean values of rupture force and energy were increased from 105 to 166.1 N and from 27.1 to 28 mj, respectively.

Key words: mechanical properties, sugarloaf, Compression tests, modulus of elasticity, rupture force, energy.

Introduction

In scientific use, the term sugar refers to sucrose a white crystalline solid disaccharide. In this research, the word “sugar” principally refers to prism of sugar loaf. Commercially produced sugar comes either from sugar cane or from sugar beet. The five largest producers in 2007 are Brazil, India, EU, USA and China. Global production of Sugar was 152 Million 600 Thousand Tons in the past year. Even as sugar production increases in the world (from 50 million ton in 1960 to 150 million ton in 2007), sugar are subject to major quantity loss during production processes. The most important reason for this quantity loss is that sugar loaf processes have been performed by hand or by using old techniques. Determination of some physical and mechanical properties of the sugar loaf is necessary for design of sugar loaf crackers. Many food processes, such as shredding and cutting, involve breaking the food into smaller components. The concern of food technologists is in designing foods that break down in the optimal way. For example, during a separation process, the food must not crumble to reduce wastage.

No published work seems to have been carried out on the mechanical properties of the sugarloaf. For this reason, the objective of this study is to show, for quasi-static compression, how the force, deformation, and toughness of the Sugarloaf at failure, along with the maximum tangent modulus and maximum secant modulus, are related to the position, sugarloaf kind and speed of compression.

Materials and methods

2.1. Materials:

In this study, two different Sugarloaves, soft and hard, were used for measurements. Two types...
Sugarloaf were brought from Damavand Sugarloaf factory of Tehran-Iran. These sugarloaves have the most percent of consumption Sugarloaf in Tehran. These sugarloaves were divided into three zones, up, middle and bottom. Then each zones were slabed into square prisms with dimensions of $5 \times 5 \times 20$ mm by using an circular blade with 0.2 mm thickness and 60 mm diameter mounted on an air motor (Fig 1) with rotary speed of 23000 rpm at 6.3 bars pressure. The mechanism used for producing specimen (Fig 1) consists of a fixed jaw for holding the air motor and a guide that make the precise and controlled sugar slice motion.

![Fig. 1: Schematic areas loaf](image1)

**Fig. 1: Schematic areas loaf**

2.2. *Uniaxial compression tests:*

Specimens were transported to the Karaj agricultural research Institute for testing. Special trays were prepared to hold the 72 sugar prisms for four replications, two sugarloaf kinds, three speeds (1.24, 50, 100 mm/min), three locations (top, middle, and bottom) and one orientation treatment. The 1.24 mm/min velocity used for comparing two types Sugarloaf in their three zones. An Instron Universal Test Machine with a 500 N load cell was used for measuring the compression force of sugar prisms. Measurement resolution was 0.1 N. Completely randomized design with four replications was used in this research. At the first, the effects of sugarloaf kinds (soft and hard) and three locations (top, middle, and bottom) at a constant loading velocity of 1.24 mm/min were studied on mechanical properties. The second experiments were conducted to determine the effect of loading velocity, at 1.24, 50, 100 mm/min levels, and locations (top, middle, and bottom) for soft sugarloaf.

Therefore sugar specimens were placed between flat steel plates in the following manner; a sample support plate, upon which the specimen is placed and a loading plate, 10.2 mm square, for applying the force. Force versus deformation data were recorded by the computer until the specimen ruptured (fig.3). The first pick of force-deformation curve was used as rapture point.

![Instron testing machine.](image2)

**Fig. 2: Instron testing machine.**
Compression force, was given by the maximum recorded force and energy was calculated by measuring the surface area under the force-deformation curve. In this case, it was found by:

$$E_a = \int F \, dx = n \times f$$  \hspace{1cm} (1)

Where $E_a$ is the absorbed energy (mj), $F$ is the compression force (N), $x$ is the crosshead displacement (mm) and $n$ is the number of units under force displacement curve on the universal testing [4].

Toughness that is expressed as the energy absorbed by the sugar prisms up to rupture point per unit volume of the prism is shown as follow:

$$T = \frac{E_a}{V_1}$$  \hspace{1cm} (2)

$V_1$ is the volume of sugar prisms ($mm^3$) and $T$ is the toughness ($mj/mm^3$).

The firmness values at rupture point were determined by using the following equation:

$$Q = \frac{F}{D}$$  \hspace{1cm} (3)

$Q$ is the firmness (N/mm), $D$ is the deformation at rupture point (mm) and $F$ is the compression force (N).

The power requirement for cracking the prism (P) is:

$$P = \frac{E_a \times V}{60000 \times D}$$  \hspace{1cm} (4)

That $P$ is the rupture power (w) and $V$ is the loading rate (mm/min) and $D$ is the deformation at rupture point (mm) [7].

The modulus of elasticity is an index of the stiffness of sugar prisms. In this section it was measured using the central loading method. The formula used for the calculation of modulus of elasticity is:

$$E = \frac{Fl}{\delta A}$$  \hspace{1cm} (5)

Where $E$ is the modulus of elasticity (Mpa), $F$ is the load applied on the specimen (N), $I$ is the length of test prism (mm), $\delta$ is the longitudinal strain and $A$ is the cross sectional area ($mm^2$). [11,10];

3- Results and conclusions:

3-1- The rupture force:

Table 1 shows the results of the variance analysis the effect of location, velocity and their interaction on rupture force, energy, power, modulus of elasticity, toughness and firmness. The rupture force increased from bottom to top of the sugarloaf, from 132.9 to 212.1 N for soft and 198.2 to 243 N for hard sugar (Fig.5). Results of Duncan’s multiple range test shows that with increasing the loading velocity, from 1.24 to 100 mm/min, the mean values of rupture force were decreased from 162.09 to 117.71 N. The effect of specimen location had a significant effect on rupture force at 1% significance level and the effect of loading velocity had a significant effect at 5% significance level. The effect of top and middle location on rupture force was more than bottom location. One of the reasons can be the higher density at the top of the sugarloaf resulted from production process. Also the effect of the loading velocity at 1.24 mm/min was more than 50 and 100 mm/min. With the increase in loading velocity, the rupture force decreased that has incoherence with the results of Henry et al [5] that it may be because of brittle structure of sugarloaf.
3-2- Energy:

The increasing procedure of energy from bottom to top was significant for two kinds of sugarloaves. The required energy for hard sugar was 1.7 times more than soft sugar. The results of the variance analysis the effect of location and loading velocity was not significant but the effect of sugar kind was significant at 5% significance level. The results of this section were similar to Aktas et al. Aktas showed that the variety of almond with harder hull requires more rupture energy.

3-3- Power:

There was considerable difference between the required power for soft and hard sugarloaf. For soft type, the required power was equal for the location of sugarloaf (1.6 w), but for hard sugar power had considerable increment from bottom through up (1.4 to 8.6 w). The effect of sugar location and loading velocity was significant at 1% significance level. Results of Duncan’s multiple range test shows that effect of top and middle location on rupture power was more than bottom.

### Table 1: Results of analysis of variance

<table>
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<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F value</th>
<th>Prob</th>
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<td>(v x p)</td>
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<td>340.3</td>
<td>1.57</td>
<td>0.2264</td>
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<td>Error</td>
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<td>3913</td>
<td>217.4</td>
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<td><strong>Energy</strong></td>
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<td>(v x p)</td>
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</table>

Fig. 4: Effect of the position and velocity on force.

Fig. 5: Variation of the compression force, as function of The position and sugar type.
3-4. *Modulus of elasticity:*

Modulus of elasticity was increased from bottom to top of the sugarloaf from 37.4 through 64.4 Mpa for soft and 49.2 through 84.9 Mpa for hard sugar (fig.11). Specimen location had significant effect on Modulus of elasticity at 1% significance level, but loading velocity had not. With increasing velocity from 1.24 to 100 mm/min the mean values of Modulus of elasticity was decreased from 34.1 to 23.73 MPa.
3-5- **Toughness:**

Toughness increased from bottom (72.1 mj/mm$^3$ for hard sugar and 45.8 mj/mm$^3$ for soft sugar) to the top (111 mj/mm$^3$ for hard sugar and 68.7 mj/mm$^3$ for soft sugar) of the sugar loaf. Loading velocity and specimen location had no significant effect on toughness. Toughness for middle location of sugar loaf was more than two other locations. Also with increment in loading velocity (from 1.24 to 100 mm/min), toughness decreased from 0.069 to 0.0505 mj/mm$^3$.

3-6- **Firmness:**

Firmness varied from bottom (840 mj/mm$^3$ for hard sugar and 411 mj/mm$^3$ for soft sugar) to the top (111 mj/mm$^3$ for hard sugar and 68.7 mj/mm$^3$ for soft sugar) of the sugar loaf. Loading velocity had not significant effect on firmness but specimen location had. The effect of top location on firmness of sugar loaf was more than two other locations.

![Fig. 10: Effect of the position and velocity on modulus of elasticity.](image1)

![Fig. 11: Variation of the modulus of elasticity, as a function of The position and sugar type.](image2)

![Fig. 12: Effect of the position and velocity on toughness.](image3)
Fig. 13: Variation of the toughness, as a function of the position and sugar type.

Fig. 14: Effect of the position and velocity on firmness.

Fig. 15: Variation of the firmness, as a function of the position and sugar type.

4- Conclusion:

Studying the combined influence of velocity and location, showed that the mean values of rupture force, energy, toughness, firmness and modulus of elasticity for soft Sugarloaf samples were 79.6-295.5 N, 14.7-61.9 (mj), 0.029-0.123 (mj/mm3), 139.2-1154.1 (N/mm) and 24.6-92.7 (Mpa), respectively. Corresponding values for hard samples were 131.2-308.3 N, 20.8-83.6 (mj), 0.0416-168 (mj/mm3), 428.2-624.4 (N/mm) and 34.4-108.1 (Mpa), respectively. Velocity had significant effect
on force and power, but location was significant on power, firmness and toughness. Their interaction was significant on toughness and modulus of elasticity. With increasing the loading velocity, from 1.24 to 100 (mm/min), the mean values of modulus of elasticity and energy were decreased from 34.1 to 23.7 (Mpa) and 68.3 to 44.6 (mj), respectively.

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**References**