



## Use of automatic tensile testing machines for assessing the strength properties of packaging materials for baked confectionery products

### Uso de máquinas automáticas de ensayos de tracción para evaluar las propiedades de resistencia de los materiales de envasado para productos de confitería horneados

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#### ABSTRACT

The authors conducted this study to assess the influence of the strength properties of packaging materials for baked confectionery products on the tensile strength, fracture strength, and elongation level. The purpose of this study was to evaluate the mechanical properties (impact strength, fracture strength, and distance to fracture). The paper presents a brief overview of modern methods of functional and operational properties control for polymer packaging materials used for food products and describes their features. The objects of the study were samples of packaging for gingerbread purchased from trade organizations. It has been shown that quality control of polymer packaging materials for food is key in determining the possibility of their intended use. The test results allow evaluating the possibilities and limitations, optimizing the technological process, and obtaining high-quality packaging. In conclusion, the authors give recommendations to gingerbread manufacturers to increase the competitiveness of the product and meet consumer demand.

**Keywords:** packaging; strength characteristics; freshness and safety; consumer demand satisfaction.

#### RESUMEN

Los autores realizaron este estudio para evaluar la influencia de las propiedades de resistencia de los materiales de empaque para productos de confitería horneados en la resistencia a la tracción, la resistencia a la fractura y el nivel de elongación. El propósito de este estudio fue evaluar las propiedades mecánicas (resistencia al impacto, resistencia a la fractura y distancia a la fractura). El documento presenta una breve descripción de los métodos modernos de control de propiedades funcionales y operativas para los materiales de envasado de polímeros utilizados para productos alimenticios y describe sus características. Los objetos del estudio fueron muestras de envases para pan de jengibre comprados a organizaciones comerciales. Se ha demostrado que el control de calidad de los materiales de envasado de polímeros para alimentos es clave para determinar la posibilidad de su uso previsto. Los resultados de las pruebas permiten evaluar las posibilidades y limitaciones, optimizar el proceso tecnológico y obtener empaques de alta calidad. En conclusión, los autores dan recomendaciones a los fabricantes de pan de jengibre para aumentar la competitividad del producto y satisfacer la demanda de los consumidores.

**Palabras claves:** embalaje; características de resistencia; frescura y seguridad; satisfacción de la demanda del consumidor.

## 1. INTRODUCTION

Interest in gingerbread has increased significantly in recent years, which has led to an expansion of the assortment and an increase in its production volumes. The market of baked confectionery products, in terms of sales, is currently the largest segment of the Russian confectionery market. Due to the relatively low price on average for products, this segment is the most affordable one for most Russian consumers. The main confectionery product manufacturers are large bakeries, confectionery factories, and confectionary plants. Most often, the largest part of the products is distributed in the region where the enterprise is located (Klimov, 2015; Naumova, 2015).

Gingerbread products are the object of numerous studies related to improving their quality, where issues of freshness and preservation are of no small importance. The shelf life is a reflection of a whole set of indicators of the quality of the raw materials used, the parameters of the technology, the equipment used, the sanitary condition of production and storage conditions, and the quality of packaging. The latter, in turn, is crucial, since the packaging is a factor that ensures the qualitative characteristics of the product group in question. Modern packaging not only allows for preserving the integrity and freshness of baked confectionery products but also minimizes harmful effects and ensures product sterility (Chernaya et al., 2016).

A competent choice of packaging material is of great importance for the subsequent storage of packaged products. When choosing a packaging material, it is necessary to consider the assortment, weight, physicochemical properties, and expected shelf life of products.

The following basic requirements are imposed on all types of packaging by manufacturers: packaging safety; environmental properties of packaging; reliability; compatibility; interchangeability; and economic efficiency (Chernaya et al., 2016; Ermolaeva et al., 2020; Rossieva et al., 2017).

An important problem of the baking industry is bread staling, which is accompanied by several complex processes occurring in high-polymer compounds of bread crumbs and leading to the deterioration of its structural and mechanical properties (Cazón et al., 2018; Amza et al., 2014). A similar problem is typical for gummy gingerbread (Calligaris et al., 2007; Romani et al., 2012; Vitali et al., 2009).

Gingerbread packaging requires protection from oxygen and high humidity. Although it is stable during storage, spoilage can sometimes occur, which is mainly associated with lipid oxidation and water absorption, leading to textural changes (Robertson, 1994; Galić et al., 2009; Smith et al., 2004).

Lipid oxidation causes the development of primary and secondary products. The primary products, such as hydroperoxides, are characterized by high instability and quickly decompose into a wide range of secondary products (Mandić et al., 2012), which, in turn, leads to the development of foreign odors and tastes that negatively affect the taste qualities of products and the shelf life of gingerbread (Smith et al., 2004).

To exclude or at least minimize the spoilage of gingerbread during storage, it is necessary to choose the appropriate packaging and work with materials with high barrier properties to environmental factors such as light, oxygen, and humidity (Robertson, 1994; Galić et al., 2009).

Therefore, the quality of packaging materials is of great importance to deter undesirable processes that cause loss of quality. Polypropylene is usually used as a polymer for gingerbread packaging. It can be produced in different forms, such as plain or opalescent, co-extruded, or coated on both sides with acrylic. The acrylic

coating is often used in combination with polyvinyl chloride (PVC)/polyvinylidene chloride (PVDC) copolymer because it provides a higher barrier for oxygen but also provides a stronger barrier effect for taste and aroma compared to conventional polypropylene (Robertson, 1994; Galić et al., 2009; Komprda et al., 2017).

The growing interest in the quality and safety of food products dictates the need to introduce new types of packaging that meet modern requirements. The introduction of smart packaging with touch sensors will allow monitoring of the condition of food products, reduce the amount of food waste, extend the shelf life and improve the overall quality of food products (Rossieva et al., 2017; Amza et al., 2014).

Advances in sensors and biosensors have made it possible to develop new materials, devices, and multifunctional sensor systems for food quality control (Robertson, 1994). The types of innovative environmentally safe packaging under development will not only reduce food waste and quality losses but also solve long-term problems of accumulation of environmentally resistant plastic waste, saving raw materials (Romani et al., 2012; Vitali et al., 2009).

The issue of the influence of packaging on the quality and safety of gingerbread remains particularly relevant, since the transportation of products is carried out over long distances, and this requires a guarantee of their safety, which determined the purpose and objectives of this work.

Currently, there is an increase in the use of bioplastics in the food packaging sector, which is very likely to displace synthetic plastic in the future (Mandić et al., 2012; Gavahian et al., 2020; Tölgyesi, Sharma, 2020; Minh et al., 2019; Stender, 2020).

Various innovative materials are already on the market, but research on innovative biological and/or biodegradable film continues. In particular, it is necessary to increase knowledge about the behavior of these materials in real environmental conditions to evaluate the interaction of food and packaging (Balestra et al., 2019; Deshwal et al., 2019; Uharceva et al., 2020; Rozhkov, 2020; Tveritnikova et al., 2019; Moeini et al., 2020).

We have studied the experience of scientists on the example of the study of the protective properties of the packaging of sweet shortbread cookies in the research laboratory of the Rajamangala University of Technology Phra Nakhon (Bangkok, Thailand). The conducted studies have shown the high efficiency of using combined packaging (polypropylene combined with colored cardboard) and choosing the optimal thickness of materials that ensure the long-term preservation of consumer properties of baked confectionery products.

However, the question of the impact of packaging on the quality and safety of gingerbread remains poorly understood, which determined the purpose of this work.

The purpose of the study is to assess the reliability of packaging for baked confectionery products of various types at the operational stage by testing the packaging strength properties.

## **2. MATERIALS AND METHODS**

The objects of the study were samples of packaging for gingerbread purchased from trade organizations (Figure 1):

– a pastry tray made of corrugated cardboard covered with a polymer film (sample No. 1);

- a cardboard box with a plastic compartment insert made in the form of a pallet with cells for products inside the box, sealed in a polyethylene pouch (sample No. 2);
- a polyethylene pouch (sample No. 3).



Sample No. 1 The pastry tray made of corrugated cardboard covered with food film



Sample No. 2 The cardboard box with a plastic compartment insert in the form of a pallet with cells for products inside the box, sealed in polyethylene



Sample No. 3 The polyethylene pouch  
Figure 1. Photos of packaging samples

The experimental studies were carried out in the engineering center of the Institute of Engineering Technologies of the Federal State Budgetary Educational Institution of Higher Education (FGBOU VO) "Kemerovo State University".

The tests were run on the confectionery cardboard tray and polymer film (sample No. 1), the cardboard box, the compartment insert, the pouch (sample No. 2), and the other pouch (sample No. 3). When performing the study, we used measurement analysis methods. The technical requirements were determined under:

- State Standard (GOST) 13512 "Corrugated cardboard boxes for confectionery";
- GOST 52903 – 2007 "Pouches made of polymer films and combined materials";
- GOST 10354-82 "Polyethylene film. Technical conditions".

We visually assessed the presence of defects in packaging samples. The main parameters and dimensions of the package and the seal width of the polymer film pouch were determined by a ruler according to GOST 427 with an error of 0.5 mm. The strength properties of the film were determined on an automatic tensile testing machine Labthink XLW (PC) according to the following indicators: tensile strength, elongation at

fracture, and a strength test of the pouch seal according to GOST 14236. All tests also met the international requirements of the Deutsche Institut für Normung (DIN) standard DIN 53363. Determining the tear resistance of plastic film and sheeting by the trouser tear method, DIN 55529-2012.

The seal airtightness of the pouches was analyzed according to GOST 19360.

XLW (PC) professional automatic tensile testing machine (Fig. 2) developed under international standards, was designed to study physical properties, to determine the strength properties during tensile and fracture tests, peeling and elongation tests at fracture, and to determine the seal quality.

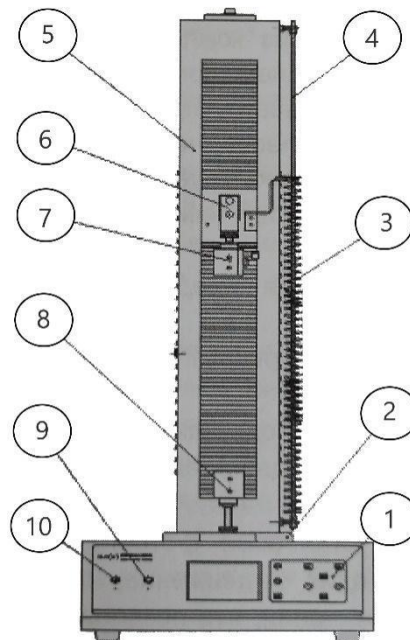


Figure 2. The device diagram

1. Control unit. 2. Support stand. 3. Spiral gas tube. 4. Guide rod. 5. Device body. 6. Tension sensor. 7. Upper clamp. 8. Bottom clamp. 9. Upper grip valve. 10. Lower grip valve.

The equipment has an accuracy of 0.5% of the full-scale range and a range of test speeds from 50 mm/min to 500 mm/min. The tester has a pad length of 1000 mm and can have a load capacity of 50N or 500N. It is equipped with a standard gripper that measures a sample width of 30 mm. The sample is tightly mounted with a pneumatic sample clamp to ensure the accuracy of the test results. The device has different ranges of load sensors and 7 different testing speeds to meet different testing requirements. The device is controlled by a microcomputer with a user menu interface. It has smart designs of overload protection, automatic position reset, and power failure memory for safe test operation. It is equipped with an RS232 port and a micro printer port, which is convenient for data transfer and personal computer (PC) connection. The professional operating software supports statistical analysis of group samples, analysis of overlapping test curves and historical data comparison functions, as well as multi-functional options for parameter setting, printing, querying, cleaning, calibration, etc.

#### *Experiment design*

All studies were carried out in laboratory conditions at a temperature of  $23 \pm 2^\circ\text{C}$  and relative humidity of  $50 \pm 5\%$ .

A pre-prepared sample was placed between two grippers that moved in a relative direction during the test. Changes in force and displacement were separately recorded by a load sensor mounted on the drive gripper and the integrated displacement sensor. The tensile strength, fracture strength, and elongation were obtained by further calculation.

The strength tests were carried out on samples 15-20 mm wide and at least 150 mm long.

The arithmetic mean of the five tests was taken as the final result.

### 3. RESULTS

First of all, obvious defects were identified in the packaging samples, the presence of which could affect the change in strength characteristics:

It was observed that the pastry tray made of cardboard covered with food film had no mechanical damage and the film fit snugly on the tray. When assessing the appearance of the film, it was noted that the film was clean, without cracks, pressed folds, tears, and holes, which met the requirements of the normative document GOST 10354.

When visually evaluating the polyethylene pouch, it was noted that the pouch was clean, without mechanical damage, with no cracks, tears, or holes on the surface. The pouch seal was airtight and smooth along the entire length, without burnt places and folds, and the seal width was 10 mm (no more than 30 mm), which met the requirements of GOST R 52903.

When assessing the appearance of sample No. 3, the absence of contamination, mechanical damage, and package integrity were observed. The inner pouch was clean, with no tears and damages. The seal width of the inner pouch was 10 mm.

The results of the evaluation of the parameters and dimensions of the packaging samples are shown in Table 1. When determining the dimensions, it was considered that the maximum deviation from the dimensions of the cardboard tray and cardboard box should not exceed  $\pm 10\text{mm}$  in length and width, and the dimension error for the pouches should be no more than 0.5 mm.

Table 1. Parameters and dimensions of packaging samples

Sample name	Internal/external dimensions, mm			Thickness, mm
	length	width	height	
No. 1 Cardboard tray film	380	280	85	0.360 0.010
No. 2 cardboard box Pouch	230	100	55	0.150 0.044
No.3 Pouch	215	160	0.080	0.040

The evaluation of the parameters showed that the nominal thickness of one of the samples (film, sample 1) was lower than the parameters set in GOST 10354-82.

At the same time, the seal width in the pouch of samples No. 2 and No. 3 was 10 mm.

The airtightness control of the pouches in sample No. 2 and sample No. 3 was determined by filling the suspended pouch with ½ of the volume with water (20±5°C) and leaving it for 30 minutes.

The airtightness assessment showed that after the tests there was no seal fracture or leak, which corresponded to the normalized requirements.

To test the strength characteristics on an automatic tensile testing machine, the samples were prepared according to the set parameters (Table 2).

Table 2. Set parameters

Sample number	Packaging material	Length, mm	Thickness, mm	Width, mm	Speed, mm/min
Sample 1.	food film	61	0.010	23	500
	corrugated cardboard	61	0.360	5.8	500
Sample 2.	polyethylene	35	0.040	26	500
Sample 3.	polyethylene	60	0.044	26	500
	cardboard	60	0.150	5.5	500

The tensile and fracture strength of the samples was evaluated. The results are shown in Figure 3.

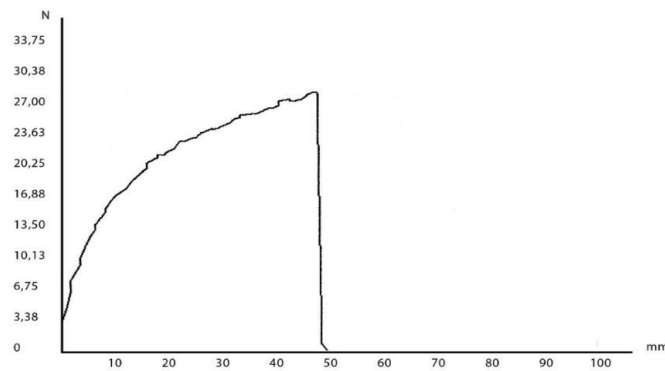


Figure 3. Stretching diagram of sample 1 (food film)

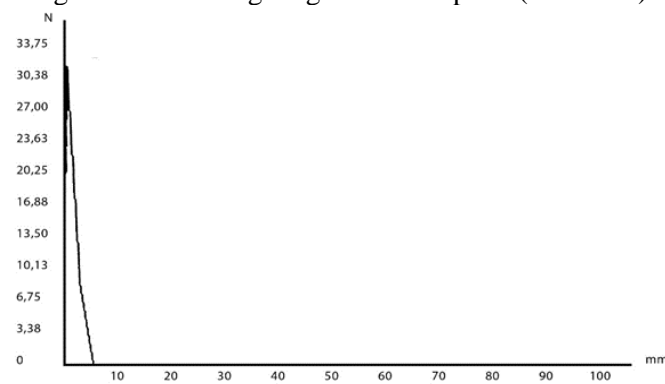


Figure 4. Stretching diagram of sample 1 (corrugated cardboard)





a: food film



b: corrugated cardboard

Figure 5. Tensile and fracture test of sample 1

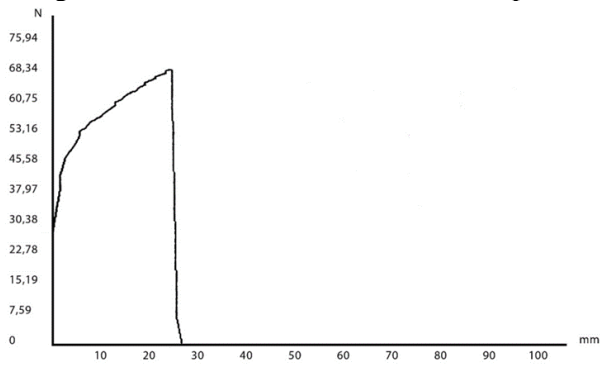


Figure 6. Stretching diagram of sample 2 (polyethylene)



Figure 7. Tensile and fracture test of sample 2 (polyethylene)



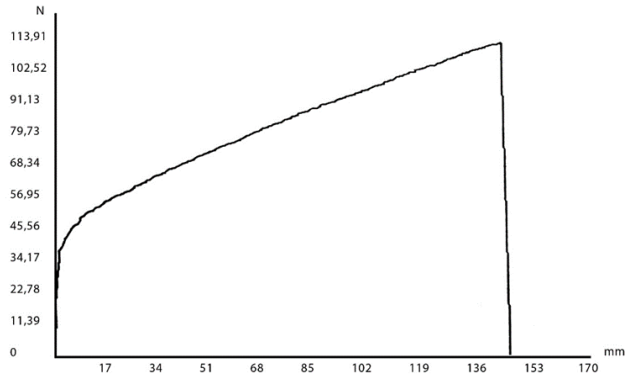


Figure 8. Stretching diagram of sample 3 (polyethylene)

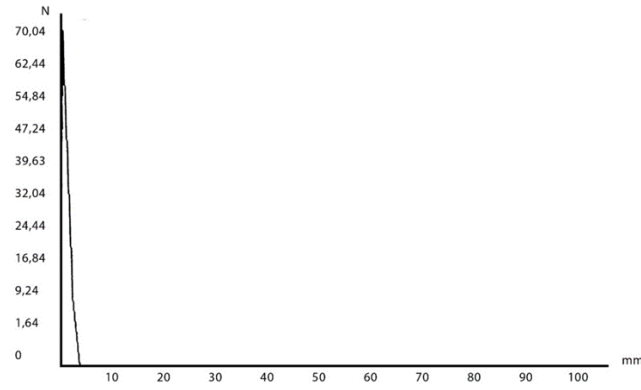
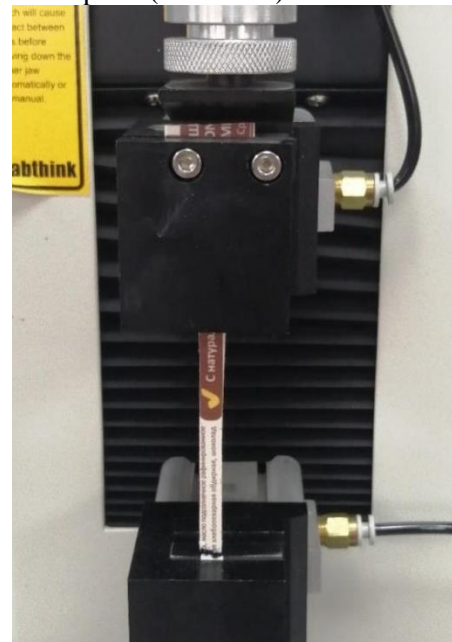


Figure 9. Sample stretching diagram of sample 3 (cardboard)



a: polyethylene



b: cardboard

Figure 10. Tensile and fracture test of sample 3

Table 3. Obtained results

Sample number	Packaging material	Maximum force, N	Stretching, mm	Tensile strength, kN/m	Relative elongation, %
Sample 1	food film	30.66±0.5	50±0.5	1.18±0.4	81.96±0.5
	corrugated cardboard	32.07±0.5	4±0.5	8.59±0.4	6.56±0.5
Sample 2	polyethylene	72.09±0.5	26±0.5	2.77±0.4	74.28±0.5
Sample 3	polyethylene	111.77±0.5	147±0.5	4.3±0.4	245.0±0.5
	cardboard	70.04±0.5	3±0.5	12.73±0.4	5±0.5

According to the documentation, the fracture force for the samples of the presented packages shown in Table 3 corresponds to the permissible normal tensile stress. The fracture strength according to the results of our tests and calculations according to the GOST 14236-81 method corresponds to the standards established in GOST 10354-82 for the brands under study.

The average values of the elastic modulus given in the reference and scientific literature (Beldie, 2001) and accepted for preliminary calculations were 3578.5 MPa in the direction along the rolling of the cardboard roll, 0, 5, 10, 15, 20, 25, 30, 35; 0, 3, 6, 9, 12, 15 along across F, H y, mm 53, and in the direction across the rolling of the roll they equaled 1367.8 MPa. As a result of our calculations, it was obtained that these values for the used cardboard of the P-35 brand were close, which makes it possible to use a model of material with isotropic properties when performing calculations.

The performed computer simulation made it possible to determine the stress-strain state of the packaging elements. The calculation results showed that at maximum amplification, damage to the cardboard box was observed due to the action of shear stresses. The results of finite element modeling showed that, for example, sticking adhesive tape allowed for a more uniform distribution of stresses arising in contact between the packaging tape and cardboard. This will make it possible to avoid a cardboard box breakout.

It was also determined that the real value of the maximum elongation of sample 1 was 81.96%, although the documentation indicated a value of at least 100%.

The value of the maximum elongation of sample 2 was 73%, which does not correspond to the values specified in GOST for grades with a thickness from 0.03 mm to 0.10 mm, equal to at least 200%. Thus, the film of samples 1 and 2 had lower strength characteristics than specified. This may cause the film to break and cause mechanical damage during transportation.

The value of the maximum elongation of sample 3 was 245.0%, which corresponded to the values specified in GOST (at least 200%).

#### 4. CONCLUSION

The analysis of the strength characteristics of the tested types of packaging showed that the cardboard tray (sample No. 1) and the cardboard box (sample No. 3) had high tensile, fracture, and elongation strength properties, which contributes to the long-term preservation of the quality characteristics of packaged products during their transportation and consumption. The polyethylene pouch (sample No. 2) and the film of sample No. 1 had lower strength properties, which must be considered when transporting and storing products in such types of packaging. Considering that the cardboard tray has a capacity of 10 kg of finished products, it is desirable to use a film with higher strength characteristics, and in the case of multilayer packaging (sample No. 3), on the contrary, polyethylene of lower strength can be used, which will affect the reduction of the cost of finished products.

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## CRITERION OF AUTHORSHIP

I. Yu. Reznichenko and S. S. Komarov were the project leaders. All the authors took part in the study, data processing, and the writing of the final text.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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