RESEARCH ON OVERSIZED LOAD PACKAGING

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Abstract. Modern packaging is rapidly developing in all industries. The development of packaging in agriculture, processing, and construction industries is intensive due to a significant share of large-sized cargo (styrofoam plates, rolls of mineral wool, fuel briquettes from agricultural and forest biomass, etc.). Therefore, the urgent task is to create equipment for high-quality packaging of large cargoes. During the large-size packaging process, the stretched film is welded. One of the problems is the need to tighten the package with a film, to ensure the density and strength of the welds, which will withstand the stretching of the film after sealing the formed package. The design of such machines is specific because it includes both the mechanisms of forming the package and the mechanisms of wrapping it with a film followed by welding. A model of the process of welding polymer films with a thickness of 25-200 µm was built, which describes the dependence of the quality indicators of the packaging on the technological modes - the temperature of the heater, the duration of welding, and the pressure during welding. The welding contact pressure depends on the viscosity of the packaging material and its softening temperature, and it is greater for a higher viscosity of the material. It should be noted that pressure affects the strength of welds at low heater temperatures and short heating durations. At the heater temperatures of 250 - 290°C, the pressure practically does not affect the strength of the welds. Analysis of the deformation properties of the films shows that the amount of tensile stress for these films in packaging equipment should not exceed 10-12 MPa. Deformation of 5-7% for polyethylene films is completely reversible, if this threshold is exceeded, the film package will lose its shape. A new roller mechanism for welding and cooling the film is described. An experimental setup has been developed for researching the process of packing large cargoes. The dependence of the quality of the welding seam of the packaging film on the temperature and force of its welding, as well as on the duration of heating and cooling of the seam, was determined experimentally.

Keywords: packaging, cargo, film, tightening, welding.

Introduction

The modern packaging industry is one of the most dynamically developing industries. The development of packaging in agricultural and construction production is particularly intense due to the large share of large-sized cargo (plates, rolls, etc.). This made it necessary to improve the equipment for packing large cargoes. The task of designing machines for large-sized packaging is a complex problem. Therefore, the urgent task is to create equipment for high-quality packaging of large cargoes. During the large-size packaging process, the stretched film is welded. One of the problems is the need to tighten the package with the film, to ensure the density and strength of the welds, which will withstand the stretching of the film after sealing the formed package. The design of such machines is specific because it includes both the mechanisms of forming the package and the mechanisms of wrapping it with the film followed by welding.

We will analyse the structure of the generalized design of the installation for packing large-sized cargo (Fig. 1), and conduct a synthesis of its layout options from the main mechanisms identified during the analysis [1].

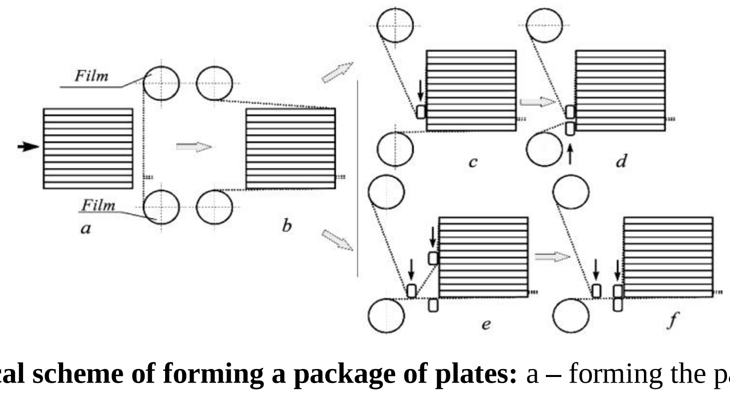

Fig. 1. **Technological scheme of forming a package of plates:** a – forming the package; b – feeding, c – wrapping with a film; d – pressing and welding; e – wrapping with the film and clamping its ends; f – tightening and welding of the package

The technological operation of packing plates consists of the following technological and auxiliary transitions:

1. Formation of the set (Fig. 1, a). Slabs in the given quantity.
2. Feeding the formed package (Fig. 1, b) for covering with a film from three sides.
3. Final free formation of the package (Fig. 1, c) or with its collection (Fig. 1, e).
4. Welding the package and cutting the finished package from the roll film material (Fig. 1, d or Fig. 1, e).
5. Removal of the formed and packed package from the table of finished products.

Materials and methods

In order to calculate the parameters of the tightening mechanism, it is necessary to determine the value of the maximum elongation of the wrapping film material within the limits of its plasticity, check the correspondence between theoretical values of the tensile force of the film material and experimental values, determine how much the material can be stretched so that it returns to its original position after the load is removed, and what maximum force is required for this.

Mathematical planning of the experiment with fractional plans is used to determine the dependences of the strength, tightness, and waviness of film-welded polymer seams [2-6] on the temperature of the heater, the pressure during heating, the duration of heating, and the duration of cooling of the weld.

This article describes only the strength research of film welded polymer seams.

To increase the accuracy of the results, 4 parallel experiments were conducted to reduce the measurement error by a factor of 2. The reproducibility of the experiments was checked based on the results of the dispersion of parallel experiments and the Cochrane test.

Mathematical processing of the research results is carried out according to standard methods using statistical criteria.

The main technological factors in the formation of packaging, i.e. welding of tight film material, are the heater temperature T, heating pressure p_w, cooling pressure p_c, heating time t, holding time under pressure after welding t_c.

Preliminary studies have shown that overlap seams are used mainly for longitudinal welding of the bag, and T-shaped seams are used for transverse welding. We have found that T-shaped seams mainly determine the strength and tightness of packages, so the experimental part is devoted to the study of T-shaped seams.

To carry out experimental studies of the process of welding the film material, an experimental installation of thermopulse welding of film materials was developed (Fig. 2).

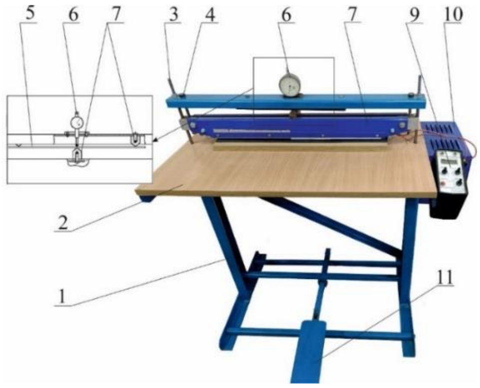

Fig. 2. **General view of the installation for researching the welding parameters of film materials**

It has a welding element in the form of a nichrome tire and a cutting element in the form of a nichrome string. It consists of a frame 1, working table 2, system of rods and levers 3, console 4, flat spring 5, indicator 6, system of cones 7, combined welding jaws 8, control panel 9, power supply unit 10 and a pressure pedal 11.

We calculate the relative strength of the welded joint using the expression [6-7]:

$$\delta_{sm} = \frac{\delta_{s.w}}{\delta_{s.m}}, \tag{1}$$

where $\delta_{s.w}$ – tensile breaking force of the weld, N/15mm;
$\delta_{s.m}$ – tensile breaking force of the base material, N/15mm.

The seam is considered suitable for strength if $0.7 < \delta_{s.m} < 1.0$.

The preliminary analysis of the experimental results showed that it is advisable to present the mathematical model of the welding process in power form:

$$\begin{aligned} \delta_{sm} &= b_{01} \cdot T^{b11} \cdot t_h^{b21} \cdot p_w^{b31} \cdot h^{b41} \cdot (T \cdot t_h)^{b51} \cdot (T \cdot p_w)^{b61} \cdot (t_h \cdot p_w)^{b71} \\ W_{z.sm} &= b_{02} \cdot T^{b12} \cdot t_h^{b22} \cdot p_w^{b32} \cdot h^{b42} \cdot t_c^{b52} \cdot (t_h \cdot h)^{b62} \cdot (T \cdot h)^{b72} \\ \zeta_{sm} &= b_{03} \cdot T^{b13} \cdot t_h^{b23} \cdot p_w^{b33} \cdot h^{b43} \cdot (T \cdot t_h)^{b53} \cdot (T \cdot p_w)^{b63} \cdot (t_h \cdot p_w)^{b73} \end{aligned} , \quad (2)$$

where δ_{sm} – strength of the welded seams of the packaging film, H/15 mm;
$W_{z.sm}$ – height of the waviness of the seams of the packaging film, µm;
ζ_{sm} – tightness of film packaging, MPa;
T – temperature of the heater, ºC;
t_h – heating time, s;
p_w – specific clamping force, MPa;
h – film thickness, µm;
t_c – cooling time in the compressed state after welding, s.

Limits of parameter changes when welding film materials:

T_n = 130÷250 ºC; t_n = 2÷5 s; p_w = 0.1÷0.2 MPa; h = 40÷80 µm, t_h = 1÷3s.

The reproducibility of the experiments was checked based on the results of 4 parallel experiments. An automated calculation program using Microsoft Excel spreadsheets was developed to process the results. The results of the samples were tested using Cochran's C, Student's T and Fisher's tests. The equation of the response function of the strength of polyethylene film welds obtained for tire welding was obtained:

$$\begin{aligned} \delta_{sm} &= \frac{T^{6.3501179} \cdot h^{0.79636764} \cdot t_h^{17.81217} \cdot t_h^{1.4233411 \cdot ln\, p_w}}{p_w^{1.6386835} \cdot e^{39.72553} \cdot t_h^{2.710338 \cdot \ln T}} \\ W_{z.sm} &= \frac{T^{1.254} \cdot h^{0.577} \cdot t_h^{1.113}}{t_c^{0.559} \cdot e^{5.784}} \\ \zeta_{sm} &= \frac{T^{3.2627} \cdot t_h^{(10.763 - 1.949 \cdot \ln(T))}}{e^{19.624}} \end{aligned} . \quad (3)$$

In Table 1, a comparison of the experimental values of the strength of flat weld with those calculated by the experimental response function is given.

Table 1

Comparative analysis of flat seam strength values strength, tightness, and waviness

Parameter					**Strength of flat weld, N/15 mm**			**Waviness of flat weld seam, $W_{z.sm}$, µm**			**Tightness of flat weld seam ζ_{sm}, MPa**		
T	t_h	p_w	h	t_c	**Exper.**	**Calc.**	**Δ, %**	**Exper.**	**Calc.**	**Δ, %**	**Exper.**	**Calc.**	**Δ, %**
250	5	0.2	80	5	11.30	10.579	6.4	95.585	93.75	1.9	0.212	0.2	5.9
130	5	0.2	40	1	1.85	1.660	10.3	69.409	65.00	6.4	0.196	0.2	2.2
250	2	0.2	40	1	3.95	3.659	7.4	56.827	58.75	3.4	0.212	0.2	5.9
130	2	0.2	80	5	0.40	0.341	14.7	15.181	16.25	7.0	0.061	0.065	6.8
250	5	0.1	40	5	3.65	3.876	6.2	64.073	66.25	3.4	0.212	0,2	5.9
130	5	0.1	80	1	1.70	1.835	7.9	103.546	115.00	11.1	0.196	0.1725	11.9
250	2	0.1	80	1	9.35	9.985	6.8	84.776	85.00	0.3	0.212	0.2	5.9
130	2	0.1	40	5	0.30	0.309	3.0	10.176	12.50	22.8	0.061	0.055	9.6

To facilitate visual perception and ease of use, we will carry out a graphic analysis (Fig. 3) of the dependence, constructed based on the results of experimental studies of the height of the waviness of the film material of the weld seam.

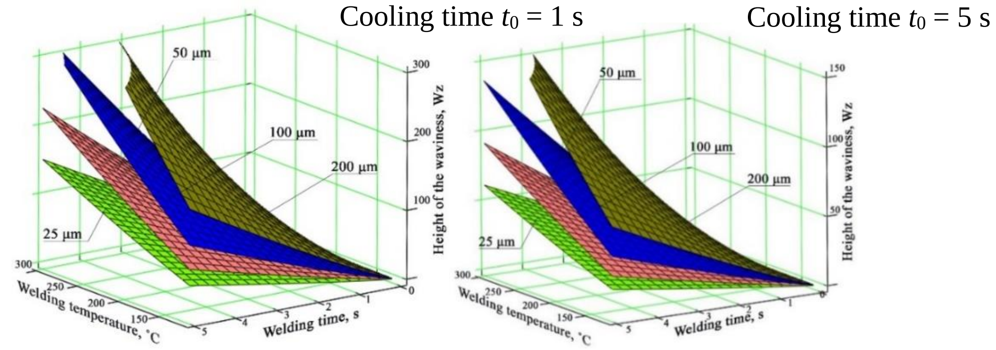

Fig. 3. **Dependence of waviness of flat weld on the duration and temperature of welding at different cooling times for different film thicknesses (25, 50, 100, and 200 µm)**

From the graph in Fig. 3 it can be seen that with an increase in the temperature, duration of welding, thickness of the film material, and a decrease in the duration of cooling of the seam, the waviness of the film material increases. Moreover, it is the welding temperature that has the greatest influence on the phenomenon of waviness.

Fig. 4 presents graphs of the dependence of the amount of waviness on the duration of welding and cooling at different welding temperatures (for example, 200 ºC and 300 ºC) for different film thicknesses (25, 50, 100, 200µm, respectively, from the bottom to the top), and on the graphs (Fig. 4, b, and 4, c) the cooling time is presented in the range of 0÷1 s.

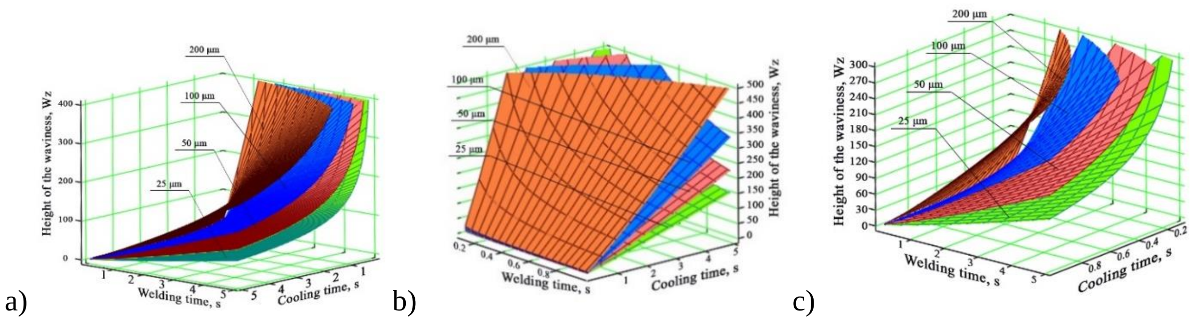

Fig. 4. **Dependence of the amount of waviness on the duration of welding and cooling at different welding temperatures for different film thicknesses:** a, b – 300 ºC; c – 200 ºC)

To facilitate visual perception and ease of use, we will conduct a graphical analysis (Fig. 4) of the dependence (3), constructed based on the results of experimental studies of the tightness of film packaging.

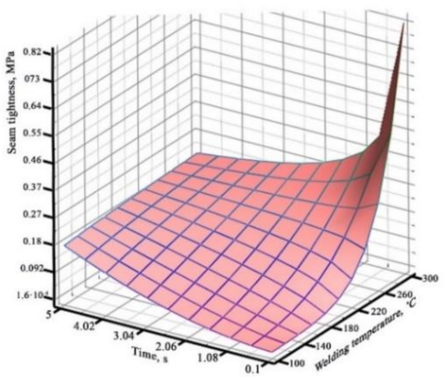

Fig. 5. **Dependence of tightness of polyethylene packages on the duration and temperature of welding**

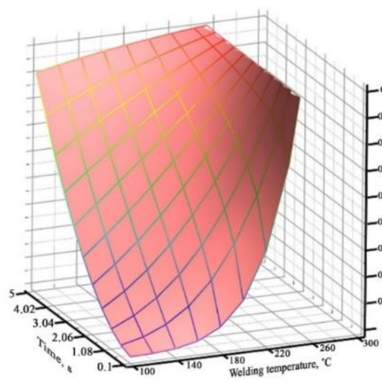

Fig. 6. **Partial dependence of tightness of polyethylene packages on the duration and temperature of welding**

Analysing the results of the experimental research on the tightness of polymer bags, we can see that the tightness directly proportionally depends only on the temperature and duration of welding.

For a clearer graphic analysis, let us limit the tightness to its value of 0.2 MPa (Fig. 6).

The graph above shows that the required tightness is always achieved at a temperature of the welded elements above 245 ºC. With welding times of up to 2 seconds, the tightness depends more on the welding time, while with longer welding times, this dependence becomes less pronounced.

Results and discussion

Based on the results of the research, the welding mechanism was improved (Fig. 7).

The device for packing large loads includes a wrapping film feeding mechanism, load feeding mechanism on the wrapping table 1, welding mechanism 2 of the wrapped package with a pressure sponge 3 and a counter pressure 4, tightening unit 5 with a pressure roller 6, which is placed on one rocker 7 with a pressure sponge 3, opposite the support jaw 8. The package welding mechanism was improved.

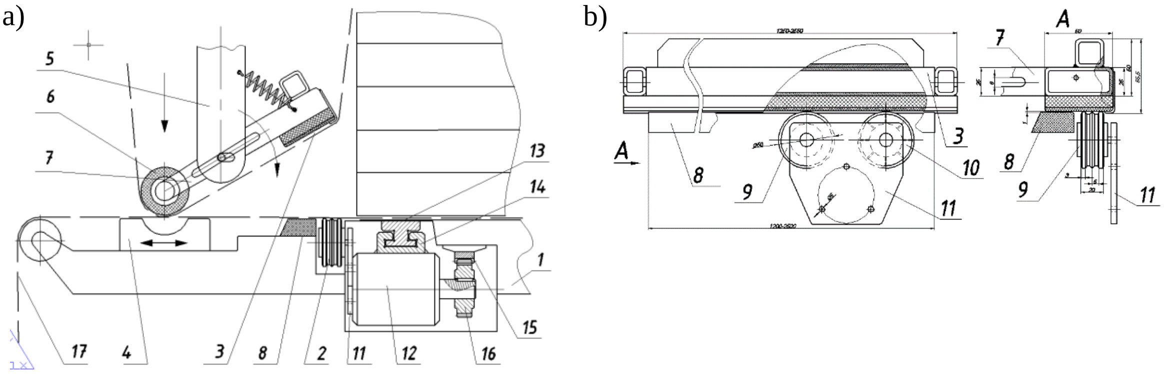

Fig. 7. **General view of the package wrapping, closing and welding unit (a) and view of the welding mechanism at the moment of contact – the side and the frontal view of the welding mechanism(b):** 1 – stretching table; 2 – welding mechanism; 3 – pressure jaw; 4 – counter pressure; 5 – tightening unit; 6 – pressure roller; 7 – support arm; 8 – support jaw; 9 – constant heating roller; 10 – cooling roller; 11 – bracket; 12 – motor – gearbox; 13 – guide bar; 14 – carriage; 15 – rail gear; 16 – gear; 17 – packaging film

This mechanism consists of sequentially located welding 9 constant heating and cooling 10 rollers, which are fixed on the bracket 11 with the possibility of free rotation and forming contact with the pressure sponge 3 until the end of the seam. On this bracket 11, an engine is fixed - a reducer 12, which moves the entire welding mechanism 2 in the transverse direction with the help of a guide 13 with a carriage 14 and a rail gear 15 through the gear 16. The packaging of goods is carried out with a wrapping film 17.

The device for packing bulky goods works as follows. The formed large package of cargo is fed by the cargo feeding mechanism to the wrapping table 1. The wrapping material, which is unwound from the upper and lower rolls, wraps the cargo from three sides.

After returning the feed mechanism to its initial position, the package tightening unit 5 moves vertically and completes wrapping and closing the load along the perimeter, that is, from the last, fourth side.

The new technical result is expressed in the improvement of the quality of the weld seam of a considerable length, reliability, and stability of the welding mechanism of the device for packing large-sized packages.

Conclusions

1. A model of the process of welding polymer films with a thickness of 25-200 μm was built, which describes the dependence of the quality indicators of packaging (strength, tightness and waviness of the seam) on the technological modes – the temperature of the heater, the duration of welding and the pressure during welding.
2. The strength of the seam increases with an increase in the duration and temperature of welding, the thickness of the films and the force of their pressing.

3. The tightness of the seam is directly proportional to the temperature of the heater and the duration of welding.
4. The welding contact pressure depends on the viscosity of the packaging material and its softening temperature, and it is greater for a higher viscosity of the material. It should be noted that the pressure affects the strength of welds at low heater temperatures and short heating durations. At the heater temperatures of 250-290 °C, the pressure practically does not affect the strength of the welds.
5. Analysis of the deformation properties of the films shows that the amount of tensile stress for these films in packaging equipment should not exceed 10-12 MPa. Deformation of 5-7% for polyethylene films is completely reversible, if this threshold is exceeded, the film package will lose its shape.

Author contributions

Conceptualization B.V.; methodology, M.T. and N.T.; software, Y.F.; validation, B.V. and Y.F.; formal analysis, M.T. and N.T.; data curation, B. V. and Y.F.; writing – original draft preparation, B.V.; writing – review and editing, B.V. and Y.F.; visualization, Y.F.; project administration, B.V. All authors have read and agreed to the published version of the manuscript.

References

[1] Valetskyi B. Structural optimization of packaging machines with film welding mechanisms. Scientific journal “Computer-integrated technologies: education, science, production”. Issue 8. Lutsk, 2012. pp. 135-139.
[2] Morris B. A. Application of modeling to speed flexible package development. Journal of Plastic Film & Sheeting, 2013, 29(3), pp. 249-270. DOI: 10.1177/8756087913477857
[3] Qiu J., Zhang G., Sakai E., Liu W., Zang L. Thermal Welding by the Third Phase Between Polymers: A Review for Ultrasonic Weld Technology Developments, 2020, Polymers, 12(4): 759. DOI: 10.3390/polym12040759
[4] Yasuo H., Umaru I., Wai Y.L., Hiroyuki H., Tetsuya T. Effect of heat-sealing temperature on the failure criteria of oriented polypropylene/cast polypropylene heat seal. Polymer Engineering & Science, 46, 2006, pp. 205-214. DOI: 10.1002/pen.20452
[5] Papathanasiou T. K., Markolefas S. I., Filopoulos S. P. and Tsamasphyros G. J., Heat transfer in thin multilayered plates - Part I: A new approach, Journal of Heat Transfer, 133 (2011), 021302 (9 pages). DOI: 10.1115/1.4002630
[6] ASTM F2029, Standard Practices for Making Laboratory Heat Seals for Determination of Heat Sealability of Flexible Barrier Materials as Measured by Seal Strength. West Conshohoken: ASTM International, 2021. DOI: 10.1520/F2029-16R21
[7] Gellerich, P., Majschak, J-P. Pareto-based design of experiments for identifying and comparing optimum sealing parameters of heat sealing applications in packaging machines. TAPPI Journal, 2023, 22(6), pp. 383-397. DOI: 10.11822/springerhandbooks.9789811053899-17