OPTIMIZATION OF VALUES OF TECHNOLOGICAL PARAMETERS FOR OBTAINING THERMOPLASTIC POLYMER COMPOSITION FOR BOTTOM SHOES

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OPTIMIZATION OF VALUES OF TECHNOLOGICAL PARAMETERS FOR OBTAINING THERMOPLASTIC POLYMER COMPOSITION FOR BOTTOM SHOES

ABSTRACT. This work reveals the dependence of the composition and production parameters on the properties of a thermoplastic polymer composition based on a copolymer of ethylene with vinyl acetate and suspension polyvinyl chloride (EVA / PVC-S), as well as the choice of the optimal composition of the mixture and finding the optimal technological parameters for its production. Thermoplastic polymer-sole compositions were obtained by the method of thermomechanical mixing. To describe the properties of polymer - plantar compositions, depending on the ratio of components and technological parameters of obtaining, the method of mathematical planning – "Full factorial experiment" of type № = 2^k was chosen, which allows to obtain separate estimates of linear effects and two-, three-factor interactions. In this work, to build a mathematical model, the following factors were selected: the content of EVA in the composition, the temperature and mixing rate, and regression equations were used when obtaining a new type of shoe bottom material using a full factorial experimental method. Optimal results were obtained when the EVA content of the polymer composition was 15%, the mixing temperature was 185°C, and the mixing speed was 25 rpm. The strength and operational-technological indicators of the quality of a thermoplastic polymer composition for the bottom of footwear based on a copolymer of ethylene with vinyl acetate and suspension polyvinyl chloride have been determined. Regression equations for the dependence of the deformation-strength properties on the technological factors of the creation of polymer sole compositions are constructed. It has been proved that by selecting the optimal values of technological parameters it is possible to obtain a sole material with high deformation-strength and operational-technological characteristics.

KEYWORDS: copolymer of ethylene with vinyl acetate, suspension polyvinyl chloride, mathematical planning of the experiment, generalized quality indicator, desirability function.

OPTIMIZAREA VALORILOR PARAMETRILOR TEHNOLOGICI ÎN VEDEREA OBȚINERII UNUI COMPOZIT POLIMERIC TERMOPLASTIC PENTRU TĂLPI DE ÎNCĂLȚĂMINTE

REZUMAT. Această lucrare scoate în evidență dependența compoziției și a parametrilor de producție de proprietățile unui compozit polimeric termoplastic pe bază de copolimer de etilenă-acetat de vinil și clorură de polivinil în suspensie (EVA / PVC-S), precum și alegerea compoziției optime a amestecului și găsirea parametrilor tehnologici optimi pentru producerea acestuia. Compozitele polimerice termoplastice pentru tălpi au fost obținute prin metoda amestecării termomecanice. Pentru a descrie proprietățile compozitelor polimerice, în funcție de raportul dintre componente și parametrii tehnologici de obținere, s-a ales metoda de planificare matematică – „Experiment factorial complet" de tip № = 2^k, care permite obținerea unor estimări separate ale efectelor liniare și interacțiuni cu doi sau trei factori. În această lucrare, pentru a construi un model matematic, au fost selectați următorii factori: conținutul de EVA în compoziție, temperatura și viteza de amestecare, precum și utilizarea ecuațiilor de regresie la obținerea unui nou tip de material pentru tălpi de încălțăminte folosind un plan experimental factorial complet. S-au obținut rezultate optime atunci când conținutul de EVA al compoziției polimerice a fost de 15%, temperatura de amestecare a fost de 185°C și viteza de amestecare a fost de 25 rpm. S-au determinat rezistența și indicatorii operaționali-tehnologici ai calității unui compozit polimeric termoplastic pentru talpa încălțămintei pe bază de copolimer de etilenă-acetat de vinil și clorură de polivinil în suspensie. S-au dezvoltat ecuații de regresie care să indice dependența proprietăților de deformare și rezistență de factorii tehnologici ai procesului de obținere a compozitelor polimerice pentru tălpi. S-a dovedit că prin selectarea valorilor optime ale parametrilor tehnologici este posibilă obținerea unui singur material cu rezistență mare la deformare și caracteristici tehnologice operaționale.

CUVINTE CHEIE: copolimer de etilenă-acetat de vinil, clorură de polivinil în suspensie, planificarea matematică a experimentului, indicator de calitate generalizat, grad de dezirabilitate.

OPTIMISATION DES VALEURS DES PARAMÈTRES TECHNOLOGIQUES AFIN D'OBTENIR UNE COMPOSITION POLYMÈRE THERMOPLASTIQUE POUR LES SEMELLES POUR CHAUSSURES

RÉSUMÉ. Ce travail révèle la dépendance de la composition et des paramètres de production sur les propriétés d'une composition polymère thermoplastique à base d'un copolymère d'éthylène-acétate de vinyle et du chlorure de polyvinyle en suspension (EVA/PVC-S), ainsi que le choix de la composition du mélange et trouver les paramètres technologiques optimaux pour sa production. Des compositions polymères thermoplastiques pour les semelles ont été obtenues par la méthode de mélange thermomécanique. Pour décrire les propriétés des compositions polymère, en fonction du rapport des composants et des paramètres technologiques d'obtention, la méthode de planification mathématique – « Expérience factorielle complète » de type № = 2^k a été choisie, ce qui permet d›obtenir des estimations séparées des effets linéaires et interactions à deux ou trois facteurs. Dans ce travail, pour construire un modèle mathématique, les facteurs suivants ont été sélectionnés : la teneur en EVA dans la composition, la température et la vitesse de mélange, et on a utilisé les équations de régression lors de l'obtention d'un nouveau type de matériau pour les semelles pour chaussure en utilisant une méthode expérimentale entièrement factorielle. Des résultats optimaux ont été obtenus lorsque la teneur en EVA de la composition polymère était de 15 %, la température de mélange était de 185°C et la vitesse de mélange était de 25 tr/min. La résistance et les indicateurs opérationnels et technologiques de la qualité d'une composition de polymère thermoplastique pour les semelles à base d'un copolymère d'éthylène-acétate de vinyle et du chlorure de polyvinyle en suspension ont été déterminés. Des équations de régression pour la dépendance des propriétés de déformation et de résistance aux facteurs technologiques de la production de compositions polymère pour les semelles ont été construites. Il a été prouvé qu'en sélectionnant les valeurs optimales des paramètres technologiques, il est possible d'obtenir un matériau pour les semelles avec une résistance à la déformation et des caractéristiques technologiques opérationnelles élevées.

MOTS CLÉS : copolymère d'éthylène-acétate de vinyle, chlorure de polyvinyle en suspension, planification mathématique de l'expérience, indicateur de qualité généralisé, fonction de désirabilité.

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INTRODUCTION

Analysis of scientific and technical literature shows that thermoplastic polymer compositions based on a copolymer and thermoplastic, obtained by the method of "mechanical" mixing, in terms of their properties, occupy an intermediate position between thermoplastic and elastomeric polymers. They are considered as two-phase heterogeneous systems in which the copolymer layer is distributed over a thermoplastic matrix [1].

Such thermoplastic polymer compositions with a high range of properties are promising for use in the footwear industry.

It is known that the properties of such complex heterogeneous polymeric materials as thermoplastic polymer compositions based on a copolymer of ethylene with vinyl acetate and suspension polyvinyl chloride (EVA / PVC-S) depend both on the ratio of the initial components and on the technological parameters of production.

However, systematic studies to optimize the technological parameters of obtaining a thermoplastic polymer composition (TPK) based on EVA / PVC-S, taking into account the ratios of the main components, have not been carried out. In the literature, there are only indications that thermoplastic polymer compositions based on a copolymer-thermoplastic are obtained at high temperatures and shear rates, and the resulting material is characterized by flow instability during processing. In addition, different authors [1, 2] obtained thermoplastic polymer compositions of the same composition, but sharply differing from each other in the values of physical and mechanical parameters, which ultimately indicates a very high dependence of properties on both the composition and technological parameters.

Therefore, at this stage of the study, it is advisable to identify the dependence of the composition and technological parameters of production on the properties of a thermoplastic polymer composition, as well as to select the optimal composition of the mixture and find the optimal technological parameters for its production.

EXPERIMENTAL PART

In this work, the main object of the study was suspension polyvinyl chloride grade 6346 M with the trade name "Suspension polyvinyl chloride" produced by JSC "Navoiyazot" in Navoiy (Republic of Uzbekistan) and a copolymer of ethylene with vinyl acetate (vinyl acetate content 18%) with the trade name "Sevilen" produced JSC "Orgsintez", Kazan (Russia), the main characteristics of which are shown in Table 1.

Table 1: Main characteristics of the studied polymers

№	The name of indicators	SEVA (VA-18%)	PVC-S-6346-M
1	Appearance	granules	powder
2	GOST or TU	11507-70	14332-78
3	Molecular weight, thous.	30-500	10 -150
4	Solubility parameters, (cal / cm^3) 1/2	8.4	9.4
6	Density, kg / m^3	0.944	1.34
7	Tensile strength, MPa (not less)	8.0	25
8	Elongation at break, %	800 -700	50
9	Residual elongation at break, %	More than 100	10
10	Vicat heat resistance, °C	100	150
13	Melting point, °C	125	150-220
14	Glass transition temperature, °C		105
15	Crystallinity, %		10
16	Thermal stability at 180 °C, min		190

The choice of these polymers as the main object of research is due to a complex of valuable properties, the possibility of obtaining a thermoplastic polymer composition based on them and processing them into a product on high-performance injection molding units, a stable raw material base, and a relatively low cost of these polymers.

In addition, one of the important characteristics of PVC is the temperature of the beginning of its decomposition and thermal stability. Thermal stability is the time (in minutes) of heating it at a certain temperature until the first signs of the release of toxic gases. Suspension polyvinyl chloride has the highest thermal stability. Therefore, to obtain a thermoplastic polymer composition for the bottom of shoes used in dry and hot climates, this polymer brand was chosen [3].

Polymer compositions based on mixtures of polymers were obtained by the method of thermomechanical mixing under certain conditions in the mixing chamber of a plasticorder manufactured by Brabender (Germany) model PLV-651. Plasticorder specifications:

Loading volume 60-600 cm^3

Front rotor speed 2-150 rpm

The temperature of the mixing chamber is 18-300°C.

The plasticorder is equipped with a device for registering and recording the torque on the shaft.

The technology for manufacturing polymer mixtures consists of the following operations:

1. Preparation of raw materials and ingredients.
   1.1. Drying of polymers.
   1.2. Grinding caked ingredients.
2. Mixing of components.
   2.1. Mixing and melting of the thermoplastic with the copolymer was carried out in the mixing chamber of the plasticorder with constant intensive stirring at a temperature 10-40°C higher than the melting temperature of the thermoplastic for 2-6 minutes.
3. Cooling and granulation.
   3.1. The resulting homogeneous thermoplastic mixture was cooled on cold rollers.
   3.2. Granulation was carried out on a Marris granulator (Italy). As a result of granulation, granules with a size of 2-4 mm were obtained.
4. Recycling. To increase the homogeneity of the mixture, the composition was re-melted, cooled and granulated.
5. Samples for testing were obtained by pressing on vulcanizing presses and by casting on an automatic plating machine from Marris (Italy). The size of the test pieces is 250x130x8 mm.

To assess the qualitative and quantitative indicators of the properties of thermoplastic polymer compositions, standard and original research methods were used with the use of modern equipment and devices given in Table 2.

Table 2: Methods for determining the physical, mechanical and thermophysical indicators of polymer compositions

№	Research methods	Standard number	Applied equipment
1	Tensile strength, elongation and permanent elongation at break	GOST 270 GOST 7926	Tensile testing machine RMI-250 for determination of ultimate strength and elongation at break.
2	Slip resistance coefficient	GOST 4.387	Tearing torsion machine RT-250M with a special device for determining the frictional properties of the bottom of the shoe.
3	Sole attachment strength	GOST 22307	A torsional tearing machine RT-250M with a special device for determining the strength of fastening the bottom of the shoe.
4	Hardness	GOST 263	Hardness tester IT-5078 for measuring the hardness of rubber Shore A
5	Abrasion resistance	GOST 426	MI-2 machine for determination of abrasion resistance of rubbers and rubber products.

№	Research methods	Standard number	Applied equipment
6	Thermal conductivity	GOST 23630.2	IT-1 device for determining thermal conductivity.
7	Density	GOST 267	Hydrostatic method
8	Flexural resistance	GOST 422	Machine MRS-2 for testing the repeated bending of rubbers for the bottom of shoes.
9	Heat resistance	GOST 15088	A device for determining the Vicat softening temperature of thermoplastics in air.

The rheological properties of the studied polymer compositions were judged by the effective viscosity of the melt.

The effective viscosity of the melt was determined by the torque on the plasticorder shaft at a given temperature and rotor speed.

The studies were carried out on a traditional PLV-651 rheometer manufactured by Brabender (Germany), equipped with a special attachment with a N60H mixing chamber volume.

The effective viscosity of the polymer composition was calculated by the formula:

$\eta_{eff} = \tau/\gamma$, Pa•s (1)

from here:

$\tau = M_{кр}/V_{load}$; (2)

$\gamma = \pi \cdot n/30$; (3)

Substituting the values of τ and γ from formulas (2) and (3) into formula (1), we obtained

$\eta_{eff} = Mcr \cdot 30/\pi \cdot n \cdot V_{load}$, Pa•s

where: η_{eff} - effective viscosity, Pa•s;

τ - shear stress, N/m^2, Pa;

γ - shear rate, s-1;

$M_{кр}$ - torque on the plasticorder shaft, N • m;

V_{zagr} - the volume of the composition in the mixing chamber, m^3;

n - is the number of revolutions of the rotor, rpm.

Recently, for the solution of optimization problems of chemical-technological processes, methods of mathematical planning of experiments, based on the widespread use of electronic computers, have become widespread.

In this work, to describe the properties of polymer-sole compositions based on EVA / PVC-S, depending on the ratio of components and technological parameters of production, the method of mathematical planning is chosen – "Full factorial experiment" of type No. = 2^k, which makes it possible to obtain separate estimates of linear effects and two, three-factor interactions [4].

To construct a mathematical model, the following factors were selected: the content of EVA in the composition, temperature and mixing rate. The values of the variation factors are presented in Table 3.

Table 3: Factors of variation when planning an experiment by the method "Complete factorial experiment"

Factors	Designation	Factor value at the level of variables, conventional units		Step variations
		-1	+1	
The content of EVA in the polymer-plantar composition, wt.%	X_1	15	40	5
Mixing temperature, ºC	X_2	175	200	5
Displacement speed, rpm	X_3	25	50	5

The output characteristics of the strength and operational and technological properties of polymer-sole compositions were complex indicators of the quality of the material being developed, consisting of 11 single quality indicators, identified as a result of an expert survey of specialists.

U_1 - ultimate strength at break, MPa;

U_2 - elongation at break, %;

U_3 - residual elongation at break, %;

U_4 - slip resistance, conventional units

U_5 - the strength of the sole attachment, kN/m;

U_6 - Shore A hardness, conv. units;

U_7 - abrasion resistance, mm^3;

U_8 - thermal conductivity, W/m • K;

U_9 - density, g/cm^3;

U_{10} - resistance to multiple bending, thousand cycles;

U_{11} - heat resistance, °C

Regression equations describing the quantitative relationship between variables can be represented as a polynomial:

$$\hat{Y}= b_0+ b_1 x_1+ b_2 x_2+ b_3 x_3+ b_{12} x_1 x_2+ b_{13} x_1 x_2+ b_{23} x_2 x_3+b_{123} x_1 x_2 x_3, \quad (1)$$

where: $\hat{Y}$ - values of the criterion;

b_0 - free member;

b_1, b_2, b_3 - linear coefficients;

b_{12}, b_{13}, b_{23} are the double interaction coefficients;

b_{123} is a coefficient that determines the triple interaction of factors.

The planning matrix and the results of the experiment are shown in Table 4.

Table 4: Planning matrix and experiment results

№ experi-ence	Factors planning			Output parameter values										
	X_1	X_2	X_3	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}
1	-1	-1	-1	12.2	250	20	1.0	4.5	75	18.2	0.180	1.21	95	115
2	+1	-1	-1	3.9	80	10	0.8	2.3	79	14.2	0.235	1.18	12	90
3	-1	+1	-1	11.8	255	18	0.87	4.7	76	17.3	0.175	1.31	90	105
4	+1	+1	-1	5.2	105	15	0.65	2.7	79	12.6	0.245	1.18	17	86
5	-1	-1	+1	11.2	230	19	0.95	4.2	77	17.8	0.180	1.25	80	107
6	+1	-1	+1	4.7	50	8	0.7	2.0	80	13.2	0.220	1.15	15	87
7	-1	+1	+1	9.2	185	15	0.8	3.5	75	17.5	0.190	1.23	85	100
8	+1	+1	+1	4.2	70	10	0.5	1.8	86	12.5	0.252	1.15	20	85

To check the adequacy of the mathematical model, 3 identical experiments were carried out with the values of the levels of variation of the factors equal to 0 (X_1 = 0, X_2 = 0, X_3 = 0), the results of which are shown in Table 5.

Table 5: Checking the adequacy of the mathematical model with the values of the levels of variation of factors equal to 0 (X_1 = 0, X_2 = 0, X_3 = 0)

Level of variation of factors	Factors		
	X_1 The content of EVA in the polymer compositions	X_2 Displacement temperature, ºC	X_3 Displacement speed, rpm
-1	15	175	25
0	27.5	187.5	37.5
+1	40	200	50
Variation intervals	12.5	12.5	12.5

To calculate the regression coefficients, a personal computer program PENTIUM IV was compiled. Data processing, namely, deformation-strength and operational-technological characteristics, was carried out using the FUIL. FAC program.

The significance of the coefficients of the regression equation was checked for each coefficient separately according to the Student's test. Insignificant coefficients were excluded from the regression equation. The values of the coefficients of the regression equation characterize the contribution of the corresponding factor to the value of Y. Therefore, in the center of the plan, three additional parallel experiments are placed and the values of Y_i are obtained.

After that, the significance of the coefficients was assessed by the Student's test.

The tabular value of the Student's test for the significance level ρ=0.05 and the number of degrees of freedom f = 2 tp(f) = 4.3.

Thus, insignificant coefficients that are below the tabular value of the Student's test were excluded from the regression equations.

The adequacy of the obtained equations was checked by Fisher's criterion:

$$F = S_{res}^2 / S_{rep}^2 \; ; \quad (2)$$

$$S_{res}^2 = \frac{\sum_{i=1}^{8}(y_i - \hat{y}_i)^2}{N-l} \; ; \quad (3)$$

$$S_{rep}^2 = \frac{\sum_{i=1}^{3}\left(y_u^0 - \bar{y}^0\right)^2}{2} \quad (4)$$

l is the number of significant coefficients in the regression equation, equal to 4.

Then F = 2 / 0.26 = 7.6. Tabulated value of Fisher's criterion for ρ=0.05, f = 4, f_2 = 2, f_{1-p} (f_1, f_2) = 19.3, F < F_{1-p} (f_1, f_2).

Consequently, the resulting equation adequately describes the experiment.

The regression equations for the dependence of the deformation and strength properties on the technological factors of creating polymer sole compositions are as follows:

- for the indicator “Tensile strength at break”:

Y_1=13,36 - 0,85•Z_1 + 0,032•Z_2 + 0,40•Z_3 + 0,0026•Z_1Z_2 + 0,0027•Z_1Z_3 - 0,0027•Z_2Z_3 (МПа); (5)

- for the indicator “Relative elongation at break”:

Y_2 = 380.38 - 6.15 • Z_1 - 1.55 • Z_3 (%); (6)

- for the indicator “Residual elongation”:

Y_3 = 22.35 - 0.29 • Z_1 (%). (7)

If the top of the shoe is traditionally made of genuine leather or fabric, then the bottom of the shoe is made of polymer compositions. The connection of the bottom of the shoe with the upper is carried out by the glue method or by the method of direct casting onto a protracted blank. The service life of the shoe is determined by the strength of the fastening. The dependence of the influence of the technological parameters of the processing of the composition on the adhesive strength of the fastening of the top with the bottom is determined by the equation:

Y_5 = -1.98 - 0.08 • Z_1 + 0.045 • Z_2 + 0.20 • Z_3 - 0.0012 • Z_2 Z_3 ; (kN/m) (8)

Shoes are used in different climatic conditions, including dry tropical climates. It is believed [6, 7] that the sole material intended for operation in these climatic conditions should have high values of heat resistance and low values of thermal conductivity. This will ensure the shoe's dimensional stability and consumer comfort. The regression equations describing the parameter “Heat resistance of the composition” are as follows:

Y_{11} = 168.1 - 0.79 • Z_1 - 0.23 • Z_2 - 0.17 • Z_3 (°C) (9)

It is believed [6, 7] that the sole material intended for use in dry hot climates should have a minimum thermal conductivity to protect the foot from overheating.

The regression equation describing the “Thermal conductivity of the composition” is:

Y_8 = 0.15 + 0.0023 • Z_1; (W / (m • K)) (10)

When developing polymeric materials for the bottom of shoes, it is necessary to pay special attention to the issues of frictional interaction with the supporting surface.

According to [7-9], the suitability of a certain sole material from the point of view of the safety of a person's movement on a particular surface can be characterized by comparing the static and dynamic coefficients of friction of the contact between the bottom system and the supporting surface. According to this, the static coefficients of friction must be at least 0.7, and the dynamic ones must be at least 0.8.

In this work, to study the coefficient of sliding resistance, a standard surface (for a glass-glazed plate) is taken.

The regression equation describing slip resistance is:

Y_4 = 2.37 - 0.0097 • Z_1 - 0.0063 • Z_2 - 0.0037 • Z_3; (conventional units) (11)

An important ergonomic characteristic of the sole composition, in terms of ease of wear, is its density.

The approximate dependence of the density on the investigated technological factors is described by the equation:

Y_9 = 1.30 - 0.0034 • Z_1; (g / cm^3) (12)

Hardness is one of the most important characteristics of the technological and operational properties of polymeric materials used for the manufacture of shoe bottom parts. This indicator largely determines the possibility of using a polymer composition for a particular type and purpose of footwear. The dependence of the hardness (Y_6) of the composition on the investigated factors is as follows:

Y_6 = 78.375; (conventional unit according to Shore, scale A) (13)

When using shoes, their contact with the supporting surface and the human body is permanent. As a result, the surface of the rubbing parts is destroyed and wears out [6-9].

The work investigates the abrasion resistance of the samples obtained as a result of the optimization of the experiment. The resulting regression equation describing the dependence of abrasion resistance on the factors investigated has the form:

$Y_7 = 35.93 - 0.18 \cdot Z_1 - 0.08 \cdot Z_2 - 0.24 \cdot Z_3 + 0.0012 \cdot Z_2 Z_3$; ($mm^3$) (14)

It is known that footwear undergoes multiple bending during operation. The approximate dependence of multiple bending on the investigated factors is described by the equation in the form:

$Y_{10} = 130.4 - 2.86 \cdot Z_1$; (thousand cycles) (15)

The analysis of the obtained mathematical models (5-15) is of certain interest for identifying the nature of the influence of the factors considered.

The analyzed factors have an ambiguous effect on the considered single indicators: if an increase in the values of factors has a positive effect on the hardness, i.e. with an increase in the value of the factors, the strength indicator increases, then on the output characteristics: elongation at break, thermal conductivity, slip resistance, multiple bending - the effect is negative.

For other indicators, the influence of factors is not unambiguous.

The complexity of the interpretation of the obtained results of the study lies in the fact that at present the mechanism of the formation of a thermoplastic polymer composition has not been fully elucidated, and it is practically impossible to recreate the complete picture of the process from some responses.

However, for some indicators, the mechanism of the process is obvious, for example, for equation (5) - tensile strength at break. Factor X_1 - the amount of EVA in the composition has a negative value and a relatively lower value, which can be logically explained from the point of view of the additivity of the properties of the mixture. Replacing the amount of a low strength component with a high strength component results in an increase in tensile strength values for the entire composition. Influence of factors: the temperature and mixing rate on the strength indicator is much lower than for the EVA content factor.

Paired interactions of factors: $X_1 X_2$ and $X_1 X_3$ are positive. Paired interactions $X_2 X_3$ have a negative effect: with an increase in the values of technological properties, the strength of the resulting composition decreases.

For this system EVA : PVC-S in the considered range of compositions, it is unlikely to achieve a significant increase in strength, since all coefficients for linear, paired and triple terms of the equation have a negative value.

One of the most important indicators of synthetic sole materials is the ability to cast, that is, the rheological behavior of the material under the influence of temperature and external conditions.

In this work, effective viscosity is taken to study the rheological properties.

The conducted research shows that an increase in the volume of the crystalline phase, temperature, mixing rate and the pairwise interaction of temperature with the rate decreases the value of the effective viscosity.

Based on the results obtained, a curve of viscosity change versus temperature and shear rate was constructed (Fig. 1).

The viscosity of such compositions in the investigated range of parameter changes depends to a greater extent on the shear rate than on temperature [10, 11].

This appears most clearly in the following ranges of values of the factors under consideration.

X_1 =15-20, X_2 =185-190, X_3 =25-30

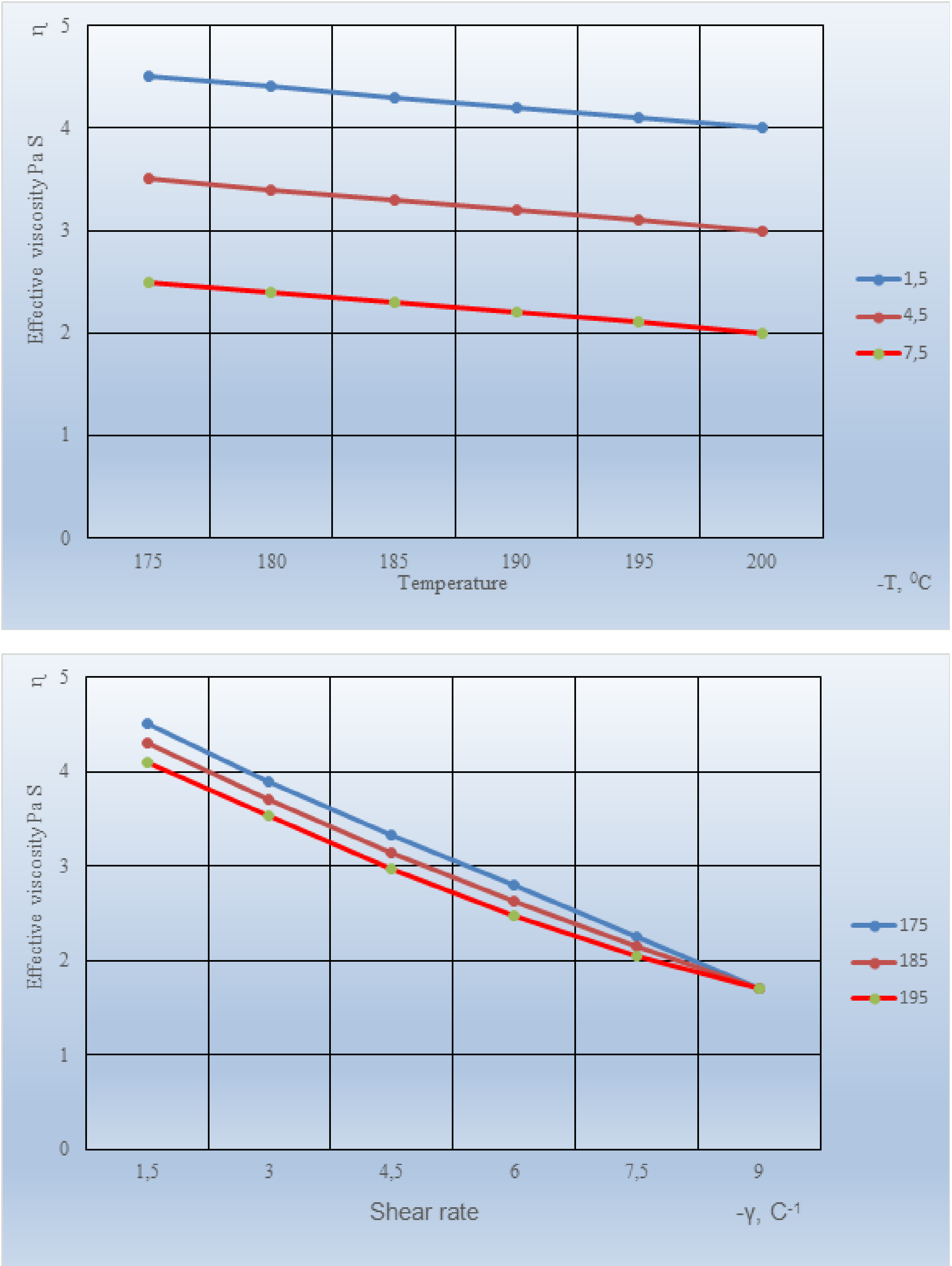

Figure 1. Dependence of the viscosity of a thermoplastic polymer composition based on PVC / EVA in the ratio 0.85 / 0.15 on temperature (a) and shear rate (δ)

Thus, considering the above equations, we can say that a scientifically grounded choice of the values of the factors X_1, X_2 and X_3, at which the optimization parameter Y_i reaches its maximum value, is possible only if a special mathematical apparatus is used.

RESULTS AND DISCUSSION

One of the most successful ways to solve the problem of optimizing processes with a large number of responses is to use the Desirability Function method proposed by Harrington [4, 5, 13]. The method consists in converting single quality indicators (Y_i), expressed on a physical scale, into a dimensionless indicator (Y_i'). Conversion of Y_i' into the values of unit quality indicators (di), which can be carried out either by the graphical method shown in the figure (Figure 2), or by the analytical method according to the dependence:

$$d_i = exp\left(-exp\left(-Y'_i\right)\right) \quad (16)$$

The generalized quality indicator (D), combining all the single ones into a complex indicator, was determined by the dependence:

$$D = \sqrt[n]{d_1 d_2 d_3 \dots d_n} \quad (17)$$

where: D - generalized quality indicators, calculated according to a simplified method, taking into account the weight of single quality indicators;

d_1, d_2, d_3,… d_n are particular desirability functions;

Y_i - the desired value of the natural indicator of the i-th property;

i = 1 … 11- quality indicator numbers.

The resulting mathematical model of the generalized quality indicator (D), for the study area, has the form:

$$D = \left[exp\left(-\frac{1}{11}(0{,}127\ \exp\ (-0{,}70 + 0{,}44\,Y_1) + 0{,}111 exp(-0{,}65 + 0{,}0086\,Y_2) + 0{,}106\,exp(3{,}48 - 0{,}066\,Y_3) + 0{,}091\,exp(-1{,}27 + 3{,}95\,Y_4) + 0{,}088\,exp(-1{,}64 + + 1{,}16\,Y_5) + 0{,}081\,exp(-3{,}11 + 0{,}066\,Y_6) + 0{,}075\,exp(-0{,}52 + 0{,}20\,Y_7) + 0{,}075\,exp(2{,}82 - 6{,}59\,Y_8) + 0{,}070\,exp(12{,}37 - 9{,}88\,Y_9) + 0{,}065\ exp(-1{,}32 + 0{,}056\,Y_{10}) + 0{,}061\,exp(-3{,}44 + 0{,}049\,Y_{11})\right)\right] \quad (18)$$

Where Y_1…Y_{11} - natural values of the quality indicator.

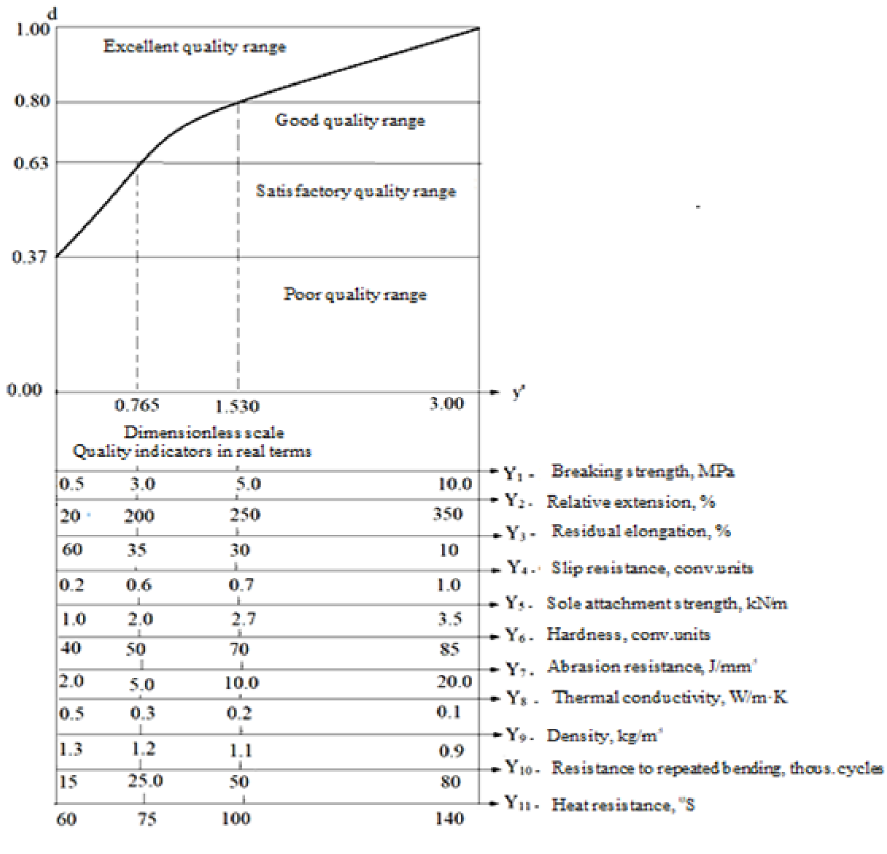

Figure 2. The function of desirability and the scale of assessing the quality indicators of the polymer composition for the bottom of the shoe

Therefore, to select the optimal value of the factors (X_1, X_2, X_3), with the optimal operating and technological parameters, the Desirability Function method was used [12].

The scale of assessing quality indicators and the graph "Desirability function" are shown in Fig. 2.

Based on the calculations, the generalized quality indicator is recognized as the best composition with the maximum value of D, i.e. having the best set of values of consumer characteristics.

The optimal values of the factors X_1, X_2, X_3, at which D = 0.84, which corresponds to excellent quality, are equal to:

X_1 = 15 mass. %; X_2 = 187°C; X_3 = 25 rpm.

The results obtained under these conditions - tensile strength at break is 12.0 MPa, elongation - 249%, residual elongation - 18%, slip resistance - 0.95 conventional units, adhesive bond strength - 4.56 kN/m, Shore hardness 78 conv. units, resistance to abrasion - 17.9 mm^3, thermal conductivity - 0.18 W / m • K, density - 1.25 g / cm^3, resistance to multiple bending - 87.5 thousand cycles, heat resistance - 110°C.

The calculation results show that the consumer and technological properties of the polymer-sole composition vary in a wide range depending on the input parameters.

CONCLUSION

Thus, by selecting the optimal values of technological parameters for obtaining thermoplastic polymer compositions, it is possible to obtain a sole material with high deformation-strength and operational-technological characteristics.

The obtained mathematical equations (5) - (15) should be used to create a computer-aided design system for the manufacturing of shoe bottom parts based on domestic suspension polyvinyl chloride and ethylene-vinyl acetate copolymer by injection molding.

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