Optimization method of the extrusion mixture components formulation and consumption in the processing of the secondary heterogeneous polymeric materials

V V Dyadichev¹, A V Kolesnikov², A V Dyadichev¹, S G Menyuk¹, O F Babushkina¹ and S Ye Chornobay¹

¹V.I. Vernadsky Crimean Federal University, 295000, Pavlenko Str. 3, Simferopol, Crimea, Russia
²Lugansk National University named after Vladimir Dal, Department of Automation and Computer-Integrated Technologies, 20-A Molodezhnyi Sq., Lugansk, 91034, Ukraine

*mr.dyadichev@mail.ru

Abstract. The paper scrutinizes the main methods, applied practically, for correcting the consumption of the components considering their fullness in the technological extrusion process. The method, chosen as the basic one, includes the following: the common fullness of the components, getting into the mixer, is subtracted from the common consumption of the filler. A mathematical model for determining the values of the components for setting the dosing devices is designed. For the operational control of the filler’s components content we determined the dependencies of these values correction on the period of the filler content evaluation and transport delay of the components supply. The algorithm of the method for controlling the extrusion mixture components’ consumption, considering the content of the filler in it, is made.

1. Introduction

In the beginning of XX century the world polymer production was only several thousand tons of different polymeric materials [1]. If compare to the classical construction materials – metals, cement, and glass – it was a small percentage. Nowadays modern developed countries produce polymers in the amount of more than melt steel, not mentioning aluminum, copper and other non-ferrous metals taken together. The general tendency of plastic production development is that every year the increase of polymeric materials production goes on with a stable speed, while on the contrary, the metal production is constant. In 2016 122, 800 thousand tons of different polymeric materials were produced [2]. The growth of polymeric materials continues and the amount of the generated waste, unfortunately, passes ahead their production increase. Nowadays the polymeric materials waste in the world is hundreds of millions tons. The reuse of polymeric waste as the secondary raw material allows efficiently using the materials during the production, as well as solving the urgent problem of waste recycling, the most problematic of which is mixed heterogeneous polymeric waste [3-5]. One of the most promising technology for this purpose is the extrusion due to combination of the modification phase and the main processing, due to a wide range of the obtained products with the prospect of their expansion for account of the secondary deformation additional phases; however, it is necessary to research in details the process for optimization of the extrusion mixture components’ consumption, considering the content of the filler in it [6-7].
Polymeric materials as the initial materials of the extrusion mixture are used; these materials are mainly heterogeneous in compatibility and have been used in the production and the processing spheres, plastic masses from the sphere of individual and common use (the filled waste, secondary polymers). That is why the content of these components’ filler varies from 7 to 15 %, and in some cases reaches up to 20 – 30 % [8-9]. This cannot help affecting the strength and rheological properties of the mixture. And if the decrease of the shift limit stress \( \tau_0 \), caused by the presence of additional filler in the mixture, leads only to the lessening of the extruder and the extrusion head obstruction probability, the decrease of the product strength requires taking particular measures to correct the components consumption [10-11].

2. Method of controlling the consumption of the extrusion mixture components considering the presence of a filler in it

Let us consider the main methods applied practically to control the consumption of the components considering their fullness [12-15].

One of the methods is as follows: the common fullness of the components, supplied into the mixer, is subtracted from the common filler consumption. This method is the most used in practice [16-19]. The total calculating amount of the filler in the mixer is preserved, as the fullness of the components is considered. However, in this case the consumption of the components, occupied by the filler, is not corrected. As the content of the filler in the initial polymer is insignificant, then the initial dry polymer consumption can be accepted as constant. Consequently, the volume of the obtained mixture turns out to be less than of the set volume, and the consumption of the initial polymer for 1 m³ of the mixture is overrated. The application of this method meets the requirement of the durability, but does not comply with the aim of the set function – minimum consumption of the initial polymer. The actual efficiency of the equipment \( V_f \) will be less than the set one.

We offer the method for correcting the filler in the inert materials according to the content of the filler in them while making the mixture; this method consists of measuring the filler in the materials \( \omega_i \) and of identifying the amount of the filler in the material \( Q_m \):

\[
Q_m = \omega_i \frac{Q}{100},
\]

where \( \omega_i \) is the content of the filler in the component;

\( Q \) is the set consumption of the component.

Then the amount, occupied by the filler \( Q_m \), is subtracted from the set component consumption, and the component consumption increases for this value. However, in this case it is not taken into account that there is a filler in the added portion of the material while dosing.

For instance, if the components consumption (durability 55.0 MPA) for 1 m³ of the prepared mixture is 100 kg of the filled wastes, 730 kg of the secondary waste, 540 kg of the initial polymer and 650 kg of the filler, then the content of 10 % filler in the secondary polymer, which is not considered in the addition of the secondary polymer, and 15 % in the filled wastes, gives additionally \( \Delta m_n \), 88 kg of the filler, and its total consumption for 1 m³ of the mixture \( m_n \) will be 738 kg [20-21]. The increase of the filler consumption \( \Delta m_n \) by 88 kg decreases the durability of the product by 0.27 MPa. For maintaining the permissible durability the consumption of the initial polymer has to be decreased, approximately, by \( \Delta n_{ip} = k \Delta m_n = 0.3332 \cdot 88 = 29.32 \ k\varphi \).

The considered above allows us concluding that for the accuracy increase of correcting the components’ consumption depending on the content of the filler in them, it is necessary to consider the filler in the correcting additions while weight dosing. Further the method of influencing the materials consumption under the change of the filler content in them is presented; this method considers the complete content of the filler in the main mixture and in the additions.

If the consumption of the non-filled components is set by the basic values \( m_{0ip}, m_{0ip}, m_{0tm}, \) and the content of the filler in the components is determined by the values of the fullness coefficients \( \omega_{ip}, \omega_{ip}, \omega_{tm}, \omega_{tm} \), then to provide the required value of the consumption of the non-filled components (basic), the dosing devices have to increase the setting for the filler value, contained in the actual material:
\[ \Delta m_{ai} = m_{ai} \frac{\omega_i}{100}, \]  

(2)

where \( i \) are ‘и’ (filled waste), ‘пн’ (secondary polymeric waste), ‘пп’ (initial polymer).

The formula (2) is got from the analysis of the known formula of the filler content:

\[ \omega = \frac{m_{ai}}{m_{ci}} \times 100\%, \]  

(3)

where \( m_{ai}, m_{ci} \) are the mass of the filler and the mass of the constituent material without the filler respectively.

Then the actual dosing value of the mixture components, considering the content of the filler in the materials, has to be at the level:

\[ m_{qna} = m_{qna0} + \Delta m_{nna} = m_{qna0} + m_{qna0} \frac{\omega_{nn}}{100} = m_{qna0} \frac{100 + \omega_{nn}}{100}, \]  

(4)

\[ m_{qns} = m_{qns0} + \Delta m_{nns} = m_{qns0} \frac{100 + \omega_{ns}}{100}, \]  

(5)

\[ m_{qnp} = m_{qnp0} + \Delta m_{npn} = m_{qnp0} \frac{100 + \omega_{np}}{100}. \]  

(6)

At the same time the actual consumption of the filler will be determined:

\[ m_{qna} = m_{qna0} - \sum_i \Delta m_{ai}, \]  

(7)

where \( i \) is ‘и’, ‘пс’, ‘пп’.

Thereby, if the content of the filler \( \omega_i \) component is known, then the task for giving \( i \)-component has to be corrected according to the expressions (4) – (6), and for the filler – (7). Along with this, the addition \( m_{di} \) of the dry component, being calculated by the expression (2) in its turn contains the filler, which has to be calculated:

\[ \Delta m_{ei+1} = \Delta m_{ei} \frac{\omega_i}{100}; \]  

(8)

and considered in the addition:

\[ m_{di} \leftarrow m_{di} + \sum_{k=1}^i \Delta m_{di}^{e+1}. \]  

(9)

where ‘k’ is a step of the correction of the filler’s content in the additions to the component consumption, \( k \) is 1,2,...,\( l \). When \( k \) is 1, \( \Delta m_{di} = \Delta m_{ai} \), calculated by the expression (2). Thus, the expressions (4 – 7) are specified due to their iteration considering index \( k \).

The expressions (8 – 9) describe the iterative process of identifying the value of the addition \( m_{di} \) to the consumption of \( i \)-component, compensating the content of the filler in dry material. The given iterative process is fast converging with different amount of the steps for each component and continuing till the condition is satisfied:

\[ \left| \Delta m_{ei+1}^{e+1} - \Delta m_{ei}^{e+1} \right| > \varepsilon_i, \]  

(10)

where \( \varepsilon_i \) is the value set beforehand for \( i \)-component, conditioned by the facilities and characteristics of the equipment used for dosing.

The obtained after the iterative processes values \( m_{di} \) are considered when setting the tasks for the consumption of dry components and the filler for 1 m³ of the mixture:

\[ m_{di} = m_{di0} + m_{di} = m_{di0} \frac{100 + \omega_i}{100} + \sum_{k=1}^i \Delta m_{di}^{e+1}; \]  

(11)

\[ m_{wi} = m_{wii} - \sum_i m_{wi} = m_{wii} - \sum_i \left( m_{wii} \frac{\omega_i}{100} + \sum_{k=1}^i \Delta m_{di}^{e+1} \right), \]  

(12)

where \( i \) is ‘и’, ‘пс’, ‘пп’.
As the mixture volume has to be invariable while doing corrections, the sum of the components mass portions has to be equal to the start volume:

$$V_{cs} = 10^{-3} (\vartheta_{s_{10}}m_{s_{10}} + \vartheta_{s_{11}}m_{s_{11}} + \vartheta_{w}m_{w} + \vartheta_{m}m_{m}) = 1 m^3,$$

where $\vartheta_{s_{10}}$, $\vartheta_{s_{11}}$, $\vartheta_{w}$, $\vartheta_{m}$ are specific volumes of the initial polymer, the secondary mixture, the filled waste and the filler, respectively, $m^3$/kg.

The expression (13) may be used as the referent one while correcting the consumption of components considering the content of the filler in them.

For the values of the components (11) – (12) the dosing devices are adjusted. If the control of the content of the filler components is done promptly, the correction of these values is done according to the formulae (11) – (12) with the period of filler content evaluation and transport delay of the component supply (it depends on the location of the device for determining the filler content in the transport feed gear).

The algorithm of the method for controlling the extrusion mixture components’ consumption considering the presence of the filler in it is presented in Figure 1.

![Figure 1](image_url)

**Figure 1.** The algorithm of the method for controlling the extrusion mixture components’ consumption considering the content of the filler in it.
3. Conclusion
A method is developed and analytical dependencies are obtained for correction of the tasks on the consumption of mixture components, considering the content of the filler in the main material and additional portions, and allowing eliminating the influence of the mixture materials fullness on the durability of the extrusion product.

We also developed the algorithm for accounting the content of the filler in the consumption of the extrusion components of a multicomponent mixture, which provides the implementation of the suggested mathematical model of the process and method for controlling the extrusion equipment.

References
[1] Dyadichev V V, Kolesnikov A V, Menyuk S G and Dyadichev A V 2019 Improvement of extrusion equipment and technologies for processing secondary combined polymer materials and mixtures IOP Conf. Series: Journal of Physics: Conf. Series 1210 Art. No 012035 doi: 10.1088/1742-6596/1210/1/012035
[2] Kim V S 1988 Dispersion and mixing in the production of plastic (Moscow: Chemistry) p 293
[3] Davis B. and et al. 1998 Grooved Feed Single Screw Extruders – Improving Productivity and Reducing Viscous Heating Effects. Polym. Eng. Sci. 38 (7) 1199
[4] Han C D 1981 Multiphase flow in polymer processing (New York: Academic Press)
[5] Steller R T 1990 Theoretical Model for Flow of Polymer Melts in the Screw Channel, Polym. Eng. Sci. 30 (7) 400-7
[6] Rauwendaal C 2001 Polymer extrusion (Munich, Hauser Garduer) p 777
[7] Pape J, Potente H and Obermann C 1999 Influence of Model Simplifications on the Accuracy of Simulation Results in Single Screw Extruders 15th Annual Meeting of the Polymer Processing Society (Den Bosch, the Netherlands)
[8] Elemans P 2000 Enhancing Dry-Color Efficiency in Starve-Fed Injection Molding 58th SPE ANTEC 2582-6
[9] Elemans P and van Wunnik J M 2000 The Effect of Feeding Mode on the Dispersive Mixing Efficiency in Single-Screw Extrusion 58th SPE ANTEC 265-7
[10] Shvetsov P A 1988 The technology of processing plastic masses (Moscow: Chemistry) p 462
[11] Dyadichev V, Kolesnikov A, Dyadicheva E, Menyuk S and Dyadichev A 2018 Model of creation a multilayer structure for production of building pipes MATEC Web Conf., VI International Scientific Conference “Integration, Partnership and Innovation in Construction Science and Education” (IPICSE–2018) 251, Art. No 251 01006 doi: 10.1051/matecconf/201825101006
[12] Dyadichev A V, Dyadicheva E A, Kolesnikov A V, Dyadichev V V, Menyuk S G and Chornobay S Ye 2019 Mathematical model of adhesion junction of layers during coextrusion Journal of Physics: Conf. Ser. (JPCS): Int. Scientific Conference APITECH 2019 1399 (4) Art. No 044112 doi: 10.1088/1742-6596/1399/4/044112
[13] Lyubomirskiy N V, Fedorkin S I, Bakhtin A S and Bakhtina T A 2017 Structuring of composite systems based on lime harden through carbonation and secondary limestone raw materials Malaysian Construction Research Journal (MCRJ) 23 (3) 15-26
[14] Fic S, Lyubomirskiy N and Barnat-Hunek D 2018 The Influence of the Natural Aggregate Roughness on the ITZ Adhesion in Concrete Mater. Sci. Forum: Materials and Technologies in Construction and Architecture 931 564-7
[15] Gusev A, Shul’gin V, Braga E, Zamnius E, Starova G, Lyssenko K, Eremenko I and Linert W 2018 Luminescent properties of zinc complexes of 4-formylpyrazolone based azomethineligands: Excitation-dependent emission in solution J of Luminescence 202 370-6
[16] Gusev A N, Shul’gin V F, Braga E V, Nemec I, Minaev B F, Baryshnikov G V, Trávníček Z, Ágren H, Eremenko I L, Lyssenko K and Linert W 2018 Synthesis and photophysical properties of Zn(II) Schiff base complexes possessing strong solvent-dependent solid-state fluorescence/ A. N. Gusev Polyhedron
[17] Shul’gin V, Pevzner N, Gusev A, Sokolov M, Panyushkin V, Devterova J, Kirillov K, Martynenko I and Linert W 2018 Tb(III) complexes with 1-phenyl-3-methyl-4stearoyl-
pyrazol-5-one as a material for luminescence Langmuir–Blodgett films J. of Coordination Chem.

[18] Yankovskaya V S, Dovhyi I I, Bezhin N A, Milyutin V V, Nekrasova N A, Kapranov S V and Shulgin V F Sorption of cobalt by extraction chromatographic resin on the base of di-(tert-butylbenzo)-18-crown-6 Journal of Radioanalytical and Nuclear Chemistry 318 (2) 1085–97

[19] Dyadichev V V, Kolesnikov A V and Dyadichev A V 2020 Determination of rational technological parameters of co-extrusion processing of secondary polymeric materials by the method of physical modeling Solid State Phenomena: 5th International Conference on Industrial Engineering, ICIE 2019 299 43-8 https://doi.org/10.4028/www.scientific.net/SSP.299.43

[20] Malitskova E A and Potapov I I 1997 Processing of plastic waste (Moscow: Avis Original) p 159

[21] Fogarty J, Rauwendaal C, Fogarty D and Rios A 2001 Turbo-Screw, New Screw Design for Foam Extrusion SPE ANTEC Techn. Papers

Acknowledgments
The study was carried out with the financial support of the Ministry of Education and Science of the Russian Federation within the framework of the scientific project FZEG-2020-0030.