Influence of technological parameters extruder on the quality of polymer compositions

Y. Bardadym, E. Sporyagin

Dnipropetrovsk national university Oles Honchar

Gagarin Avenue, 72, Dnipropetrovsk, 49010, Ukraine

ferocen@i.ua

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The process of mixing in combined extruders is discussed in this paper. We propose a method for determining the quality of the composites. Strip thickness is a quality criterion. As a result of our research, programs have been established, which can determine the mixing quality of polymer compositions. The quality criterion in this method is the strip thickness. Objective was to create programs that allow specifying the desired compositions quality during their processing. Adequacy of the task solution has been verified by experimental studies in the test unit.

Introduction

Getting a high physical and chemical characteristics of uniformity depends on the uniform components distribution in the bulk polymer. Therefore the mixing step is one of the most important in the processing of polymers [1 – 3].

A new promising direction for the implementation of this process is using of combined or screw-disc extruders that combine the advantages of both screw and disc machines, providing: high plasticizing and homogenizing power; high degree of mixing; high productivity; the possibility of obtaining complex profile products. Combined extruders provide the intensive melt degassing and allow a high degree of mixing and homogenization of the molten polymer.

This paper is dedicated to the discussion of the mixing quality of composite materials in the combined disk extruders' area. The quality criterion in this method is the strip thickness. Objective was to create programs that allow specifying the desired compositions quality during their processing. Adequacy of the task solution has been verified by experimental studies in the test unit.

Mathematical model

This paper describes the mixing process of polymer composite materials in the combined disk extruders' area. Some assumptions were made to simplify the mathematical calculations: the material is fed into the working gap as viscoelastic fluid and extruded as quasi-rigid body. Processed material is subjected to shear and stress-strain deformations due to the rotational-translational motion. These

deformations appear due to the uniform height change of the working gap. Therefore, detailed description of the mixing process in the disc area can be divided into three zones: entry zone, shear deformation and exit zone (Figure 1).

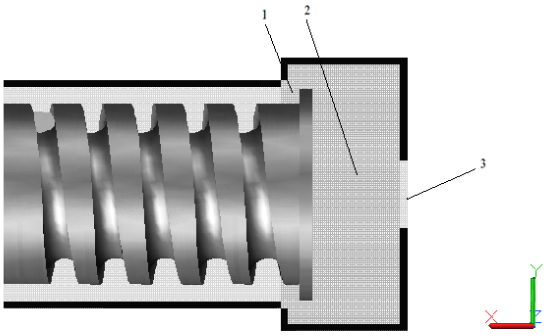


Figure 1. Disc zone components of the combined extruder: 1 – entrance area; 2 – zone of shear deformation; 3 – exit area.

Since the initial location of the interface in space is almost never known, we consider the idealized case. The starting mixture components are sequentially entered to the combined extruder working zone on the disc perimeter in the form of rings with certain thickness.The shear strain is directly proportional to the interface values. Thus, the shear deformation and the initial orientation of the particles in a shear field are important parameters for consideration of the mixing process. Increasing of the interfacial area will be equal to zero if the surface is oriented parallel to the initial flow direction. Increase the interface will be maximal if the original surface is oriented perpendicular to the flow direction. Interfacial surface can either increase or decrease at low shear deformation values depending on the initial orientation.

The concept of a generalized deformation is used for description of polymer melt conditions. Generalized deformation, determined in the area of shear deformation, has decisive importance.

$$\gamma_{Gd} = \frac{3}{2\sqrt{2}(1+\mu)}\gamma_{oss} \qquad (1)$$

where μ – Poisson's ratio; γokt – octahedral shear strain.

The dwell time of the polymer melt in the working gap is directly proportional to the disc radius, and is inversely proportional to the radial velocity Vr [4, 5]:

$$\tau = \int_R^{r_1} \frac{dr^{|}}{V_r} = \int_R^{r_1} \frac{dr^{|}}{UwR} = \int_R^{r_1} -\frac{r^{|}dz}{2\beta_1 \operatorname{Re} RwR} \qquad (2)$$

The strip thickness is used as a quantitative characterization of the mixing process. Thicknesses in lanes shear field decreases with increasing of the shear strain in accordance with the equation:

$$\frac{S}{S_0} = \frac{1}{\sqrt{1+\gamma^2}} \qquad (3)$$

As follows from the theory of ideal mixing, amount of the strip thickness is most affected by the initial interface components orientation. Therefore, the strip thickness depends on the distribution and surface volume of processed material:

$$l = \frac{2}{S/V} = \frac{2}{(S/S_0)(S_0/V)} \qquad (4)$$

Since the strip thickness in the stream is directly proportional to the initial size of the dispersed component particles and inversely proportional to the volume fraction and the shear strain, the equation for the calculation of this value will be:

$$l = \frac{2l_0 x_0 x_1}{\sqrt{1+\gamma_{Gd}^2 \frac{x_1^2}{y_1^2}}} \qquad (5)$$

It means that the minimal strip thickness values the stream can be achieved with small sizes of initial particles and large volume fraction of dispersible component.

Results and discussion

Important component of thickness of a strip is the consistence coefficient K:

$$\tau = \eta \cdot \gamma^n \qquad (6)$$

$$\ln \tau = \ln K + n \cdot \ln \gamma \qquad (7)$$

Figure 2 shows the dependencies lnτ from ln γ.

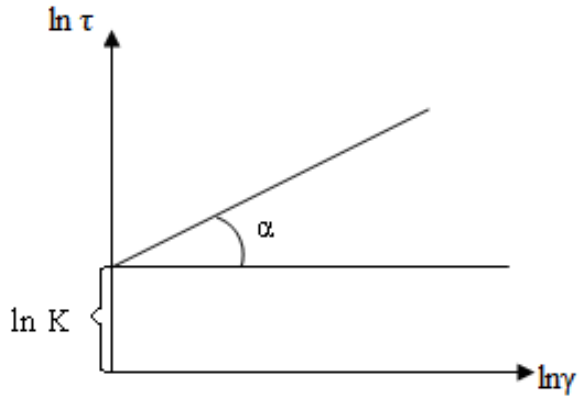


Figure 2. The graph represents dependencies lnτ from ln γ.

Figure 3 and Figure 4 show the dependence between the strip thickness and layer position in the gap. Curves do not take into account the stress-strain deformation at the entrance to the gap and the output, i.e., reflect only the influence of generalized deformation.

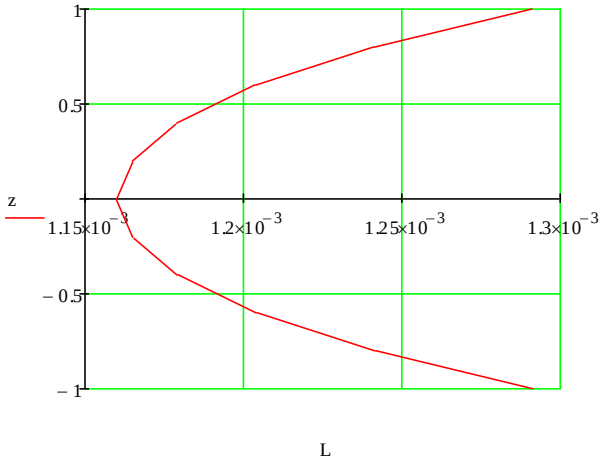


Figure 3. Dependence between the layer thickness and strips position in the discs gap: w = 5.25 s $^{-1}$; h = 0.01 m.

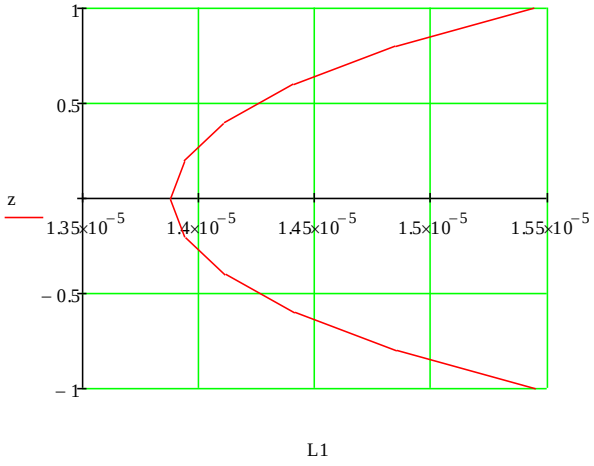


Figure 4. Dependence between the layer thickness and strips position in the discs gap: w = 21 s $^{-1}$; h = 0.01 m.

Strain-compression deformations have little influence on the mixing process at the small values of the working gap and disc speed. Thus, width of the bands is inversely proportional to the total deformation. Consequently, the larger particles and the

smaller dispersed phase volume concentration, the more deformation amount required to achieve any desired final bandwidths value. Empirical regularity was obtained by Z. Tadmor during the experiments on polymer compositions mixing: good (adequate) mixing is achieved when the amount of deformation is 18 000±6 000 shift units. It corresponds to the reduction in strips width to 10^4 [2]. However, it should be noted that the term "adequate mixing" is defined by requirements applying to the mixture. Our results are in good agreement with Z. Tadmor and presented on Figures 3 and 4.

If the smallest strip thickness is on the low speeds and small gaps, i.e. better mixing is observed at the gap center, there are two areas where the strip thickness is the minimal (at the high speed rotation and larger gaps). Position of these regions is defined by the octahedral deformation profile γokt. It should be noted that the strip thickness is reduced by approximately two orders of magnitude with increasing of the disc speed rotation from 50 rpm/min to 200 rpm/min. Strip thickness is reduced by about three orders of magnitude with an increase in the gap from 0.001 to 0.003 m at the constant rotational speed (ω = 21 s-1) [6, 7].

Analysis of the results shows that the mixing quality in combined extruders depends on the presence of secondary (circulation) flows in the disk area. In addition to the main melt stream extending on the spiral of Archimedes to the exit area, there will be a backflow to the disc center (Figure 5).

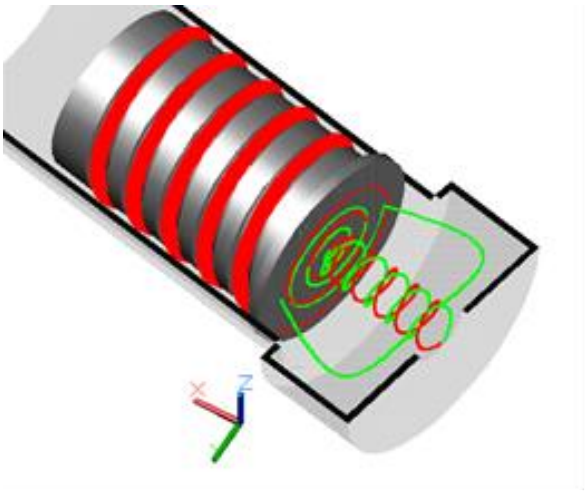


Figure 5. Scheme of the mixing process in the combined extruder

It is confirmed by microscopic examination. (Figure 6 - 9).

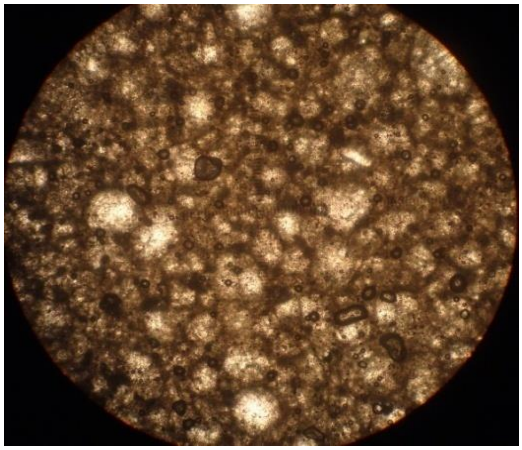
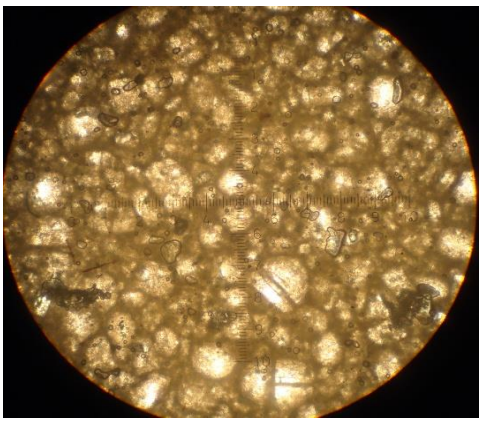
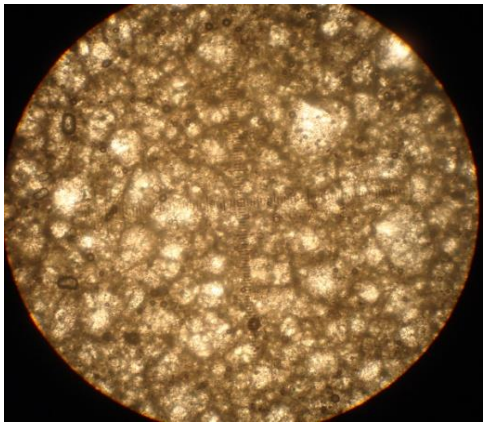


Figure 6. Microscopic photograph of the composition 1.



a)



b)

Figure 7. Microscopic photographs of the compositions 2 and 3.

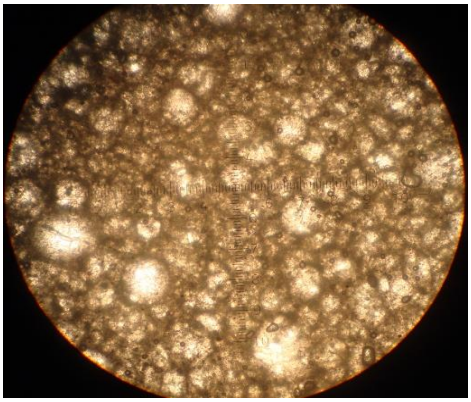


Figure 8. Microscopic photograph of the composition 4.

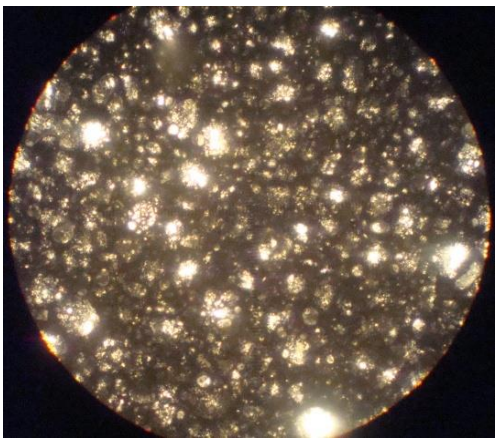


Figure 9. Microscopic photograph of the composition 5.

Conclusions

As a result of the research programs have been established, which can be used for determination the quality of polymer composition mixing. The experimental results support provided theoretical calculations (result convergence is near 96 %).

Experimental part.

Model highly filled compositions based on low molecular weight polybutadiene-nitrile rubber SKN-10Ktr and synthetic oil-containing diene rubber SKDO-80 were studied. NaCl formulation with following granulometric fractions (fraction 1 – 130 microns, fraction 2 – 130-160 microns) was used as an excipient. Sunflower oil fatty acids, stearic and oleic acids were selected as surfactants.

Table 1. Structure of composition

Worm-disc (combined) extruder was used. Figure 10 shows a combined extruder. Its faced disc surface and body are inclined to the rotation axis normal and there is working gap between them. The minimum operating gap value is defined by the axis of rotation, constant for selected disc radius and depends on the angle values of end surfaces inclination to the axis rotation normal. Due to this structure, there is a shift of the relative movement of the melt particles from one to another strain plane. It is caused by the tension-compression strains, which are determined by changes in the working gap in one disc revolution at a constant minimum operating gap [8].

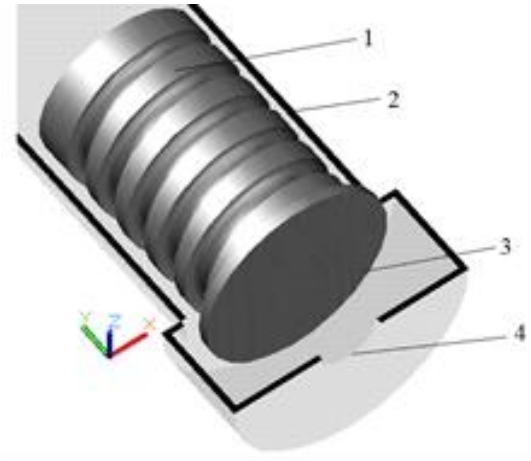


Figure 10. Combined extruder: 1 – screw; 2 – body of extruder; 3 – disc; 4 – outlet.

Screw and disc rotation (R = 0,055 m) was carried out using DC motor with adjustable speed in the range of ω = 50-200 rev/min. Test unit was equipped by the thermostatic cylinder system, screw, forming head with thermocouple and controlling devices for the coolant (water) temperature monitoring. Thermocouples were installed to the material cylinder for mixture temperature measuring. The forming head is provided with a pressure sensor and a thermocouple to measure the processed mixture temperature at the outlet of the cutting auger, respectively. 2 mm-thick samples from the half finished product were made and subjected to the microscopic examination on microscope Carl Zeiss Yena nu 2 with 50 -fold magnification.

№ composition	NaCl, mass %	SKN–10Ktr, mass %	SRDO–80 mass %	FAP–4, mass %	Surfactant, mass %	DOS, mass %
1	81,50	18,50	–	–	–	–
2	81,50	–	18,50	–	–	–
3	80,00	12,27	–	4,00	0,73	3,00
3а	83,00	12,27	–	3,00	0,73	1,00
3б	85,00	12,27	–	1,00	0,73	1,00
4	74,25	–	10,20	12,70	–	2,85
5	68,50	–	11,50	18,00	0,50	1,50

References

[1] V. Stobiac, M. Heniche, C. Devales, *Chem. enginer. research and design*. 2008, 86, 1410.

[2] I. O. Mikulionok, L. B. Radchenko *Applied chemistry*. 2012, 85, 1475.

[3] Z. Tadmor, C. Gogos, *Principles of Polymer Processing*. Wiley: Hoboken, NJ 2006.

[4] D. J. Zuilichem, E. Kuiper, W. Stolp, T. Jager, *Powder technology.* 1999, 106, 147.

[5] F. Ilinca, J. F. Hetu, *Comput Fluids*. 2010, 39, 1656.

[6] K. Rauvendaal, *Jekstruzija polimerov*, Professija, Sankt-Peterburg, 2008.

[7] Ju. V. Bardadym, E. O. Sporjagin, *Him. promisl. Ukraina*. 2012, 6, 45.

[8] Ju. V. Bardadym, E. O. Sporjagin , *Visnik Dnipr. univer*. 2013, 17, 10.