Вісник Тернопільського національного технічного університету
Scientific Journal of the Ternopil National Technical University
2017, № 1 (85)
*ISSN 1727-7108. Web: **visnyk.tntu.edu.ua***

UDC 678.023.5

DETERMINATION OF RATIONAL STRUCTURAL PARAMETERS OF DEVICES FOR POLYMER RECYCLING

Oleh Synyuk

Khmelnytskyi national university, Khmelnytsky, Ukraine

Summary*. The method of definition of rational structural parameters of gear rolls (step and angle of teeth profile, radius of curvature, the depth of the channel) was developed for such a stress-strain state of a polymeric material in which the change of orientation of conglomerates (groups) of a spheruline polymeric material occurs, causing the creation of a structure in the material. When it is exposed to tensile stresses in the direction perpendicular to the orientation, the polymer material can be destroyed.*

Key words*: recycling, deformation, rollers, teeth, profile angle, structure, destruction.*

Received 03.04.2017

Problem setting. Today the problem of waste products recycling of polymeric material has actual meaning not only from the position of environmental protection, but also it is connected with, it under the conditions of deficiency of polymeric raw materials plastic waste products become additional resources of raw materials and power (energy) resources.

Nevertheless the problem solution, connected with the environmental protection, demands considerable capital expenses. The value of trimming and the destruction of waste plastics approximately eight times increases wastes for the recycling of the majority of the most industrial and almost three times – for the destruction of the domestic wastes. It is connected with the specific plastics peculiarities, which considerably complicate or do unusable famous methods of firm wastes destruction. Especially this pertains to film materials of polyethylene.

The main way of usage of waste plastics – this is their utilization or reusing. In the works [1] is shown, that capital and operation (working) expenses according to the main ways of waste utilization don't increase, and in many cases even below wastes for their destruction. The positive moment of given means usage is the possibility of receiving while recycling polyethylene wastes of useful products for different branches of national economy and the decreasing of environmental pollution.

The article suggests the construction of the gear for the secondary waste recycling of polymeric materials by mechanic means. This recycling way doesn't demand expensive special equipment and can be realized at any place of waste accumulation. Except of it, mechanic waste processing of polymeric materials allows to reserve in the renewed polymer practically all mechanic properties, which are similar to original.

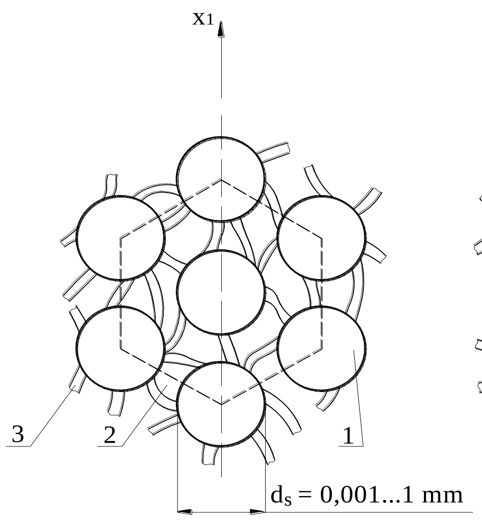
Analysis of available research results. An endless amount of works [2 – 3] is dedicated to the equipment development for the polymeric wastes recycling, nevertheless under it weren't analyzed the mechanic and structural characteristics changing of polymeric material under the deformation process. For the development of technologic equipment for such process it is necessary to created common model approach, which would allow following the directed changes in polymeric material, with different types of strained and deformation state [4], which are generated by technological devices during recycling process of polymeric waste products. It will give ability to supply with necessary loads in definite succession that will allow supplying with the recycling of waste products of polymeric materials under minimum power wastes.

Corresponding author: Oleh Synyuk; e-mail: synoleg@ukr.net

Research objectives. To devise the method of determination of rational constructions of parameters of teeth rollers, which will allow polymeric material recycling, by getting the material with the structure, oriented lengthwise of the action of extending load.

Task setting. As it is known [5, 6, 7], if we influence on polymeric material by definite load, it can be received the changing of its structure, so supplying properties anisotropy in various directions. As the result of this polymeric material will have maximum firmness in one direction and minimum – in another. Applying the loading into the direction of minimal firmness of polymer technologic equipment for recycling loses minimum energy quantity for polymeric material destruction.

Previous researches determined that for the polymeric material destruction with minimal energy wasting it is firstly necessary to give it for the action of strain extension into the direction x1, and then strains of tensions into the direction x2 (fig. 1).



a b

Figure 1. Change of spheruline supramolecular structure of polymer material as a result of the tensile stress (a) – not oriented structure, (b) – oriented structure; 1 – spherulite; 2 – amorphous space; 3 – passable microfibrils

Applying the stress and strain along the axis x1 we will orient membranous (film) material into the action direction of this load, and applying after this the tension strain alongside the axis x2 we orient macromolecules. At the end of the recycling process the polymeric material diminishing in size is done. Technologic equipment that is carried out, should supply the realization of such load succession.

Having analyzed all available devices now for polymeric material recycling we can say that given gears destroy the polymer by the way of acting of big loadings of definite type – extension, shrinkage, shear et cetera. Time and the sequence of operation of these loadings at the final result haven't been investigated, but reckon on only the equipment constructional and technological parameters, which supply the polymeric material diminishing in size.

The polymeric material recycling process is investigated, taking into consideration its structure, and the changing of this structure depending on dimension and applied loads succession. It will allow decreasing energy expenses for the polymeric wastes recycling, and maximum reserve structural and mechanic characteristics in recycled polymeric material.

Main material and results. On the base of mentioned above for waste recycling of polymeric material it is suggested to use the device, which supply its destruction – and material tension into the axis direction x1 and then extension in perpendicular to the prior direction deformation, it is alongside the axis x2 and hereby to finish the recycling process (fig. 2).

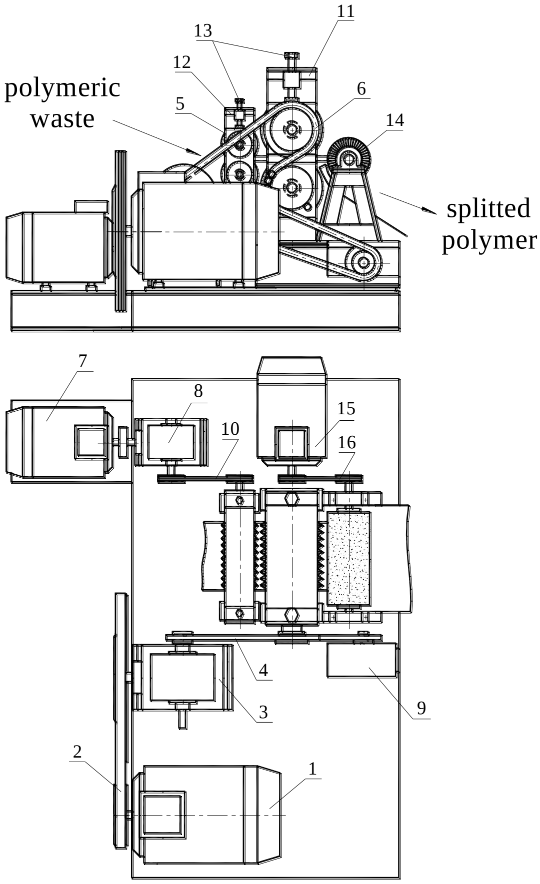


Figure 2. The device for polymer recycling
1, 7, 15 – electric motor; 2 – belt drive;
3, 8 – worm gear reducer; 4, 10, 16 – chain transmission;
5 – toothed roller device; 6 – roller device with a profile Rolo; 11, 12 – supports; 13 – thrust bolts; 14 – wire brush

The first joint (fig. 2) – teeth rollers – supplying the polymer material tension into the direction, perpendicular to polymer feeder. On these rollers surface teeth are done. These teeth location on the rollers is done by the way that the hollow on the one roller was correspondent to the lug on the other. This will supply maximum polymeric material tension into the transversal to the direction feeder.

The second joint – rollers, made according to Rolo profile – supply the polymeric material tension into two directions: lengthwise and crosswise material feeder, and the largest tensions and, correspondingly, the biggest deformations appear in the direction x1, id est lengthwise the pellicle (film) polymeric material feeder.

In the result of pellicle polymeric material sequential deformation into the directions x1 and x2 was received the material with weaken connections between the spherulites conglomerates, which is under diminishing at needle cutter (fig. 2).

Let us enter into details of every stage of technologic operation of polymeric material recycling. In the suggested article the teeth rollers constructive parameters are determined, allowing polymeric material destruction, receiving the material structure oriented into the effort application direction. Under the action of teeth rollers on the film polymeric material, the material being appeared between the lug of one roller and the hollow of the other, is stretched.

The polymeric material deformation between the roller lugs and hollows is done only in the case, when the pellicle polymeric material will be situated on the teeth that is it won’t be slipping (gliding) available and its free location on the rollers surface. So, the efforts, pressing polymeric material between the lugs and the hollows, have to be always in comparison with tensile (fig. 3). In another case the polymer sliding without deformation is possible.

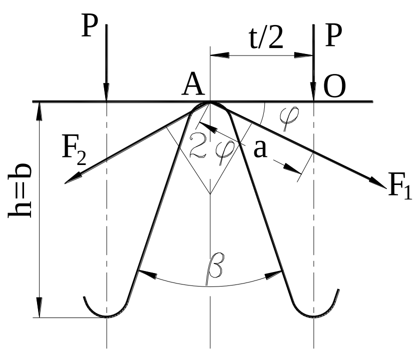


Figure 3. Deformation of the polymer in the toothed roller device

To supply above mentioned conditions it is necessary to determine the rollers constructive parameters and the technological parameters of the polymeric material deformation process between the rollers.

We will consider, firstly, the polymeric material deformation process in the places of compression at the teeth ends. The supplying of necessary material jamming (pinching) in the indicated places will allow receiving of the necessary deformation. For the indicated process providing it is necessary to add the force P, which is determined of such correlation (relation):

$$F = \frac{24 E \cdot I \cdot b}{t^3}, \tag{1}$$

when E – momentary elasticity module; $I = \frac{h^3}{12}$ – the inertia moment of material transversal crosscut; t – teeth step; b – polymeric material sagging when passing via teeth rollers; h – the hollow depth (the lug height).

On the teeth top it is necessary to create the effort (force) F_1, which won't give for polymeric material to glide:

$$F_1 = F \cdot f, \tag{2}$$

where f – the coefficient of polymeric material friction on the teeth surface.

The opposite polymeric branch is stretched by the force F_2, which can be received of Eiler equation:

$$F_2 = F_1 \cdot e^{2\cdot\varphi\cdot f} = \frac{24 f \cdot E \cdot I \cdot b}{t^3} \cdot e^{2\cdot\varphi\cdot f}, \tag{3}$$

when $2\varphi = 2\,arctg\,\frac{2b}{t}$ – the angle of tooth girth.

The tension extension, appearing in polymeric material, we'll get of such equation:

$$T = \sigma_{str}\, S = E \cdot \varepsilon_{str} \cdot \delta, \tag{4}$$

where S – the area of diametrical polymer crosscut; δ – the polymer thickness; $\varepsilon_{str} = \frac{\sqrt{4b^2 + t^2}}{t} - 1$ – relative polymeric material extension.

To provide necessary extension it is required to obtain the condition execution $F_2 \geq T$, id est:

$$\frac{24 f \cdot E \cdot I \cdot b}{t^3} \cdot e^{2 f \, arctg \frac{2b}{t}} \geq E\delta \left(\frac{\sqrt{4b^2 + t^2}}{t} - 1 \right). \tag{5}$$

The maximum polymeric material extension is possible in the case, when its caving in (b) while passing via teeth rollers will be equal to the hollow depth (the lug height) (h), id est $h = b$.

Taking into consideration the condition (5) and supplying the maximum polymeric material extension we'll express the hollow depth (the lug height) via teeth step in such a way:

$$h = \frac{t}{2 tg \frac{\beta}{2}}. \tag{6}$$

Substituting into the equation (5) instead of polymeric material deflection (caving in) the hollow depth (the lug height) we will get:

$$\frac{24 f \cdot E \cdot I \cdot t}{2 t^3 tg \frac{\beta}{2}} \cdot e^{2 f \, arctg \left(\frac{1}{tg \frac{\beta}{2}} \right)} \geq E\delta \left(\frac{\sqrt{\frac{t^2}{tg^2 \frac{\beta}{2}} + t^2}}{t} - 1 \right). \tag{7}$$

Having done some mathematical changes of equation (7) we will receive the expression for the step t:

$$t \leq \sqrt{\frac{12 f \cdot I \cdot e^{2 f \, arctg \left(\frac{1}{tg \frac{\beta}{2}} \right)}}{h \left(\sqrt{1 + tg^2 \frac{\beta}{2}} - tg \frac{\beta}{2} \right)}}. \tag{8}$$

Having put into equation (8) the expression for the inertia moment we have:

$$t \leq \sqrt{\frac{f \cdot h^2 \cdot e^{2 f \, arctg \left(\frac{1}{tg \frac{\beta}{2}} \right)}}{\sqrt{1 + tg^2 \frac{\beta}{2}} - tg \frac{\beta}{2}}}. \tag{9}$$

From the equation (9) it is seen, that for the teeth of rollers the angle of teeth profile influences, which has to be chosen in such a manner, that at the action on polymeric material in it was created necessary extension, under which recycled film polymeric material will have oriented structure.

By means of teeth profile angle we can determine the polymeric lot length, gripped between the rollers teeth:

$$t' = 2l_1 = \frac{t}{\sin\frac{\beta}{2}}, \tag{10}$$

where l_1 – the length of lateral tooth surface.

Polymeric material elongation after it passing between teeth rollers we will determine out of such formula:

$$\varepsilon_{str} = \frac{t'-t}{t} = \frac{1}{\sin\frac{\beta}{2}} - 1. \tag{11}$$

According to the known deformation, which is necessary to be created in polymeric material, to receive oriented structure, out of equation (11) we'll define teeth angle:

$$\beta = 2\arcsin\frac{1}{1+\varepsilon_{str}}. \tag{12}$$

Out of equation (9) according to the known teeth angle β we'll define teeth step t.

On the fig. 4 a the teeth angle dependency is shown β of extension deformation or compression $\hat{\varepsilon}_1$. The equation for the determination of necessary extension or compression deformation, to destroy the polymeric material structure, got before and given in works [5 – 7]. According to the known angle of teeth profile, it can be determined the teeth step t fig. 4 b.

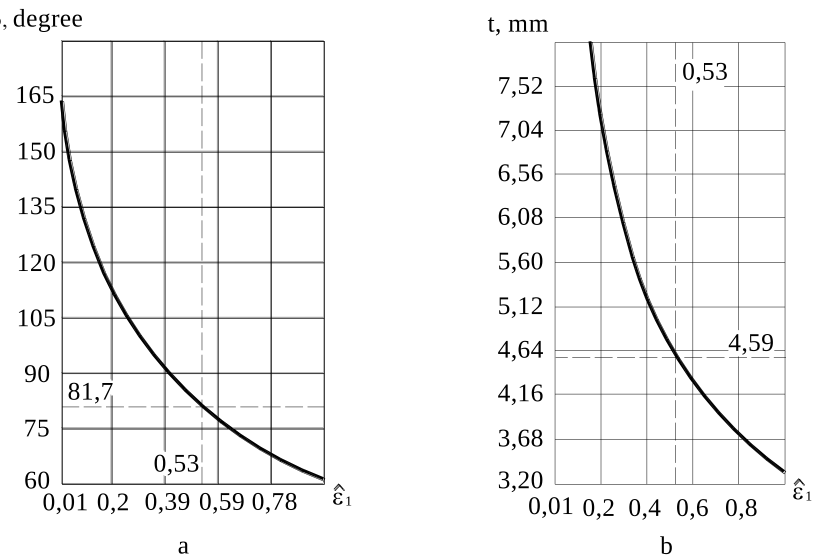


Figure 4. The dependence of the angle of teeth β (a) and step of teeth *t* (b) from the strain $\hat{\varepsilon}_1$ that is created in the polymer by passing it between teethed rollers

During the polymeric material passing between the teeth rollers except its extension on the teeth tops observed its bend on the tooth top radius (fig. 5). It is known [8], that while bending the polymeric material outer layer will be stretched, and inner – will be shrunk.

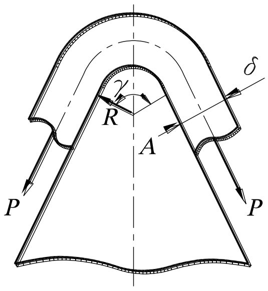


Figure 5. Bend of the polymer on a tooth

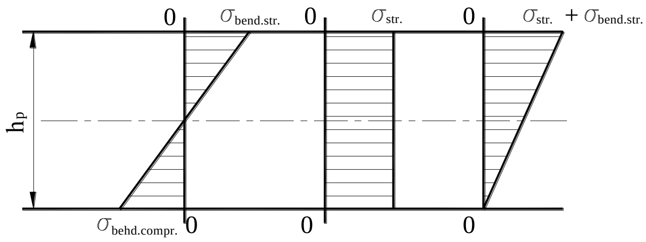


Figure 6. Diagrams of internal stresses arising in the polymeric material

The polymeric material inner layer pressing on the teeth tops will encumber its air hole. For polymeric material elongation we'll follow the condition, which is that the shrinking tension in the inner layer will be compensated by the stretching tension (fig. 6): $\varepsilon_{compr} = \varepsilon_{str}$.

$$\varepsilon_{str} = \frac{\gamma\left(r + \frac{h}{2}\right) - r\gamma}{r\gamma} = \frac{h}{2r}. \qquad (13)$$

The compression strain should be compensated by extension. Consequently, the roller teeth radius can be defined out of such equation:

$$r = \frac{h}{2\varepsilon_{str}}. \qquad (14)$$

According to [8] at transversal bend of tension are equal to zero on the polymeric material axis and are maximum near its surfaces. So, it is necessary to define the maximum compression deformation.

Hereby, having determined the necessary deformation, that leads to the polymeric structure changing, according to the above mentioned equations constructive parameters can be calculated (step and the angle of teeth profile, the rounding radius, the channel depth), that will supply the given deformation.

Conclusions.

In the given article the method of determination of rational constructive parameters of teeth rollers is presented for the receiving of such polymeric material deformation, by which orientation of its structure into the direction of the action of the strain tension is realized.

Having added to the film polymeric material of oriented structure perpendicular to the orientation direction strain tension we will ruin the connections that are created by passing macromolecules. For these tensions creation it is necessary to let pass before stretched polymeric material between the rollers that are made according to Relo's profile. The constructive parameters calculations of these rollers will be explicated in the next publications.

References

1. Mantiya F.La. Vtorichnaya pererabotka plastmass. St. Petersburg, Professiya, 2006. 400 p. [In Russian].
2. Misiats V.P., Burmistenkov O.P., Hladchuk O.Z. Modeliuvannia protsesiv ruinuvannia polimernykh materialiv pry podribnenni. Visnyk KNUTD, 2007, no. 3, pp. 40 – 45. [In Ukrainian].
3. Skyba M.Ie., Mykhailivskyi Iu.B., Holovko H.S. Modeliuvannia protsesu podribnennia kompozytsiinykh materialiv z vykorystanniam metodu skinchenykh elementiv. Visnyk Tekhnolohichnoho universytetu Podillia, 2003, no. 6, pp. 7 – 11. [In Ukrainian].
4. Giginyak F.F., Lebedev A.O., Shkodzins'kyi O.K. Strenth of Structural Materials under Low-Cycle Loading at a Complex Stress State. Kyiv, Naukova Dumka, 2003. 270 p. [In Ukrainian].

5. Syniuk O.M. Model budovy nedeformovanykh polimeriv sferolitnoi struktury. Visnyk Khmelnytskoho natsionalnoho universytetu, 2016, no. 3, pp. 181 – 187. [In Ukrainian].
6. Syniuk O.M., Skyba M.Ie. Modeliuvannia zminy nadmolekuliarnoi struktury polimernykh materialiv pid chas oriientatsiinoi vytiazhky. Visnyk Khmelnytskyi natsionalnyi universytet, 2016, no. 6, pp. 45 – 51. [In Ukrainian].
7. Syniuk O.M. Vyznachennia pruzhnykh vlastyvostei amorfno-krystalichnykh polimeriv sferolitnoi struktury. Visnyk Vinnytskoho politekhnichnoho instytutu, 2016, no. 6, pp. 77 – 85. [In Ukrainian].
8. Skyba M.Ie. Poslablennia volokonnoi struktury shkiry pry dvoosnomu deformuvanni. Visnyk Tekhnolohichnoho universytetu Podillia, 2003, no. 1, pp. 7 – 14. [In Ukrainian].

Спис ок використаної літератури

1. Мантия, Ф.Ла. Вторичная переработка пластмасс [Текст] / Ф.Ла. Мантия (ред); пер. с англ. под. ред. Г.Е. Зайкова. – СПб.: Профессия, 2006. – 400 с.
2. Місяць, В.П. Моделювання процесів руйнування полімерних матеріалів при подрібненні [Текст] / В.П. Місяць, О.П. Бурмістенков, О.З. Гладчук // Вісник КНУТД. – 2007. – № 3. – С. 40 – 45.
3. Скиба, М.Є. Моделювання процесу подрібнення композиційних матеріалів з використанням методу скінчених елементів [Текст] / М.Є. Скиба, Ю.Б. Михайлівський, Г.С. Головко // Вісник Технологічного університету Поділля. – 2003. – № 6. – С. 7 – 11.
4. Giginyak F.F., Lebedev A.O., Shkodzins'kyi O.K. Strenth of Structural Materials under Low-Cycle Loading at a Complex Stress State. Kyiv, Naukova Dumka, 2003. 270 p.
5. Синюк, О.М. Модель будови недеформованих полімерів сферолітної структури [Текст] / О.М. Синюк // Вісник Хмельницького національного університету. – 2016. – №3. – С. 181 – 187.
6. Синюк, О.М. Моделювання зміни надмолекулярної структури полімерних матеріалів під час орієнтаційної витяжки [Текст] / О.М. Синюк, М.Є. Скиба // Вісник Хмельницького національного університету. – 2016. – №6. – С. 45 – 51.
7. Синюк, О.М. Визначення пружних властивостей аморфно-кристалічних полімерів сферолітної структури [Текст] / О.М. Синюк // Вісник Вінницького політехнічного інституту. – 2016. – № 6. – С. 77 – 85.
8. Скиба, М.Є. Послаблення волоконної структури шкіри при двоосному деформуванні [Текст] / М.Є. Скиба // Вісник Технологічного університету Поділля. – 2003. – №1. – С. 7 – 14.

УДК 678.023.5

ВИЗНАЧЕННЯ РАЦІОНАЛЬНИХ КОНСТРУКЦІЙНИХ ПАРАМЕТРІВ ПРИСТРОЇВ ДЛЯ ПЕРЕРОБКИ ПОЛІМЕРІВ

Олег Синюк

Хмельницький національний університет, Хмельницький, Україна

Резюме. *Розроблено метод визначення раціональних конструкційних параметрів зубчастих валків (крок та кут профілю зубців, радіуса заокруглення, глибина каналу) для отримання такого напружено-деформаційного стану полімерного матеріалу, при якому відбувається зміна орієнтації конгломератів сферолітів полімерного матеріалу, в результаті чого в матеріалі створюється певна структура, при дії на яку напруженнями розтягу в перпендикулярному до орієнтації напрямку можна зруйнувати полімерний матеріал.*

Ключові слова*: переробка відходів, деформація, валки, зубці, кут профілю, структура, руйнування.*

Отримано 03.04.2017