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The Exploitation Properties of Hemp Fibres Containing Linear Low Density Polyethylene Composites

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Abstract. **Three types of hemp fibres that are grown under different conditions were studied, as well as the exploitation properties of linear low density polyethylene composites (tensile strength, modulus, deformation ability, microhardness, water resistance, and fluidity) were evaluated. Studies showed the possibility of using the given hemp fibres as reinforcements of LLDPE. Optimal content of fibres (length up to 1 mm) was 30 wt.%, and the obtained composites had good exploitation properties.**

Keywords: **hemp fibres, linear low density polyethylene, composites, exploitation properties.**

I. Introduction

Natural vegetable fibres and their textile waste are perspective reinforcements for the modification of different polymers [1,2]. These composites are environmentally friendly innovative materials, and their application is defined by a low cost and density. Moreover, they are unlimited sources with the ability to reproduce quickly. Technological properties of these composites allow processing materials with traditional polymer processing methods. Thermal stability of natural vegetable fibres is limited, and, when temperature exceeds 200^0C, irreversible changes begin in the structure of fibres, which dramatically worsen their exploitation properties. Therefore, the most useful polymer matrices for natural fibre composites are polyolefins, which have relatively low (under 200^0C) processing temperatures. Our previous research objects were composites based on linen yarn production waste, virgin low density polyethylene [3-6], and different types of recycled polyethylene [7-10]. Modification of all these polymers with linen waste increases physical and mechanical properties of polyolefins (optimal content of waste was 40 wt.%, sometimes 50 wt.%), but low water resistance of composites is improved by using interfacial modifier stearic acid and diphenylmethane diisocyanate, which diminish water absorption of composites 3–4 times [4,5,7,8]. Recently, due to their excellent properties the linear low density polyethylene (LLDPE) has become a very popular type of polyolefin. In scientific literature, one can find data about LLDPE and natural fibre containing composites [11-14]. The authors of these studies found out that optimal content of natural fibres in LLDPE composites is 30 wt.%. Due to considerable improvement of strength properties and decrease in shrinkage, the authors recommend materials for production of different items, which can be used in the car industry. Our first studies, where we modified the LLDPE matrix with natural textile fibre waste (flax, cotton and hemp) were summarized in [15]. Results of these studies also showed perspectives of composites based on linear low density polyethylene (LLDPE) and flax, cotton or hemp fibres waste as reinforcements. Optimal content of fibres was 30 wt.%. Based on the evaluation of fibre length influence on composite mechanical properties, it has been stated that the best properties are possible to get if the used fibre length is not higher than 1 mm.

This paper presents the results of studies of exploitation properties: tensile strength, modulus, elongation at break, microhardness, water resistance and fluidity of LLDPE and hemp fibre composites.

II. Materials and Methods

LLDPE grade LL 6201 (MFI=50g/10min.) was used as a polymer matrix. Modifiers were three types of hemp fibres grown under different conditions in Poland (Bialobrzeskie-BPL) and in Latvia (Bialobrzeskie-BLV and "Purini"-PLV). Content of hemp fibres (length up to 1 mm) in composites was 10–40 wt.%. Composites were prepared by mixing of components on two rolls mills, then cooled, granulated and pressed in 1 mm thick sheets, from which specimens were cut off for tensile tests (standard ASTM D 638 M-93). Fluidity was estimated by the method of melt flow index (MFI) (T=190^0C, P=2.16 kg) according to ASTM D 1238-90b standard. Microhardness (MH) was examined by Vickers M41 under a load of 200g. Water exposure experiments (standard ASTM D 570-98) were carried out at room temperature (+23^0C).

III. Results and Discussion

For all types of hemp fibres, their chemical composition, types and number of impurities were checked, as well as physical and mechanical properties: tensile strength, length of fibres, linear density etc. were evaluated. It has been found that fibres BLV have the lowest level of impurities (4.5%) and linear density (23.4 cN/tex), but BPL hemp fibres have the highest level of impurities (6.3%), the longest fibres (medium 289 mm) and the greatest tensile strength (35.1 cN/tex). Chemical composition of fibres differs. BPL hemp fibres have the greatest level of cellulose fibres (70.5%), pectins (1.6%) and moisture content (9.6%). On the contrary, PLV fibres have the lowest level of cellulose (64.2%), pectins (1.4%) and moisture (9.2%), but the level of hemicellulose (23.8%) and lignin (8%) is higher. BLV contains only 0.52% of fats and waxes and 5.68 % of the lignin, which are the lowest levels observed for the hemp fibres under consideration (see Fig. 1).

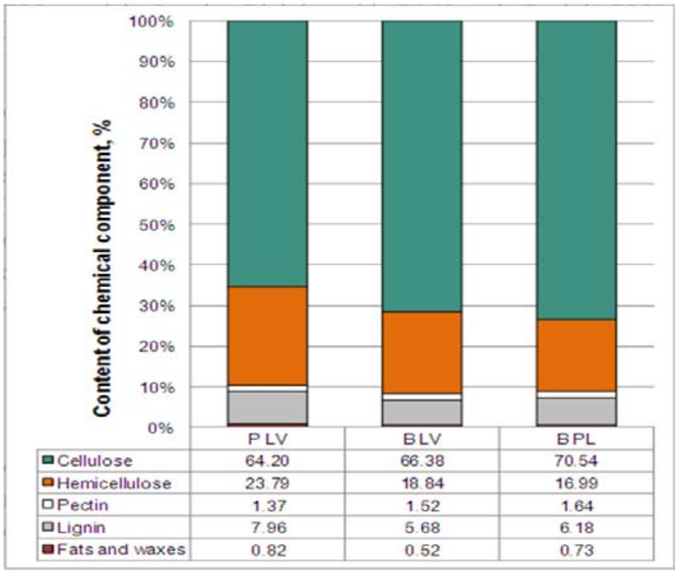

Fig.1. Chemical composition of hemp fibres
PLV-Purini Latvia, BLV-Bialobrzeskie Latvia, BPL-Bialobrzeskie Poland

The study of tensile properties of composites (Fig. 2–3) showed that for all types of fibres optimal content was 30 wt.%. Increase in fibre reinforcement in LLDPE matrix composites increases their tensile strength (Fig. 2) 2–2.5 times and reaches 21.8–25.8 MPa. The highest increase in tensile modulus (up to 3–3.5 times) was observed for composites containing BPL hemp fibres (E_t=1485 MPa) (Fig. 3).

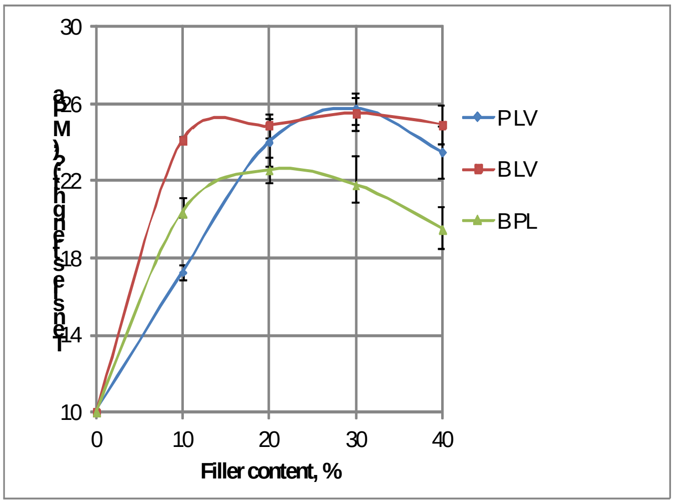

Fig. 2. Dependence of tensile strength of LLDPE composites on the content of hemp fibres. Notations as in Fig. 1

It could be explained by the highest content of cellulose fibres (70.6%) and high content of lignin (6.2%) and pectins (1.64%) in hemp BPL fibres, serving as the glue between the cellulose fibres and improving the interaction on the surface of cellulose fibres. Relative elongation at break (ε) dramatically (5 times) decreased from 60% (for LLDPE) up to 10.5–14% (filler content of 10 wt.%), and then the change was less due to an increase in the number of fibres. In the case of filler content of 40 wt.%, elongation at break was almost the same for all composites (4.8–5.8%). This fact shows that the influence of fibres on the mobility of LLDPE matrix macromolecules is similar and, therefore, the deformation ability of composite materials does not differ much.

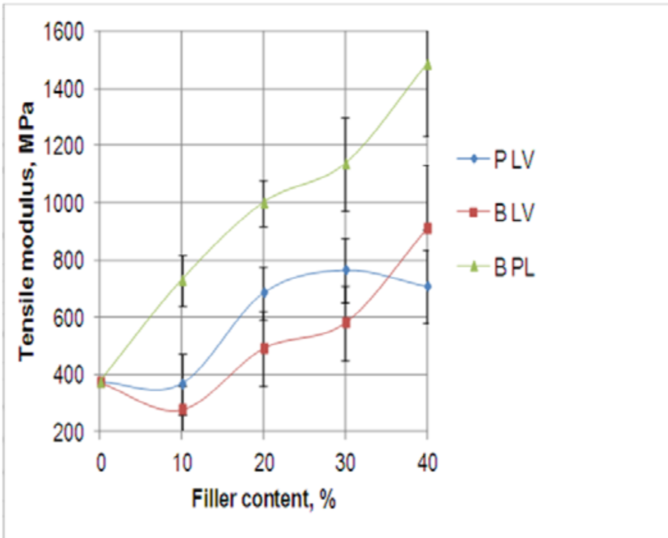

Fig. 3. Dependence of tensile modulus of LLDPE composites on the content of hemp fibres. Notations as in Fig.1

The study of tensile properties showed that chemical composition of hemp fibres did not significantly influence mechanical (tensile) properties of composites, and these values were compared with the results of our previous studies [15]. It means that all types of used hemp fibres are useful for preparing polyolefin composites.

Composite materials possess a very important property – they can be processed by different methods. This property depends on the fluidity of the molten material. To evaluate the fluidity, the authors of the paper used capillary viscosimetry, the method of melt flow index (MFI). The experiments showed that in spite of the fact that MFI numerical values decreased along with the increase in the filler content (see Table 1), almost all composites maintained good technological properties. MFI measurements gave values of 1g/10min for BPL and 1.8 g/10min for BLV, which was sufficient to process these composites with traditional polymer processing methods (extrusion, compression moulding). It is necessary to note that composites containing fibres with a high content of rough particles (such as shive) of impurities (BPL, 6.3%, BLV, 4.8%) have lower fluidity and composites with 40 wt.% fillers lose possibility to flow under the MFI measured conditions. Composites based on PLV (impurities 4.0 %) hemp fibres (40 wt.%) maintain sufficiently good fluidity (MFI=0.4 g/10 min), which is useful for the extrusion process. Better fluidity of PLV containing composites can be explained by the highest (0.82%) content of waxes and fats in hemp fibres, which can serve as additional interfacial lubricant improving the fluidity of polymer matrix.

TABLE 1

MELT FLOW INDEX (MFI) VALUES OF LLDPE COMPOSITES CONTAINING DIFFERENT TYPES OF HEMP FIBRES

Type of hemp fibre	Fibre content, wt.%	MFI, g/10min	Absolute mistake,%
Purini PLV	10	20.45	2.2
	20	6.62	0.3
	30	1.38	0.3
	40	0.40	0.1
Bialobrzeskie, BLV	10	18.11	1.7
	20	5.45	0.6
	30	1.85	0.3
	40	0	0.0
Bialobrzeskie, BPL	10	15.68	2.4
	20	2.36	0.4
	30	1.02	1.4
	40	0	0.0

Very important properties of composite materials are friction, wear resistance and hardness. One of the methods, which characterizes and evaluates these properties, is microhardness (MH) experiments (see Table 2).

Microhardness results presented in Table 2 do not differ a lot. Deviation of MH values from the mean value was 10–12%. It is evident that hardness of materials increases along with an increase in the filler content. This phenomenon was observed for all types of hemp fibres. Moreover, the system with BPL fibres (40 wt.%) reached the largest MH values (76.4 MPa). Here we can see correlation between the MH values and the composition of hemp fibres. BPL hemp fibres contain more cellulose fibres and rough particles of impurities, which can promote an increase in MH of materials. On the contrary, the composites based on LLDPE and 40 wt.% Purini (PLV) hemp fibres have the lowest MH values (58.9 MPa). These fibres contain the lowest level of cellulose fibres (64.2%) and coarse impurities (4.0%) and the highest level (0.82%) of waxes and fats that obviously decrease the surface hardness of composites. Besides, the composites with the highest MH value are filled with BPL hemp fibres, which have the best tensile strength.

TABLE 2

MICROHARDNESS (MH) MEASUREMENT RESULTS OF LLDPE COMPOSITES CONTAINING DIFFERENT TYPES OF HEMP FIBRES

Kind of hemp fibre	Fibre content, wt.%	Medium. Diagonal, cond.units	Medium MH, MPa
Purini PLV	10	242.3	37.7
	20	209.3	49.2
	30	200.3	53.6
	40	191.2	58.9
Bialobrzeskie, BLV	10	241.8	36.8
	20	209.5	49.0
	30	200.7	53.4
	40	179.5	66.8
Bialobrzeskie, BPL	10	234.1	39.3
	20	210.7	48.5
	30	183.0	64.3
	40	167.8	76.4

One of the main drawbacks of natural fibre composites is their rather poor water resistance. Therefore, water resistance measurements are very important and necessary. Results of these experiments are presented in Table 3.

As expected, water resistance experiments gave results, which are typical for the composites containing natural fibres. Water absorption for composites containing all types of hemp fibres increased along with an increase in the number of fibres.

TABLE 3

THE EXAMINATION RESULTS OF WATER ABSORPTION (%) OF LLDPE COMPOSITES CONTAINING DIFFERENT TYPES OF HEMP FIBRES

Type of filler	Filler content wt.%	Water exposure time, h								
		1	2	5	24	48	72	96	120	240
Purini PLV	10	0.0	0.1	0.2	0.4	0.6	0.8	0.9	1.0	1.6
	20	0.1	0.2	0.5	1.2	1.8	2.4	2.7	3.0	4.6
	30	0.4	0.7	1.3	2.9	4.4	5.5	6.0	6.7	8.8
	40	0.6	1.2	2.1	4.7	7.1	9.0	9.9	10.7	11.9
Bialobr-zeskie BLV	10	0.0	0.1	0.2	0.4	0.6	1.0	1.0	1.1	1.8
	20	0.1	0.3	0.6	1.3	2.0	2.6	3.0	3.2	4.8
	30	0.3	0.6	1.3	2.9	4.3	5.7	6.3	6.8	8.5
	40	0.6	1.2	2.3	5.1	7.6	9.7	10.4	11.1	12.1
Bialobr-zeskie PLV	10	0.0	0.1	0.2	0.4	0.6	0.8	1.0	1.1	1.6
	20	0.1	0.2	0.4	1.0	1.6	2.0	2.2	2.5	3.8
	30	0.3	0.5	0.9	2.2	3.4	4.2	4.7	5.3	7.1
	40	0.5	0.9	1.6	3.6	5.5	6.9	7.6	8.5	10.8

Systems with 10 wt.% fillers absorbed almost the same water amount (1.6–1.8%) for 240 h exposure to water, but when the content of fibres increased up to 40 wt.%, the absorbed water quantity differed more. The lowest values were observed for the systems with BPL fibres of 10.8%, but for PLV – 11.9% and BLV – 12.1%. These numerical values are typical also for the composite materials containing flax fibres [5,8,9,10].

It is important to note that in spite of the very fast water absorption of the samples in the first 24 h of exposure to water, the equilibrium value of water absorption for 240 h of experiments could not be reached. It means that the examination of exposure to water should be continued, but it has not be implemented in the framework of this research. To improve the water resistance, an interfacial modifier is usually used, which will be the next step of our further research.

IV. Conclusion

The study of exploitation properties of the composites based on LLDPE/hemp fibres with different chemical composition showed that the changes in fibre chemical composition did not significantly influence the properties of composites. The best results were obtained for the composites with BPL fibres, but the results of other composites did not differ a lot. Therefore, all used hemp fibres can be successfully applied to prepare polymer composite materials. Optimal content (30 wt.%) of fibres in LLDPE matrix for all types of hemp fibres was observed. These composites maintain sufficient fluidity, and they can be processed by traditional polymer processing methods.

References

[1] **Rowell R.M.** A new generation of composite materials from agro-based fibre // Polymer and other advanced materials: emerging Technologies and business opportunities / Ed. by Prasad P.N., Mark I.E., Fai T.J.. – Plerum press. – 1995. -pp. 659 - 665.

[2] **Sanadi A.R., Caulfield D.F. and Jacobcon R.E.** Agro – fibre thermoplastic components // Paper and composites from agro – based resources. – Lewis Publ., - 1997. – pp. 377 - 401.

[3] **J. A. Kajaks, V. N. Bulmanis, S. A. Reihmane, M.G. Tsiprin**. Effect of Linen Yarn's Production Waste Composition and Concentration on Physico - Mechanical Properties of Polyolefine Composites. - Mechanics of Composite Materials, 1997,vol.33, No 3, p.408 - *416.*

[4] **J. A. Kajaks, V. N. Bulmanis, S. A. Reihmane, M.G. Tsiprin.** Influence of Coupling Agents on Physico - Mechanical Properties of Polyethylene and Linen Yarn's Production Waste Composites.- Mechanics of Composite Materials, 1997, No 4, p.540-547.

[5] **J. A. Kajaks, S. A. Reihmane, V. N. Bulmanis, J. E. Lejnieks.** Influence of water on physico - mechanical properties of composites containing low density polyethylene and linen yarn production waste./- Mechanics of composite materials, 2001, vol. 37 , N.2 p.269-274.

[6] **J.E. Lejnieks, J.A. Kajaks, S.A.Reihmane.** Correlation between the mechanical properties and the amount of desorbed water for composites based on lowdensity polyethylene and linen yarn production waste./ Mechanics of Composite Materials –2005-Vol.41, No.4, P.351-356.

[7] **J. Kajaks, S. Reihmane, M. Tsiprin.** Physico - mechanical properties of composites from recycled polyethylene and linen yarn production waste./ Mechanics of Composite Materials, 1999, N 2, p.199-209.

[8] **J.A. Kajaks, S.A. Reihmane, J. E. Lejnieks.** Effect of Water on Physicomechanical Properties of Composites containing Recycled Polyethylene and Linen Yarn Production Waste./ Mechanics of Composite Materials, 2002, vol.38, N4, p.531-538.

[9] **G. Bakradze, J.Kajaks, S.Reihmane, V. Bulmanis, and R. Krutohvostov.** The influence of water sorption-desorption cycles on the mechanical properties of composites based on recycled polyolefines and linen yarn production waste./Mechanics of Composite Materials,-2007.- vol. 43, No.6, p.573-578.

[10] **G. Bakradze, J. Kajaks, S. Reihmane, J. Lejnieks**. Correlation between mechanical properties and desorbed water amount for composites based on recycled polyethylene and linen yarn production waste./ Mechanics of Composite Materials, -2007-.vol.43, No.5.-p.427-432.

[11] **Shinoj S., Visvanathan R., Panigrahi S.** Towards industrial utilization of oil palm fibre: Physical and dielectric characterization of linear low density polyethylene composites and comparison with other fibre sources // Biosystems Engineering. – 2010. – Vol.106 (4). – pp. 378 - 388.

[12] **Panigrahi S., Li X., Tabil L., Barghout K., Kushwaha R.L., Mupoudwa E.K.** Development of flax fibre reinforced biocomposites for potential application for automotive industries // SAE international Journal of Commercial Vehicles 2 (2). – 2010. – pp. 107 – 114.

[13] **Panigrahi S.** Oil palm fibre biocomposites for automotive industries // SAE international Journal of Commercial Vehicles 3 (1). – 2010. - pp. 313 – 322.

[14] **Pasuinini D., Teixeira E.M., Curvelo A.A. et.al.** Surface esterification of cellulose fibres: processing and characterization of low density polyethylene/cellulose fibres composites // Composites Science and Technology. – 2008. – Vol.68 (1). – pp. 193 -201.

[15] **O. Nestore, J. Kajaks, I. Vancovica, S. Reihmane**. Physical-mechanical properties of composites based on linear low density polyethylene and natural fibre textile waste.//Mechanics of composite materials.-2012-, Vol.48, No.6, pp. 897-910.

[16] **Sirotong B.A.C., Tabil L.G., Panigrahi W.I.** Crerar Extrusion compounding of Flax – Fibre – Reinforced Polyethylene Composites: Effects of fibre content and Extrusion parameters // Journal of Natural fibres. – 2010. – Vol. 7:4. – pp.289 – 306.

[17] **Carlos A.C.R.** Mechanical properties of reinforced Thermoplastics / Ed. by Clegg D.W. Colleyor A.A. – London: Elsevier Appl. Sci. Publ.. – 1986. – Chap.3. – pp.110-162.+

[18] **Menson J.,Sperling L.** Polymer mixtures and composites. M.;Chemistry 1979, pp .430.

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Rita Soliženko, Jānis Kajaks, Olga Nestore, Silvija Kukle. Kaņepju šķiedru saturošu lineāra zema blīvuma polietilēna kompozītu ekspluatācijas īpašības

Pētījuma mērķis bija noskaidrot, kā dažādos apstākļos izaudzētu kaņepju šķiedru ķīmiskā sastāva un to sastāvdaļu kvantitatīvās atšķirības ietekmē uz atbilstošo šķiedru bāzes veidotu termoplastisku polimēru kompozītu ekspluatācijas īpašības. Šim nolūkam kā polimēra matrica izvēlēts zema blīvuma lineārais polietilēns, bet kā modificējošās komponentes trīs dažādas kaņepju šķiedras, kas izaudzētas dažādos apstākļos Polijā un Latvijā. Šķiedras atšķiras gan ar ķīmisko sastāvu, gan ar to sastāvdaļu kvantitatīvo saturu, spaļu piejaukuma daudzumu, šķiedras garumu un mehāniskajām īpašībām. Tās aprobētas kā armējoša komponente lineāra zema blīvuma polietilēna kompozītos ar dažādu šķiedru saturu (10, 20 30, 40 mas.%.) Noteikti kompozītu ekspluatācijas rādītāji: stiepes stiprība, modulis, deformēšanās spēja sagraušanas brīdī, virsmas mikrocietība pēc Vikersa, ūdens izturība istabas temperatūrā, kā arī novērtēta kausējumu tecētspēja, nosakot kausējuma indeksu. Konstatēts, ka visu materiālu tecētspēja samazinās, pieaugot šķiedras daudzumam kompozītā. Kompozītu kausējumi, kas satur 40 mas. % šķiedras izvēlētā eksperimenta apstākļos praktiski zaudē tecētspēju, bet visām kompozīcijām ar 30 mas.% šķiedras saturu tā ir pietiekami augstā līmenī, lai kompozīcijas varētu pārstrādāt ar tradicionālajām polimēru pārstrādes metodēm: spiedliešanu un ekstrūziju. Izvērtējot materiālu fizikāli mehāniskās īpašības, visu veidu šķiedru gadījumos (šķiedru garums kompozītos ir līdz 1 mm) optimālais šķiedru saturs kompozītā ir 30 mas.%, jo pie 40 mas.% šķiedras satura novēro stiprības samazināšanos. Šķiedru ķīmiskā sastāva, to sastāvdaļu kvantitatīvā satura un mehānisko rādītāju atšķirības būtiski neietekmē kompozītu galvenās ekspluatācijas īpašības un visas izpētītās šķiedras var sekmīgi izmantot termoplastisku polimēru kompozītu ar labām īpašībām izgatavošanai.

Рита Солиженко, Янис Каякс, Олга Несторе, Силвия Кукле. Эксплуатационные свойства композитов на основе линейного полиэтилена низкой плотности, содержащих конопляные волокна.

Целью данного исследования являлось выяснение влияния химического состава и содержания компонентов волокон конопли, в зависимости от условий выращивания, на эксплуатационные свойства композитов на основе термопластичных полимеров. Для этой цели в качестве полимерной матрицы был выбран линейный полиэтилен низкой плотности, а в качестве модифицирующего компонента три различных волокна конопли, выращенных при различных условиях в Польше и Латвии. Волокна различаются по химическому составу и содержанию компонентов, содержанием костры, длиной волокна и механическими свойствами, которые были апробированы в качестве армирующего компонента, в композитах линейного полиэтилена низкой плотности, с различным содержанием волокна (10, 20 30, 40 мас.%). Определены эксплуатационные характеристики композитов: прочность на растяжение, модуль упругости, прочность на изгиб, микротвердость по Викерсу, водопоглощение при комнатной температуре, а также индекс расплава. Было установлено, что текучесть материала уменьшается, с увеличением количества волокна в композите. Композитные расплавы содержащие 40 мас.% волокон, в выбранных экспериментальные условиях практически теряют свою текучесть. В свою очередь, в композитах с 30 масс.% содержанием волокон она сохраняется на достаточно высоком уровне, и они могут быть переработаны с помощью обычных методов переработки полимеров: литья под давлением и экструзией. Проанализировав физико-механические свойства материалов, констатировали, что оптимальным содержанием волокон в композитах является 30 масс.%, не зависимо от вида волокна (длина волокон до 1 мм), т.к., при содержании 40 мас.% волокон наблюдается уменьшение свойств. Химический состав и содержание компонентов волокна, а также показатели механических свойств существенно не влияют на основные эксплуатационные свойства полученных композитов. Все исследованные волокна могут быть успешно использованы при производстве термопластичных полимерных композитов.