http://doi.org/10.32864/polymmattech-2023-9-3-6-28

УДК 678.7:666.1

ПОЛИМЕРНЫЕ КОМПОЗИТЫ НА ОСНОВЕ ТЕРМОПЛАСТОВ, АРМИРОВАННЫЕ ДЛИННЫМИ ВОЛОКНАМИ РАЗЛИЧНОЙ ПРИРОДЫ: ПОЛУЧЕНИЕ, СВОЙСТВА, ПРИМЕНЕНИЕ (ОБЗОР)

Ю. М. КРИВОГУЗ[+], В. Н. КОВАЛЬ, В. В. ДУБРОВСКИЙ

Институт механики металлополимерных систем имени В. А. Белого НАН Беларуси, ул. Кирова, 32а, 246050, г. Гомель, Беларусь

Длинноволкнистые полимерные композиты (ДВПК) занимают важнейшее место среди конструкционных материалов. ДВПК характеризуются более высокими механическими свойствами по сравнению с классическими пластиками, а по удельным характеристикам превосходят традиционные стали, алюминиевые и магниевые сплавы, что делает возможным применение ДВПК в качестве заменителей металлов в различных областях техники.

Цель работы — обобщение научной информации о результатах теоретических и экспериментальных исследований в области ДВПК и анализ общей ситуации и перспектив развития данного направления.

В настоящем обзоре особое внимание уделено ДВПК на основе термопластичных матриц, поскольку широкое применение ДВПК на базе термореактивных связующих ограничено плохой перерабатываемостью, низкой производительностью вследствие длительности технологических циклов формования и ограниченным сроком хранения полуфабрикатов. В работе показано, что по сравнению с коротковолокнистыми полимерными композитами (КВПК), ДВПК характеризуются более высокими значениями механической прочности, жесткости, ударостойкости и теплостойкости. Основные преимущества ДВПК перед КВПК обусловлены более высокими значениями аспектного числа (отношение длины волокна к его диаметру), которое у ДВПК выше критических значений.

Обсуждены вопросы влияния рецептурных факторов, связанных с концентрацией волокна и его длиной, и технологических параметров таких, как конфигурация шнека, частота его вращения, порядок ввода волокна, температурный режим, на механические и теплофизические свойства ДВПК. Проанализированы способы улучшения адгезии между волокном и матрицей в ДВПК, основанные на процессах модифицирования матрицы, модифицирования волокна и применения специальных компатибилизаторов.

Приведена обобщающая информация о наиболее эффективном технологическом процессе получения и переработки ДВПК, основанном на технологии D-LFT, которая объединяет несколько технологических стадий в одной производственной линии и представляет собой единый производственный процесс, начиная от подготовки сырья и заканчивая изготовлением конечного изделия.

Показано, что, благодаря ценному комплексу свойств, ДВПК находят широкое применение в автомобилестроении, авиационно-космической отрасли, при изготовлении спортивного инвентаря, а также в быту и сфере обслуживания населения.

Ключевые слова: полимерные композиционные материалы, дискретное волокно, длинное волокно, армированные композиты, критическое аспектное число, структура, свойство

[+] Автор, с которым следует вести переписку. E-mail: yurikriv@tut.by

POLYMERIC COMPOSITES BASED ON THERMOPLASTS REINFORCED WITH LONG FIBERS OF DIFFERENT NATURE: PRODUCTION, PROPERTIES, APPLICATION (REVIEW)

YU. M. KRIVOGUZ[+], V. N. KOVAL, V. V. DUBROVSKY

V. A. Belyi Metal-Polymer Research Institute of National Academy of Sciences of Belarus, Kirov St., 32a, 246050, Gomel, Belarus

Long-fiber polymer composites (LFPC) occupy the most important place among structural materials. LFPC are characterized by higher mechanical properties compared to classical plastics, and their specific characteristics are superior to traditional steels, aluminum and magnesium alloys, which makes it possible to use LFPC as metal substitutes in various fields of technology.

The purpose of the work is to summarize scientific information on the results of theoretical and experimental studies in the field of LFPC, carried out over the past few decades, and to analyze the general situation and development prospects in this area.

In this review, special attention is paid to LFPC based on thermoplastic matrices, since the widespread use of LFPC based on thermosetting binders is limited by poor processability, low productivity due to the length of molding technological cycles, and limited shelf life of semi-finished products. The paper shows that, compared with short fiber polymer composites (SFPC), LFPC are characterized by higher values of mechanical strength, stiffness, impact resistance, and heat resistance. The main advantages of LFPC over CFPC are due to higher values of the aspect number (the ratio of fiber length to its diameter), which is higher than the critical values for LFPC.

The issues of the influence of prescription factors related to the fiber concentration and its length, and technological parameters such as the configuration of the screw, the frequency of its rotation, the order of fiber insertion, temperature conditions, on the mechanical and thermophysical properties of LFPC are discussed. Methods for improving the adhesion between fiber and matrix in LFPC based on the processes of matrix modifi-cation, fiber modification and the use of special compatibilizers are analyzed.

Generalized information on the most efficient technological process for the production and processing of LFPC based on D-LFT technology is given, which combines several technological stages in one production line and is a single production process, from the preparation of raw materials to the manufacture of the final product.

It is shown that, due to a valuable set of properties, LFPC are widely used in the automotive industry, the aerospace industry, in the manufacture of sports equipment, as well as in everyday life and public services.

Keywords: polymer composite materials, discrete fiber, long fiber, reinforced composites, critical aspect number, structure, property.

Поступила в редакцию 07.02.2023

Образец цитирования:

Кривогуз Ю. М., Коваль В. Н., Дубровский В. В. Полимерные композиты на основе термопластов, армированные длинными волокнами различной природы: получение, свойства, применение (обзор) // Полимерные материалы и технологии. 2023. Т. 9, № 3. С. 6–28. http://doi.org/10.32864/polymmattech-2023-9-3-6-28

Citation sample:

Krivoguz Yu. M., Koval' V. N., Dubrovskiy V. V. Polimernye kompozity na osnove termoplastov, armirovannye dlinnymi voloknami razlichnoy prirody: poluchenie, svoystva, primenenie (obzor) [Polymeric composites based on thermoplasts reinforced with long fibers of different nature: production, properties, application (review)]. *Polimernye materialy i tekhnologii* [Polymer Materials and Technologies], 2023, vol. 9, no. 3, pp. 6–28. http://doi.org/10.32864/polymmattech-2023-9-3-6-28

Литература

1. Артеменко С. Е. Композиционные материалы, армированные химическими волокнами. Саратов : Саратовский университет, 1989. 160 с.
2. Наполнители для полимерных композиционных материалов / под ред. Г. С. Каца, Д. В. Милевски. М. : Химия, 1981. 736 с.
3. Бунаков В. А., Головкин Г. С., Машинская Г. П., Михайлин Ю. А., Перов Б. В., Румянцев А. Ф., Рязанцев А. Н., Семенов В. И., Тростянская Е. Б., Тюкаев В. Н., Шибанов А. К. Армированные пластики : справочное пособие. М. : МАИ, 1997. 404 с.
4. Кербер М. Л., Виноградов В. М., Головкин Г. С., Горбаткина Ю. А., Крыжановский В. К., Куперман А. М., Симонов-Емельянов И. Д., Халиулин В. И., Бунаков В. А. Полимерные композиционные материалы: структура, свойства, технология : уч. пособие / под ред. А. А. Берлина. СПб : Профессия, 2008. 560 с.
5. Бондалетова Л. И., Бондалетов В. Г. Полимерные композиционные материалы : учебное пособие. Томск : Томский политехнический университет, 2013. 118 с.
6. Перепелкин К. Е. Армирующие волокна и волокнистые полимерные композиты: учебник. СПб. : Научные основы и технологии, 2009. 380 с.
7. Михайлин Ю. А. Волокнистые полимерные композиционные материалы в технике. СПб. : Научные основы и технологии, 2013. 720 с.
8. Gandhi U. N., Goris S., Osswald T. A., Song Y. Y. Discontinuous Fiber-Reinforced Composites: Fundamentals and Applications. Cincinnati : Hanser Publ., 2020. 465 p.
9. Goh K. L. Discontinuous-Fibre Reinforced Composites : Fundamentals of Stress Transfer and Fracture Mechanics. London : Springer, 2017. XXIV, 190 p.
10. Rohde-Tibitanzl M. Direct Processing of Long Fiber Reinforced Thermoplastic Composites and their Mechanical Behavior under Static and Dynamic Load. Cincinnati : Hanser Publ., 2016. 210 p.
11. Chawla K. K. Composite materials: science and engineering. New York : Springer; 2012. 483 p.
12. Dally J. W., Carrillo D. H. Fatigue Behavior of Glass-Fiber Fortified Thermoplastics // Polymer Engineering and Science, 1969, vol. 9, no. 6, pp. 434–444. doi: 10.1002/pen.760090610
13. Blumentritt B. F., Vu B. T., Cooper S. L. The Mechanical Properties of Oriented Discontinuous Fiber-Reinforced Thermoplastics. 1. Unidirectional Fiber Orientation // Polymer Engineering and Science, 1974, vol. 14, is. 9, pp. 633–640. doi: 10.1002/PEN.760140908
14. Blumentritt B. F., Vu B. T., Cooper S. L. Mechanical Properties of Discontinuous Fiber Reinforced Thermoplastics. II. Random-in-Plane Fiber Orientation // Polymer Engineering and Science, 1975, vol. 15, is. 6, pp. 428–436. doi: 10.1002/PEN.760150606
15. Stade K. Techniques for Compounding Glass Fiber-Reinforced Thermoplastics // Polymer Engineering and Science, 1977, vol. 17, no. 1, pp. 50–57. doi: 10.1002/pen.760170110
16. Denault J., Vu-Khanh T., Foster B. Tensile Properties of Injection Molded Long Fiber Thermoplastic Composites // Polymer composites, 1989, vol. 10, no. 5, pp. 313–321. doi: 10.1002/pc.750100507
17. Vaidya U. K., Chawla K. K. Processing of fibre reinforced thermoplastic composites // International Materials Reviews, 2008, vol. 53, no. 4, pp. 185–218. doi: 10.1179/174328008X325223
18. Haibin Ning, Na Lu, Ahmed Arabi Hassen, Krishan Chawla, Mohamed Selim, Selvum Pillay. A review of Long fibre-reinforced thermoplastic or long fibre thermoplastic (LFT) composites // International Materials Reviews, 2019. doi: 10.1080/09506608.2019.1585004
19. Зеленский Э. С. Высокопрочные и высокомодульные армированные пластики // Успехи химии. 1984. Т. LIII, вып. 2. С. 290–308.
20. Зеленский Э. С., Куперман А. М., Горбаткина Ю. А., Баженов С. Л., Денисов К. А. Однонаправленные армированные пластики // Высокомолекулярные соединения. 1994. Т. 36, вып. 4. С. 662–675.
21. Ставров В. П. Богославский А. А., Дедович Г. В., Дорожко А. В., Зуев А. П., Кордикова Е. И., Марков А. В. Механические свойства длинноволокнистого стеклонаполнненого полиамида, изготавливаемого по пултрузионной технологии // Материалы. Технологии. Инстументы. 2000. Т. 5, № 1. С. 36–41.
22. Песецкий С. С., Дубровский В. В. Полиалкилентерефталаты наполненные коротким стекловолокном: структура и свойства, механизм разрушения, перспективы исследований и разработок (обзор) // Полимерные материалы и технологии. 2020. Т. 6, № 2. С. 6–26.
23. Алентьев А. Ю., Яблокова М. Ю. Связующие для полимерных композиционных материалов : учеб. пособие. М. : МГУ им. М. В. Ломоносова, 2010. 69 с.
24. Герасимова В. М. Разработка эпоксидных композиционных материалов с повышенными эксплуатационными свойствами на основе модифицированных волокнистых наполнителей различной химической природы : дис. канд. техн. наук : 05.17.06. Саратов, 2017. 153 с.
25. Lee E. S., Kim J. S., Kim K. Y., Lim D. Y., Kim D. H. Preparation of polypropylene composites reinforced with long carbon fibers and their properties // Fibers Polym., 2014, vol. 15, pp. 2613–2617. doi: 10.1007/s12221-014-2613-6
26. Rohde M., Ebel A., Wolff-Fabris F., Altstädt V. Influence of Processing Parameters on the Fiber Length and Impact Properties of Injection Molded Long Glass Fiber Reinforced Polypropylene // Int. Polym. Process, 2011, vol. 26, no. 3, pp. 292–303. doi: 10.3139/217.2442
27. Ren P., Dai G. Fiber dispersion and breakage in deep screw channel during processing of long fiber-reinforced polypropylene // Fibers Polym. 2014, vol. 15, no. 7, pp. 1507–1516. doi: 10.1007/s12221-014-1507-y
28. Garcia-Rejon A., Meddad A., Turcott E., Carmel M. Extrusion blow molding of long fiber reinforced polyolefins // Polym. Eng. Sci., 2002, vol. 42, no. 2, pp. 346–364. doi: 10.1002/pen.10953
29. Kuboki T., Lee Y.H., Park C.B., Sain M. Mechanical properties and foaming behavior of cellulose fiber in forced high-density polyethylene composites // Polym. Eng. Sci., 2009, vol. 49, no. 11, pp. 2179–2188. doi: 10.1002/pen.21464
30. An H. J., Kim J. S., Kim K.-Y., Lim D. Y., Kim D. H. Mechanical and thermal properties of long carbon fiber-reinforced polyamide

6 composites // Fibers Polym., 2014, vol. 15, pp. 2355–2359. doi: 10.1007/s12221-014-2355-5
31. Toll S., Andersson P.-O. Microstructure of Long- and Short-Fiber Reinforced Injection Molded Polyamide // Polym. Compos., 1993, vol. 14, is. 2, pp. 116–125. doi: 10.1002/pc.750140205
32. Bijsterbosch H., Gaymans R. J. Polyamide 6 — long glass fiber injection moldings // Polym. Compos., 1995, vol. 16, is. 5, pp. 363–369. doi: 10.1002/pc.750160504
33. Wyzgoski M. G., Novak G. E. Fatigue Fracture of Long Fiber Reinforced Nylon 66 // Polymer composites, 1995, vol. 16, is. 1, pp. 38–51. doi: 10.1002/pc.750160107
34. Karger-Kocsis J., Friedrich K. Fatigue crack propagation in short and long fiber reinforced injection moulded PA 6,6 composites // Composites, 1988, vol. 19, no. 2, pp. 105–114. doi: 10.1016/0010-4361(88)90720-3
35. Lafranche E., Krawczak P., Ciolczyk, J. P., Maugey J. Injection moulding of long glass fiber reinforced polyamide 66: Processing conditions/microstructure/flexural properties relationship // Adv. Polym. Technol., 2005, vol. 24, is. 2, pp. 114–131. doi: 10.1002/adv.20035
36. Hollin J., Miller D., Vautour D. A comparison of transverse properties of 50% short and long glass fiber reinforced nylon 6/6 resin // J. Reinf. Plast. Compos., 1998, vol. 17, is. 18, pp. 1617–1624. doi: 10.1177/073168449801701803
37. Tingxiu Xie, Guisheng Yang. Interface and Mechanical Properties of Poly(methyl methacrylate)–Fiber Composites // J. Appl. Polym. Sci., 2004, vol. 93, is. 5, pp. 2478–2483. doi: 10.1002/app.20819
38. Denault J., Vu-Khanh T., Foster B. Tensile Properties of Injection Molded Long Fiber Thermoplastic Composites // Polymer Composites, 1989, vol. 10, no. 5, pp. 313–321. doi: 10.1002/pc.750100507
39. Bayerl T., Mitschang P. Rheological and Mechanical Behavior of Long-Polymer-Fiber Reinforced Thermoplastic Pellets // J. Appl. Polym. Sci., 2014, vol. 131, is. 1. doi: 10.1002/APP.39716
40. Lin S. H., Ma C. C. M., Tai N. H. Long Fiber Reinforced Polyamide and PoIycarbonate Composites. II: Fatigue Behavior and Morphological Property // Journal of Vinyl and Additive Technology, 1996, vol. 2, no. 1, pp. 80–86. doi: 10.1002/vnl.10099
41. Wang Q., Ning H., Vaidya U., Pillay S. Mechanical Behavior of Long Carbon Fiber Reinforced Polyarylamide at Elevated Temperature // J. Material. Sci. Eng., 2016, vol. 5, is. 6. doi: 10.4172/2169-0022.1000294
42. Zhaozeng Tao, Yatao Wang, Jianhua Li, Xiaodong Wang, Dezhen Wu Fabrication of Long Glass Fiber Reinforced Polyacetal Composites: Mechanical Performance, Microstructures, and Isothermal Crystallization Kinetics // Polym. Compos., 2015, vol. 36, is. 10, pp. 1826–1839. doi: 10.1002/pc.23090
43. Min He, Daohai Zhang, Jianbing Guo, Shuhao Qin, Xingxing Min. Mechanical, Thermal, and Dynamic Mechanical Properties of Long Glass Fiber-Reinforced Thermoplastic Polyurethane/Polyoxymethylene Composites // Polym. Compos., 2014, vol. 35, is. 10, pp. 2067–2073. doi: 10.1002/pc.22868
44. Daohai Zhang, Min He, Shuhao Qin, Jie Yu. Effect of fiber length and dispersion on properties of long glass fiber reinforced thermoplastic composites based on poly(butylene terephthalate) // RSC Adv., 2017, vol. 7, pp. 15439–15454. doi: 10.1039/C7RA00686A
45. Markarian J. Long fibre reinforcement drives automotive market forward // Plastics, Additives and Compounding, 2005, vol. 7, no. 3, pp. 24–29. doi: 10.1016/S1464-391X(05)70393-7
46. Daohai Zhang, Min He, Shuhao Qin, Jie Yu, Jianbing Guo, Guomin Xu. Study on Dynamic Mechanical, Thermal, and Mechanical Properties of Long Glass Fiber Reinforced Thermoplastic Polyurethane/Poly(butylene terephthalate) Composites // Polym. Compos., 2018, vol. 39, is. 1, pp. 63–72. doi: 10.1002/pc.23902
47. Vu-Khanh T., Denault J., Habib P., Low A. The effects of injection molding on the mechanical behavior of long-fiber reinforced PBT/PET blends // Compos. Sci. Technol., 1991, vol. 40, is. 4, pp. 423–435. doi: 10.1016/0266-3538(91)90032-K
48. Tan Y. H., Wang X. D., Wu D. Z. Preparation, microstructures, and properties of long-glass-fiber-reinforced thermoplastic composites based on polycarbonate/ poly(butylenes terephthalate) alloys // J. Reinf. Plast. Compos., 2015, vol. 34, is. 21, pp. 1804–1820. doi: 10.1177/0731684415599071
49. Harmia T. Fatigue behavior of neat and long glass fiber (LGF) reinforced blends of nylon 66 and isotactic PP // Polym. Compos., 1996, vol. 17, no. 6, pp. 926–936.
50. Kim N., Kim D.-Y., Kim Y.-J., Jeong K.-U. Enhanced thermomechanical properties of long and short glass fiber-reinforced polyamide 6,6/polypropylene mixtures by tuning the processing procedures // J. Mater. Sci., 2014, vol. 49, no. 18, pp. 6333–6342. doi: 10.1007/s10853-014-8358-1
51. Панова Л. Г. Наполнители для полимерных композиционных материалов : учеб. пособие. Саратов : СГТУ, 2010. 64 с.
52. Liu Yuchao. Study on the mechanical behavior of directly compounded long glass fiber reinforced polyamide 6 composites // Electronic Thesis and Dissertation Repository. 2017 [Электронный ресурс]. URL: https://ir.lib.uwo.ca/cgi/viewcontent.cgi?article=6391&context=etd (дата обращения: 18.04.2023)
53. Karger-Kocsis J., Harmia T., Czigány T. Comparison of the fracture and failure behavior of polypropylene composites reinforced by long glass fibers and by glass mats // Compos. Sci. Technol., 1995, vol. 54, no. 3, pp. 287–298. doi: 10.1016/0266-3538(95)00068-2
54. Fan Y., Liu Y. C., Whitfield T., Kuboki T., Wood J. T., Ugresic V. Effects of Processing Parameters on the Thermal and Mechanical Properties of LFT- DECM Glass Fiber/Polyamide 6 Composites // Plast. Eng., 2017, vol. 73, pp. 44–45.
55. Huan-Chang Tseng, Rong-Yeu Chang, Chia-Hsiang Hsu. Numerical Predictions of Fiber Orientation and Mechanical Properties for Injection-Molded Long-Carbon-Fiber Thermoplastic Composites // Polym. Compos., 2017, vol. 39, is. 10, pp. 3726–3739. doi: 10.1002/pc.24403
56. Sharma Bhisham N., Kijewski Seth A., Fifield Leonard S., Shin Yongsoon, Tucker Charles L., Sangid Michael D. Reliability in the Characterization of Fiber Length Distributions of Injection Molded Long Carbon Fiber Composites // Polym. Compos., 2017, vol. 39, is. 12, pp. 4594–4604. doi: 10.1002/pc.24571
57. Deák Tamás, Czigány Tibor, Maršálková Miroslava, Militký Jiří. Manufacturing and Testing of Long Basalt Fiber Reinforced Thermoplastic Matrix Composites // Polym. Eng. Sci., 2010, vol. 50, is. 12, pp. 2448–2456. doi: 10.1002/pen.21765
58. Tan H., Tan H. S., Tang X. L., Wang Y. G., Li L. P. Mechanical properties and dynamic mechanical behavior for long aramid fiber reinforced impact polypropylene copolymer // Adv. Mater. Res., 2012, vol. 591–593, pp. 1079–1082. doi: 10.4028/www.scientific.net/amr.591-593.1079
59. Tang Xinlei, Tan Hongsheng, Tan Hao, Wang Yangang. Long aramid fiber reinforced impact polypropylene copolymer composites // Engineering Plastics Application, 2013, vol. 41, no. 2, pp. 5–9.
60. Grande C., Torres F. G. Investigation of Fiber Organization and Damage During Single Screw Extrusion of Natural Fiber Reinforced Thermoplastics // Advances in Polymer Technology, 2005, vol. 24, no. 2, pp. 145–156. doi: 10.1002/adv.20037
61. Ranganathan N., Oksman K., Nayak S. K., Sain M. Structure property relation of hybrid biocomposites based on jute, viscose and polypropylene: Effect of fiber content and length on fracture toughness and fatigue properties // Composites Part A: Applied science and manufacturing, 2016, vol. 83, pp. 169–175. doi: 10.1016/j.compositesa.2015.10.037
62. Ranganathan N., Oksman K., Nayak S. K., Sain M. Regenerated Cellulose Fibers as Impact Modifier in Long Jute Fiber Reinforced Polypropylene Composites: Effect on Mechanical Properties, Morphology, and Fiber Breakage // J. Appl. Polym. Sci., 2015, vol. 132. doi: 10.1002/APP.41301

63. Jeyanthi S., Rani J. J. Development of natural long fiber thermoplastic composites for automotive frontal beams // Indian Journal of Engineering and Materials Sciences, 2014, vol. 21, pp. 580–584.
64. Ranganathan N., Oksman K., Nayak S. K., Sain M. Impact toughness, viscoelastic behavior, and morphology of polypropylene–jute–viscose hybrid composites // J. Appl. Polym. Sci., 2016, vol. 133, is. 7. doi: 10.1002/app.42981
65. Uawongsuwan P., Yang Y., Hamada H. Long jute fiber-reinforced polypropylene composite: effects of jute fiber bundle and glass fiber hybridization // J. Appl. Polym. Sci., 2015, vol. 132, is. 15. doi: 10.1002/app.41819
66. Schemme M. LFT – development status and perspectives // Reinf. Plast., 2008, vol. 52, no. 1, pp. 32–39. doi: 10.1016/S0034-3617(08)70036-5
67. Kim Sung-Eun, Ahn Jun-Geol, Ahn Seungjae, Park Do-Hyung, Choi Da-Hee, Lee Jae-Chul, Yang Hyun-Ik, Kim Ki-Young. Development of PA6/GF Long-Fiber-Reinforced ThermoplasticComposites Using Pultrusion and Direct Extrusion Manufacturing Processes // Appl. Sci., 2022, vol. 12, is. 10. doi: 10.3390/app12104838
68. Kim Y., Park O. O. Effect of Fiber Length on Mechanical Properties of Injection Molded Long-Fiber-Reinforced Thermoplastics // Macromol. Res., 2020, vol. 28, pp. 433–444. doi: 10.1007/s13233-020-8056-6
69. Whitfield T., Kuboki T., Wood J., Ugresic V., Sathyanarayana S., Dagnon K. Thermal properties of glass fiber reinforced polyamide 6 composites throughout the direct long-fiber reinforced thermoplastic process // Polym. Eng. Sci., 2018, vol. 58, no. 1, pp. 46–54. doi: 10.1002/pen.24529
70. Markarian J. Long fibre reinforced thermoplastics continue growth in automotive // Plast. Addit. Compd., 2007, vol. 9, no. 2, pp. 20–24. doi: 10.1016/s1464-391x(07)70025-9
71. Krause W., Henning F., Tröster S., Geiger O., Eyerer P. LFT-D – A Process Technology for Large Scale Production of Fiber Reinforced Thermoplastic Components // Journal of Thermoplastic Composite Materials, 2003, vol. 16, is. 4, pp. 289–302. doi: 10.1177/0892705703016004001
72. Whitfield T., Kuboki T., Wood J., Ugresic V., Sathyanarayana S., Dagnon K. Effects of process parameters on thermal properties of glass fiber reinforced polyamide 6 composites throughout the direct long-fiber-reinforced thermoplastics process // Polym. Eng. Sci., 2018, vol. 58, no. S1, pp. E114–E123. doi: 10.1002/pen.24718
73. Henning, F., Ernst, H., Brüssel R. LFTs for automotive applications // Reinforced plastics, 2005, vol. 49, no. 2, pp. 24–33. doi: 10.1016/S0034-3617(05)00546-1
74. Markarian J. Strengthening compounds through fibre reinforcement // Reinforced Plastics, 2007, vol. 51, no. 2, pp. 36–39. doi: 10.1016/s0034-3617(07)70057-7
75. Geiger O., Henning F., Eyerer P., Brüssel R., Ernst H. LFT-D: materials tailored for new applications // Reinf. Plast., 2006, vol. 50, no. 1, pp. 30–35. doi: 10.1016/S0034-3617(06)70870-0
76. Thomason J. L., Vlug M. A. Influence of fiber length and concentration on the properties of glass fiber-reinforced polypropylene: 1. Tensile and flexural modulus // Composites Part A, 1996, vol. 21, is. 6, pp. 477–484. doi: 10.1016/1359-835X(95)00065-A
77. Thomason J. L., Groenewoud W. M. The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene: 2. Thermal properties // Composites Part A, 1996, vol. 21, pp. 555–565.
78. Thomason J. L., Vlug M. A., Schipper G., Krikort H. G. L. T. Influence of fibre length and concentration on the properties of glass fibre-reinforced polypropylene: Part 3. Strength and strain at failure // Composites Part A, 1996, vol. 27, pp. 1075–1084.
79. Thomason J. L., Vlug M. A. Influence of fibre length and concentration on the properties of glass fibre-reinforced polypropylene: 4. Impact properties // Composites Part A, 1997, vol. 28, is. 3, pp. 277–288. doi: 10.1016/S1359-835X(96)00127-3
80. Thomason J. L. The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene: 5. Injection moulded long and short fibre PP // Composites: Part A, 2002, vol. 33, is. 12, pp. 1641–1652. doi: 10.1016/S1359-835X(02)00179-3
81. Thomason J. L. The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene. 6. The properties of injection moulded long fibre PP at high fibre content // Composites: Part A, 2005, vol. 36, is. 7, pp. 995–1003. doi: 10.1016/j.compositesa.2004.11.004
82. Thomason J. L. The influence of fibre length, diameter and concentration on the modulus of glass fibre reinforced polyamide 6,6 // Composites: Part A, 2008, vol. 39, is. 11, pp. 1732–1738. doi: 10.1016/j.compositesa.2008.08.001
83. Thomason J. L. The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene: 7. Interface strength and fibre strain in injection moulded long fibre PP at high fibre content // Composites: Part A, 2007, vol. 38, is. 1, pp. 210–216. doi: 10.1016/j.compositesa.2006.01.007
84. Thomason J. L. Structure–Property Relationships in Glass-Reinforced Polyamide, Part 1: The Effects of Fiber Content // Polym. Compos., 2006, vol. 27, is. 5, pp. 552–562. doi: 10.1002/pc.20226
85. Ke-qing Han, Zheng-jun Liu, Mu-huo Yu. Preparation and Mechanical Properties of Long Glass Fiber Reinforced PA6 Composites Prepared by a Novel Process // Macromol. Mater. Eng., 2005, vol. 290, is. 7, pp. 688–694. doi: 10.1002/mame.200500051
86. Bobing He, Heng Liu, Jinhua Leng, Bin Yang, Xian Chen, Jingwei Fu, Qiang Fu. Mechanical properties of long glass fiber-reinforced polypropylene composites and their influence factors // Journal of Reinforced Plastics and Composites, 2015, vol. 30, no. 3, pp. 222–228. doi: 10.1177/0731684410391513
87. Daohai Zhang, Jianbing Guo, Kaizhou Zhang. Effects of compatilizers on mechanical and dynamic mechanical properties of polypropylene–long glass fiber composites // Journal of Thermoplastic Composite Materials, 2013, vol. 28, no. 5. doi: 10.1177/0892705713486141
88. Bin Yang, Jinhua Leng, Bobing He, Heng Liu, Yu Zhang, Zhaohua Duan. Influence of fiber length and compatibilizer on mechanical properties of long glass fiber reinforced polyamide 6,6 // Journal of Reinforced Plastics and Composites, 2012, vol. 31, no. 16, pp. 1103–1112. doi: 10.1177/0731684412454199
89. Weixia Yan, Ke Qing Han, Liu Liang Qin, Mu Huo Yu. Study on Long Fiber–Reinforced Thermoplastic Composites Prepared by In Situ Solid-State Polycondensation // Journal of Applied Polymer Science, 2004, vol. 91, is. 6, pp. 3959–3965. doi: 10.1002/app.13627
90. Weixia Yan, Ke Qing Han, Hongmei Zhou, Mu Huo Yu. Study on the Grafting of PET onto the Glass Fiber Surface during In Situ Solid-State Polycondensation // Journal of Applied Polymer Science, 2006, vol. 99, is. 3, pp. 775–781. doi: 10.1002/app.22552
91. Cho S. M., Jung H.-T. Highly Enhanced Mechanical Properties of Polypropylene-Long Carbon Fiber Composites by a Combined Method of Coupling Agent and Surface Modification of Long Carbon Fiber // Macromolecular Research, 2014, vol. 22, no. 10, pp. 1066–1073. doi: 10.1007/s13233-014-2153-3
92. Priebe M., Schledjewski R. Processing and properties of glass/polypropylene in long fibre compounding extrusion // Plastics, Rubber and Composites, 2011, vol. 40, no. 6-7, pp. 374–379. doi: 10.1179/1743289810Y.0000000035
93. Yang Mingyu, Kuboki Takashi, Wood Jeffrey, Ugresic Vanja Effects of extruder screw configurations on thermal properties of glass fiber-reinforced polyamide 6 composites throughout the direct long-fiber-reinforced thermoplastics process // Polym. Compos., 2019, vol. 40, is. 9, pp. 3500–3509. doi: 10.1002/pc.25212

94. Ranganathan N., Oksman K., Nayak S. K., Sain M. Effect of long fiber thermoplastic extrusion process on fiber dispersion and mechanical properties of viscose fiber/polypropylene composites // Polym. Adv. Technol., 2016, vol. 27, is. 5, pp. 685–692. doi: 10.1002/pat.3742
95. Ying He, Wei Gong, Daohai Zhang, Shuhao Qin. Effect of Impregnation Time on Performance of Long Glass Fiber-Reinforced Polypropylene Composites // Journal of Vinyl and Additive Technology, 2018, vol. 24, is. 2, pp. 174–178. doi: 10.1002/vnl.21543
96. Inoue A., Morita K., Tanaka T., Arao Y., Sawada Y. Effect of screw design on fiber breakage and dispersion in injection-molded long glass-fiber-reinforced polypropylene // J. Compos. Mater., 2015, vol. 49, no. 1, pp. 75–84. doi: 10.1177/0021998313514872
97. Xu-Qin Hou, Xing-Yuan Chen, Bao-Chen Liu, Sheng-Chao Chen, Hai-Mei Li ,Wei Cao. Fracture and Orientation of Long-Glass-Fiber-Reinforced Polypropylene During Injection Molding // Polym. Eng. Sci., 2019, vol. 60, is. 1, pp. 13–21. doi: 10.1002/pen.25254
98. Teixeira D., Giovanela M., Gonella L. B., Crespo J. S. Influence of injection molding on the flexural strength and surface quality of long glass fiber-reinforced polyamide 6.6 composites // Materials and Design, 2015, vol. 85, pp. 695–706. doi: 10.1016/j.matdes.2015.07.097
99. Skourlis T. P., Mehta S. R., Chassapis C., Manoochehri S. Impact Fracture Behavior of Injection Molded Long Glass Fiber Reinforced Polypropylene // Polymer Engineering and Science, 1998, vol. 38, no. 1, pp. 79–89. doi: 10.1002/pen.10167
100. Lafranche E., Krawczak P., Ciolczyk J. P., Maugey J. Injection moulding of long glass fibre reinforced polyamide 6-6: guidelines to improve flexural properties // eXPRESS Polymer Letters, 2007, vol. 1, no. 7, pp. 456–466. doi: 10.3144/expresspolymlett.2007.64
101. Ogawa T., Mima M., Taya N. Change of fiber length in injection molding of carbon fiber reinforced Nylon 66 // Seikei-Kakou, 1995, vol. 7, is. 5, pp. 315–320. doi: 10.4325/seikeikakou.7.315
102. Jacob A. Car makers increase their use of composites // Reinf. Plast., 2004, vol. 48, no. 2, pp. 26–32. doi: 10.1016/s0034-3617(04)00149-3
103. Steffens M., Himmel N., Maier M. Design and analysis of discontinuous long fiber reinforced thermoplastic structures for car seat applications // Transactions on Engineering Sciences, 1998, vol. 21, pp. 35–44.
104. Пальке С. Литье под давлением стекловолокнистых термопластов // Полимерные материалы. Изделия. Оборудование. Технологии. 2007. № 3. С. 26–31.
105. Zeyrek B. Y., Aydogan B., Dilekcan E., Ozturk F. Review of Thermoplastic Composites in Aerospace Industry // International Journal on Engineering Technologies and informatics, 2022, vol. 3, no. 1, pp. 1–6. doi: 10.51626/ijeti.2022.03.00031
106. DeWayne Howell D., Fukumoto S. Compression molding of long chopped fiber thermoplastic composites. 2009 [Электронный ресурс]. URL: https://www.toraytac.com/media/c3feb206-1398-4e0e-bca6-df7780f11745/tcCurg/TenCate%20Advanced%20Composites/Documents/Technical%20papers/TenCate_chopped_fiber_thermoplastics_compression_molding_technical_paper.pdf (дата обращения: 18.04.2023).
107. Costa A. P., Botelho E., Costa M. L., Narita N. E., Tarpani J. R. A Review of Welding Technologies for Thermoplastic Composites in Aerospace Applications // Journal of Aerospace Technology and Management, 2012, vol. 4, no. 3, pp. 255–265. doi: 10.5028/jatm.2012.04033912
108. Patent 5176868A US, IPC B29C 33/12. Long fiber reinforced thermoplastic frame especially for a tennis racquet / Stephen J. Davis. Appl. No. 645255; appl. 1991-01-24; publ. 1993-01-05.
109. Manufactory in Xiamen China different contents long glass fiber and carbon fiber compound pellets [Электронный ресурс]. URL: https://www.lfrt-plastic.com (дата обращения: 18.04.2023).

References

1. Artemenko S. Ye. *Kompozitsionnyye materialy, armirovannyye khimicheskimi voloknami* [Composite materials reinforced with chemical fibers]. Saratov : Saratovskiy universitet Publ., 1989. 160 p.
2. *Napolniteli dlya polimernykh kompozitsionnykh materialov* [Fillers for polymeric composite materials] / eds. G. Kats, I. Milevski. Moscow : Khimiya publ., 1981. 736 p.
3. Bunakov V. A., Golovkin G. S., Mashinskaya G. P., Mikhaylin Yu. A., Perov B. V., Rumyantsev A. F., Ryazantsev A. N., Semenov V. I., Trostyanskaya E. B., Tyukaev V. N., Shibanov A. K. *Armirovannyye plastiki* [Reinforced plastics]. Moscow : MAI Publ., 1997. 404 p.
4. Kerber M. L., Vinogradov V. M., Golovkin G. S., Gorbatkina Yu. A., Kryzhanovskiy V. K., Kuperman A. M., Simonov-Emel'yanov I. D., Khaliulin V. I., Bunakov V. A. *Polimernyye kompozitsionnyye materialy: struktura, svoystva, tekhnologiya* [Polymer composite materials: structure, properties, technology]. Saint-Petersburg : Professiya Publ., 2008. 560 p.
5. Bondaletova L. I., Bondaletov V. G. P*olimernyye kompozitsionnyye materialy* [Polymer composite materials]. Tomsk: Tomskiy politekhnicheskiy universitet Publ., 2013. 118 p.
6. Perepelkin K. E. *Armiruyushchiye volokna i voloknistyye polimernyye kompozity* [Reinforcing fibers and fibrous polymer composites]. Saint-Petersburg : Nauchnyye osnovy i tekhnologii Publ., 2009. 380 p.
7. Mikhaylin Yu. A. V*oloknistyye polimernyye kompozitsionnyye materialy v tekhnike* [Fibrous polymeric composite materials in engineering.]. Saint-Petersburg : Nauchnyye osnovy i tekhnologii Publ., 2013. 720 p.
8. Gandhi U. N., Goris S., Osswald T. A., Song Y. Y. *Discontinuous Fiber-Reinforced Composites.* Cincinnati : Hanser Publ., 2020. 465 p.
9. Goh K. L. Discontinuous-Fibre Reinforced Composites : Fundamentals of Stress Transfer and Fracture Mechanics. London : Springer, 2017. XXIV, 190 p.
10. Rohde-Tibitanzl M. Direct Processing of Long Fiber Reinforced Thermoplastic Composites and their Mechanical Behavior under Static and Dynamic Load. Cincinnati : Hanser Publ., 2016. 210 p.
11. Chawla K. K. *Composite materials: science and engineering.* New York : Springer, 2012, 483 p.
12. Dally J. W., Carrillo D. H. Fatigue Behavior of Glass-Fiber Fortified Thermoplastics. *Polymer Engineering and Science*, 1969, vol. 9, no. 6, pp. 434-444. doi: 10.1002/pen.760090610
13. Blumentritt B. F., Vu B. T., Cooper S. L. The Mechanical Properties of Oriented Discontinuous Fiber-Reinforced Thermoplastics. 1. Unidirectional Fiber Orientation. *Polymer Engineering and Science*, 1974, vol. 14, is. 9, pp. 633–640. doi: 10.1002/PEN.760140908
14. Blumentritt B. F., Vu B. T., Cooper S. L. Mechanical Properties of Discontinuous Fiber Reinforced Thermoplastics. II. Random-in-Plane Fiber Orientation. *Polymer Engineering and Science*, 1975, vol. 15, is. 6, pp. 428–436. doi: 10.1002/PEN.760150606
15. Stade K. Techniques for Compounding Glass Fiber-Reinforced Thermoplastics. *Polymer Engineering and Science,* 1977, vol. 17, no. 1, pp. 50–57. doi: 10.1002/pen.760170110
16. Denault J., Vu-Khanh T., Foster B. Tensile Properties of Injection Molded Long Fiber Thermoplastic Composites. *Polymer composites*, 1989, vol. 10, no. 5, pp. 313–321. doi: 10.1002/pc.750100507
17. Vaidya U. K., Chawla K. K. Processing of fibre reinforced thermoplastic composites. *International Materials Reviews*, 2008, vol. 53, no. 4, pp. 185–218. doi: 10.1179/174328008X325223

18. Haibin Ning, Na Lu, Ahmed Arabi Hassen, Krishan Chawla, Mohamed Selim, Selvum Pillay. A review of Long fibre-reinforced thermoplastic or long fibre thermoplastic (LFT) composites. *International Materials Reviews*, 2019. doi: 10.1080/09506608.2019.1585004
19. Zelenskiy E. S. Vysokoprochnyye i vysokomodul'nyye armirovannyye plastiki [High-strength and high-modulus reinforced plastics]. *Uspekhi khimii* [Russian Chemical Reviews], 1984, vol. LIII, is. 2, pp. 290–308.
20. Zelenskiy E. S., Kuperman A. M., Gorbatkina Yu. A., Bazhenov S. L., Denisov K. A. Odnonapravlennyye armirovannyye plastiki [Unidirectional reinforced plastics]. *Vysokomolekulyarnyye soyedineniya* [Polymer Science: Series A – Polymer Physics], 1994, vol. 36, is. 4, pp. 662–675.
21. Stavrov V. P. Bogoslavskiy A. A., Dedovich G. V., Dorozhko A. V., Zuev A. P., Kordikova E. I., Markov A. V. Mekhanicheskiye svoystva dlinnovoloknistogo steklonapolnnenogo poliamida, izgotavlivayemogo po pultruzionnoy tekhnologii [Mechanical properties of long-fiber glass-filled polyamide produced by pultrusion technology]. *Materialy. Tekhnologii. Instumenty* [Materials. Technologies. Tools], 2000, vol. 5, no. 1, pp. 36–41.
22. Pesetskii S. S., Dubrovskiy V. V. Polialkilentereftalaty napolnennyye korotkim steklovoloknom: struktura i svoystva, mekhanizm razrusheniya, perspektivy issledovaniy i razrabotok (obzor) [Polyalkylene terephthalates filled with short glass fibers: structure and properties, fracture mechanism, research and development prospects (review)]. *Polimernyye materialy i tekhnologii* [Polymer Materials and Technologies], 2020, vol. 6, no. 2, pp. 24–26.
23. Alent'yev A. Yu., Yablokova M. Yu. *Svyazuyushchiye dlya polimernykh kompozitsionnykh materialov* [Binders for polymer composite materials]. Moscow : MGU im. M. V. Lomonosova Publ., 2010. 69 p.
24. Gerasimova V. M. Razrabotka epoksidnykh kompozitsionnykh materialov s povyshennymi ekspluatatsionnymi svoystvami na osnove modifitsirovannykh voloknistykh napol-niteley razlichnoy khimicheskoy prirody. Diss. kand. tekhn. Nauk [Development of epoxy composite materials with enhanced performance properties based on modified fibrous fillers of various chemical nature. PhD eng. sci. diss.]. Saratov, 2017. 153 p.
25. Lee E. S., Kim J. S., Kim K. Y., Lim D. Y., Kim D. H. Preparation of polypropylene composites reinforced with long carbon fib ers and their properties. *Fibers Polym*., 2014, vol. 15, pp. 2613–2617. doi: 10.1007/s12221-014-2613-6
26. Rohde M., Ebel A.; Wolff-Fabris F., Altstädt V. Influence of Processing Parameters on the Fiber Length and Impact Properties of Injection Molded Long Glass Fiber Reinforced Polypropylene. *Int. Polym. Process*., 2011, vol. 26, no. 3, pp. 292–303. doi: 10.3139/217.2442
27. Ren P., Dai G. Fiber dispersion and breakage in deep screw channel during processing of long fiber-reinforced polypropylene. *Fibers Polym.*, 2014, vol. 15, no. 7, pp. 1507–1516. doi: 10.1007/s12221-014-1507-y
28. Garcia-Rejon A., Meddad A., Turcott E., Carmel M. Extrusion blow molding of long fiber reinforced polyolefins. *Polym. Eng. Sci*., 2002, vol. 42, no. 2, pp. 346–364. doi: 10.1002/pen.10953
29. Kuboki T., Lee Y.H., Park C.B., Sain M. Mechanical properties and foaming behavior of cellulose fiber in forced high-density polyethylene composites. *Polym. Eng. Sci*., 2009, vol. 49, no. 11, pp. 2179–2188. doi: 10.1002/pen.21464
30. An H. J., Kim J. S., Kim K.-Y., Lim D. Y., Kim D. H. Mechanical and thermal properties of long carbon fiber-reinforced polyamide 6 composites. *Fibers Polym*., 2014, vol. 15, pp. 2355–2359. doi: 10.1007/s12221-014-2355-5
31. Toll S., Andersson P.-O. Microstructure of Long- and Short-Fiber Reinforced Injection Molded Polyamide. *Polym. Compos.*, 1993, vol. 14, is. 2, pp. 116–125. doi: 10.1002/pc.750140205
32. Bijsterbosch H., Gaymans R. J. Polyamide 6 — long glass fiber injection moldings. *Polym. Compos*., 1995, vol. 16, is. 5, pp. 363–369. doi: 10.1002/pc.750160504
33. Wyzgoski M. G., Novak G. E. Fatigue Fracture of Long Fiber Reinforced Nylon 66. *Polymer composites*, 1995, vol. 16, is. 1, pp. 38–51. doi: 10.1002/pc.750160107
34. Karger-Kocsis J., Friedrich K. Fatigue crack propagation in short and long fiber reinforced injection moulded PA 6,6 composites. *Composites*, 1988, vol. 19, no. 2, pp. 105–114. doi: 10.1016/0010-4361(88)90720-3
35. Lafranche E., Krawczak P., Ciolczyk, J. P., Maugey J. Injection moulding of long glass fiber reinforced polyamide 66: Processing conditions/microstructure/flexural properties relationship. *Adv. Polym. Technol*., 2005, vol. 24, is. 2, pp. 114–131. doi: 10.1002/adv.20035
36. Hollin J., Miller D., Vautour D. A comparison of transverse properties of 50% short and long glass fiber reinforced nylon 6/6 resin. *J. Reinf. Plast. Compos.*, 1998, vol. 17, 1998, vol. 17, is. 18, pp. 1617–1624. doi: 10.1177/073168449801701803
37. Tingxiu Xie, Guisheng Yang. Interface and Mechanical Properties of Poly(methyl methacrylate)–Fiber Composites. *J. Appl. Polym. Sci*., 2004, vol. 93, is. 5, pp. 2478–2483. doi: 10.1002/app.20819
38. Denault J., Vu-Khanh T., Foster B. Tensile Properties of Injection Molded Long Fiber Thermoplastic Composites. *Polymer Composites*, 1989, vol. 10, no. 5, pp. 313–321. doi: 10.1002/pc.750100507
39. Bayerl T., Mitschang P. Rheological and Mechanical Behavior of Long-Polymer-Fiber Reinforced Thermoplastic Pellets. *J. Appl. Polym. Sci*., 2014, vol. 131, is. 1. doi: 10.1002/APP.39716
40. Lin S. H., Ma C. C. M., Tai N. H. Long Fiber Reinforced Polyamide and PoIycarbonate Composites. II: Fatigue Behavior and Morphological Property. *Journal of Vinyl and Additive Technology*, 1996, vol. 2, no. 1, pp. 80–86. doi: 10.1002/vnl.10099
41. Wang Q., Ning H., Vaidya U., Pillay S. Mechanical Behavior of Long Carbon Fiber Rein-forced Polyarylamide at Elevated Temperature. *J. Material. Sci. Eng*., 2016, vol. 5, is. 6. doi: 10.4172/2169-0022.1000294
42. Zhaozeng Tao, Yatao Wang, Jianhua Li, Xiaodong Wang, Dezhen Wu Fabrication of Long Glass Fiber Reinforced Polyacetal Composites: Mechanical Performance, Microstructures, and Isothermal Crystallization Kinetics. *Polym. Compos*., 2015, vol. 36, is. 10, pp. 1826–1839. doi: 10.1002/pc.23090
43. Min He, Daohai Zhang, Jianbing Guo, Shuhao Qin, Xingxing Min. Mechanical, Ther-mal, and Dynamic Mechanical Properties of Long Glass Fiber-Reinforced Thermoplastic Polyure-thane/Polyoxymethylene Composites. *Polym. Compos*., 2014, vol. 35, is. 10, pp. 2067–2073. doi: 10.1002/pc.22868
44. Daohai Zhang, Min He, Shuhao Qin, Jie Yu. Effect of fiber length and dispersion on properties of long gla ss fiber reinforced thermoplastic composites based on poly(butylene terephthalate). *RSC Adv*., 2017, vol. 7, pp. 15439–15454. doi: 10.1039/C7RA00686A
45. Markarian J. Long fibre reinforcement drives automotive market forward. *Plastics, Additives and Compounding*, 2005, vol. 7, no. 3, pp. 24–29. doi: 10.1016/S1464-391X(05)70393-7
46. Daohai Zhang, Min He, Shuhao Qin, Jie Yu, Jianbing Guo, Guomin Xu. Study on Dynamic Mechanical, Thermal, and Mechanical Properties of Long Glass Fiber Reinforced Thermo-plastic Polyurethane/Poly(butylene terephthalate) Composites. *Polym. Compos*., 2018, vol. 39, is. 1, pp. 63–72. doi: 10.1002/pc.23902
47. Vu-Khanh T., Denault J., Habib P., Low A. The effects of injection molding on the mechanical behavior of long-fiber reinforced PBT/PET blends. *Compos. Sci. Technol*., 1991, vol. 40, is. 4, pp. 423–435. doi: 10.1016/0266-3538(91)90032-K
48. Tan Y. H., Wang X. D., Wu D. Z. Preparation, microstructures, and properties of long-glass-fiber-reinforced thermoplastic composites based on polycarbonate/ poly(butylenes terephthalate) alloys. *J. Reinf. Plast. Compos*., 2015, vol. 34, is. 21, pp. 1804–1820. doi: 10.1177/0731684415599071
49. Harmia T. Fatigue behavior of neat and long glass fiber (LGF) reinforced blends of ny-lon 66 and isotactic PP. *Polym. Compos*., 1996, vol. 17, no. 6, pp. 926–936.

50. Kim N., Kim D.-Y., Kim Y.-J., Jeong K.-U. Enhanced thermomechanical properties of long and short glass fiber-reinforced polyamide 6,6/polypropylene mixtures by tuning the processing procedures. *J. Mater. Sci*., 2014, vol. 49, no. 18, pp. 6333–6342. doi: 10.1007/s10853-014-8358-1
51. Panova L. G. *Napolniteli dlya polimernykh kompozitsionnykh materialov* [Fillers for polymer composite materials]. Saratov : SGTU Publ., 2010. 64 p.
52. Liu Yuchao. Study on the mechanical behavior of directly compounded long glass fiber reinforced polyamide 6 composites. Available at: https://ir.lib.uwo.ca/cgi/viewcontent.cgi?article=6391&context=etd (accessed 18.04.2023).
53. Karger-Kocsis J., Harmia T., Czigány T. Comparison of the fracture and failure behavior of polypropylene composites reinforced by long glass fibers and by glass mats. *Compos. Sci. Technol*., 1995, vol. 54, no. 3, pp. 287–298. doi: 10.1016/0266-3538(95)00068-2
54. Fan Y., Liu Y. C., Whitfield T., Kuboki T., Wood J. T., Ugresic V. Effects of Pro-cessing Parameters on the Thermal and Mechanical Properties of LFT- DECM Glass Fi-ber/Polyamide 6 Composites. *Plast. Eng*., 2017, vol. 73, pp. 44–45.
55. Huan-Chang Tseng, Rong-Yeu Chang, Chia-Hsiang Hsu. Numerical Predictions of Fiber Orientation and Mechanical Properties for Injection-Molded Long-Carbon-Fiber Thermoplastic Composites. *Polym. Compos*., 2017, vol. 39, is. 10, pp. 3726–3739. doi: 10.1002/pc.24403
56. Sharma Bhisham N., Kijewski Seth A., Fifield Leonard S., Shin Yongsoon, Tucker Charles L., Sangid Michael D. Reliability in the Characterization of Fiber Length Distributions of Injection Molded Long Carbon Fiber Composites. *Polym. Compos*., 2017, vol. 39, is. 12, pp. 4594–4604. doi: 10.1002/pc.24571
57. Deák Tamás, Czigány Tibor, Maršálková Miroslava, Militký Jiří. Manufacturing and Testing of Long Basalt Fiber Reinforced Thermoplastic Matrix Composites. *Polym. Eng. Sci*., 2010, vol. 50, is. 12, pp. 2448–2456. doi: 10.1002/pen.21765
58. Tan H., Tan H. S., Tang X. L., Wang Y. G., Li L. P. Mechanical properties and dynamic mechanical behavior for long aramid fiber reinforced impact polypropylene copolymer. *Adv. Mater. Res*., 2012, vol. 591–593, pp. 1079–1082. doi: 10.4028/www.scientific.net/amr.591-593.1079
59. Tang Xinlei, Tan Hongsheng, Tan Hao, Wang Yangang. Long aramid fiber reinforced impact polypropylene copolymer composites. *Engineering Plastics Application*, 2013, vol. 41, no. 2, pp. 5–9.
60. Grande C., Torres F. G. Investigation of Fiber Organization and Damage During Single Screw Extrusion of Natural Fiber Reinforced Thermoplastics. *Advances in Polymer Technology*, 2005, vol. 24, no. 2, pp. 145–156. doi: 10.1002/adv.20037
61. Ranganathan N., Oksman K., Nayak S. K., Sain M. Structure property relation of hybrid biocomposites based on jute, viscose and polypropylene: Effect of fiber content and length on fracture toughness and fatigue properties. *Composites Part A: Applied science and manufacturing*, 2016, vol. 83, pp. 169–175. doi: 10.1016/j.compositesa.2015.10.037
62. Ranganathan N., Oksman K., Nayak S. K., Sain M. Regenerated Cellulose Fibers as Impact Modifier in Long Jute Fiber Reinforced Polypropylene Composites: Effect on Mechanical Properties, Morphology, and Fiber Breakage. *J. Appl. Polym. Sci.*, 2015, vol. 132. doi: 10.1002/APP.41301
63. Jeyanthi S., Rani J. J. Development of natural long fiber thermoplastic composites for automotive frontal beams. *Indian Journal of Engineering and Materials Sciences*, 2014, vol. 21, pp. 580–584.
64. Ranganathan N., Oksman K., Nayak S. K., Sain M. Impact toughness, viscoelastic behavior, and morphology of polypropylene–jute–viscose hybrid composites. *J. Appl. Polym. Sci*., 2016, vol. 133, is. 7. doi: 10.1002/app.42981
65. Uawongsuwan P., Yang Y., Hamada H. Long jute fiber-reinforced polypropylene composite: effects of jute fiber bundle and glass fiber hybridization. *J. Appl. Polym. Sci*., 2015, vol. 132, is. 15. doi: 10.1002/app.41819
66. Schemme M. LFT – development status and perspectives. *Reinf. Plast*., 2008, vol. 52, no. 1, pp. 32–39. doi: 10.1016/S0034-3617(08)70036-5
67. Kim Sung-Eun, Ahn Jun-Geol, Ahn Seungjae, Park Do-Hyung, Choi Da-Hee, Lee Jae-Chul, Yang Hyun-Ik, Kim Ki-Young. Development of PA6/GF Long-Fiber-Reinforced Ther-moplasticComposites Using Pultrusion and Direct Extrusion Manufacturing Processes. *Appl. Sci*., 2022, vol. 12, is. 10. doi: 10.3390/app12104838
68. Kim Y., Park O. O. Effect of Fiber Length on Mechanical Properties of Injection Molded Long-Fiber-Reinforced Thermoplastics. *Macromol. Res*., 2020, vol. 28, pp. 433–444. doi: 10.1007/s13233-020-8056-6
69. Whitfield T., Kuboki T., Wood J., Ugresic V., Sathyanarayana S., Dagnon K. Ther-mal properties of glass fiber reinforced polyamide 6 composites throughout the direct long-fiber re-inforced thermoplastic process. *Polym. Eng. Sci*., 2018, vol. 58, no. 1, pp. 46–54. doi: 10.1002/pen.24529
70. Markarian J. Long fibre reinforced thermoplastics continue growth in automotive. *Plast. Addit. Compd.*, 2007, vol. 9, no. 2, pp. 20–24. doi: 10.1016/s1464-391x(07)70025-9
71. Krause W., Henning F., Tröster S., Geiger O., Eyerer P. LFT-D – A Process Tecnology for Large Scale Production of Fiber Reinforced Thermoplastic Components. *Journal of Thermoplastic Composite Materials*, 2003, vol. 16, is. 4, pp. 289–302. doi: 10.1177/0892705703016004001
72. Whitfield T., Kuboki T., Wood J., Ugresic V., Sathyanarayana S., Dagnon K. Effects of process parameters on thermal properties of glass fiber reinforced polyamide 6 composites throughout the direct long-fiber-reinforced thermoplastics process. *Polym. Eng. Sci*., 2018, vol. 58, no. S1, pp. E114–E123. doi: 10.1002/pen.24718
73. Henning, F., Ernst, H., Brüssel R. LFTs for automotive applications. *Reinforced plastics*, 2005, vol. 49, no. 2, pp. 24–33. doi: 10.1016/S0034-3617(05)00546-1
74. Markarian J. Strengthening compounds through fibre reinforcement. *Reinforced Plastics*, 2007, vol. 51, no. 2, pp. 36–39. doi: 10.1016/s0034-3617(07)70057-7
75. Geiger O., Henning F., Eyerer P., Brüssel R., Ernst H. LFT-D: materials tailored for new applications. *Reinf. Plast*., 2006, vol. 50, no. 1, pp. 30–35. doi: 10.1016/S0034-3617(06)70870-0
76. Thomason J. L., Vlug M. A. Influence of fiber length and concentration on the properties of glass fiber-reinforced polypropylene: 1. Tensile and flexural modulus. *Composites Part A*, 1996, vol. 21, is. 6, pp. 477–484. doi: 10.1016/1359-835X(95)00065-A
77. Thomason J. L., Groenewoud W. M. The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene: 2. Thermal properties. *Composites Part A*, 1996, vol. 21, pp. 555–565.
78. Thomason J. L., Vlug M. A., Schipper G., Krikort H. G. L. T. Influence of fibre length and concentration on the properties of glass fibre-reinforced polypropylene: Part 3. Strength and strain at failure. *Composites Part A*, 1996, vol. 27, pp. 1075–1084.
79. Thomason J. L., Vlug M. A. Influence of fibre length and concentration on the prop-erties of glass fibre-reinforced polypropylene: 4. Impact properties. *Composites Part A*, 1997, vol. 28, is. 3, pp. 277–288. doi: 10.1016/S1359-835X(96)00127-3
80. Thomason J. L. The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene: 5. Injection moulded long and short fibre PP. *Composites: Part A*, 2002, vol. 33, is. 12, pp. 1641–1652. doi: 10.1016/S1359-835X(02)00179-3
81. Thomason J. L. The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene. 6. The properties

of injection moulded long fibre PP at high fibre content. *Composites: Part A*, 2005, vol. 36, is. 7, pp. 995–1003. doi: 10.1016/j.compositesa.2004.11.004

82. Thomason J. L. The influence of fibre length, diameter and concentration on the modulus of glass fibre reinforced polyamide 6,6. *Composites: Part A*, 2008, vol. 39, is. 11, pp. 1732–1738. doi: 10.1016/j.compositesa.2008.08.001
83. Thomason J. L. The influence of fibre length and concentration on the properties of glass fibre reinforced polypropylene: 7. Interface strength and fibre strain in injection moulded long fibre PP at high fibre content. *Composites: Part A*, 2007, vol. 38, is. 1, pp. 210–216. doi: 10.1016/j.compositesa.2006.01.007
84. Thomason J. L. Structure–Property Relationships in Glass-Reinforced Polyamide, Part 1: The Effects of Fiber Content. *Polym. Compos*., 2006, vol. 27, is. 5, pp. 552–562. doi: 10.1002/pc.20226
85. Ke-qing Han, Zheng-jun Liu, Mu-huo Yu. Preparation and Mechanical Properties of Long Glass Fiber Reinforced PA6 Composites Prepared by a Novel Process. *Macromol. Mater. Eng*., 2005, vol. 290, is. 7, pp. 688–694. doi: 10.1002/mame.200500051
86. Bobing He, Heng Liu, Jinhua Leng, Bin Yang, Xian Chen, Jingwei Fu, Qiang Fu. Mechanical properties of long glass fiber-reinforced polypropylene composites and their influence factors. *Journal of Reinforced Plastics and Composites*, 2015, vol. 30, no. 3, pp. 222–228. doi: 10.1177/0731684410391513
87. Daohai Zhang, Jianbing Guo, Kaizhou Zhang. Effects of compatilizers on mechanical and dynamic mechanical properties of polypropylene–long glass fiber composites. *Journal of Thermoplastic Composite Materials*, 2013, vol. 28, no. 5. doi: 10.1177/0892705713486141
88. Bin Yang, Jinhua Leng, Bobing He, Heng Liu, Yu Zhang, Zhaohua Duan. Influence of fiber length and compatibilizer on mechanical properties of long glass fiber reinforced polyamide 6,6. *Journal of Reinforced Plastics and Composites*, 2012, vol. 31, no. 16, pp. 1103–1112. doi: 10.1177/0731684412454199
89. Weixia Yan, Ke Qing Han, Liu Liang Qin, Mu Huo Yu. Study on Long Fiber–Reinforced Thermoplastic Composites Prepared by In Situ Solid-State Polycondensation. *Journal of Applied Polymer Science*, 2004, vol. 91, is. 6, pp. 3959–3965. doi: 10.1002/app.13627
90. Weixia Yan, Ke Qing Han, Hongmei Zhou, Mu Huo Yu. Study on the Grafting of PET onto the Glass Fiber Surface during In Situ Solid-State Polycondensation. *Journal of Applied Polymer Science*, 2006, vol. 99, is. 3, pp. 775–781. doi: 10.1002/app.22552
91. Cho S. M., Jung H.-T. Highly Enhanced Mechanical Properties of Polypropylene-Long Carbon Fiber Composites by a Combined Method of Coupling Agent and Surface Modification of Long Carbon Fiber. *Macromolecular Research*, 2014, vol. 22, no. 10, pp. 1066–1073. doi: 10.1007/s13233-014-2153-3
92. Priebe M., Schledjewski R. Processing and properties of glass/polypropylene in long fibre compounding extrusion. *Plastics, Rubber and Composites*, 2011, vol. 40, no. 6-7, pp. 374–379. doi: 10.1179/1743289810Y.0000000035
93. Yang Mingyu, Kuboki Takashi, Wood Jeffrey, Ugresic Vanja. Effects of Extruder Screw Configurations on Thermal Properties of Glass Fiber-Reinforced Polyamide 6 Composites Throughout the Direct Long-Fiber-Reinforced Thermoplastics Process. *Polym. Compos*., 2019, vol. 40, is. 9, pp. 3500–3509. doi: 10.1002/pc.25212
94. Ranganathan N., Oksman K., Nayak S. K., Sain M. Effect of long fiber thermoplastic extrusion process on fiber dispersion and mechanical properties of viscose fi-ber/polypropylene composites. *Polym. Adv. Technol*., 2016, vol. 27, is. 5, pp. 685–692. doi: 10.1002/pat.3742
95. Ying He, Wei Gong, Daohai Zhang, Shuhao Qin. Effect of Impregnation Time on Performance of Long Glass Fiber-Reinforced Polypropylene Composites. *Journal of Vinyl and Additive Technology*, 2018, vol. 24, is. 2, pp. 174–178. doi: 10.1002/vnl.21543
96. Inoue A., Morita K., Tanaka T., Arao Y., Sawada Y. Effect of screw design on fiber breakage and dispersion in injection-molded long glass-fiber-reinforced polypropylene. *J. Compos. Mater*., 2015, vol. 49, no. 1, pp. 75–84. doi: 10.1177/0021998313514872
97. Xu-Qin Hou, Xing-Yuan Chen, Bao-Chen Liu, Sheng-Chao Chen, Hai-Mei Li ,Wei Cao. Fracture and Orientation of Long-Glass-Fiber-Reinforced Polypropylene During Injection Molding. *Polym. Eng. Sci*., 2019, vol. 60, is. 1, pp. 13–21. doi: 10.1002/pen.25254
98. Teixeira D., Giovanela M., Gonella L. B., Crespo J. S. Influence of injection molding on the flexural strength and surface quality of long glass fiber-reinforced polyamide 6.6 composites. *Materials and Design*, 2015, vol. 85, pp. 695–706. doi: 10.1016/j.matdes.2015.07.097
99. Skourlis T. P., Mehta S. R., Chassapis C., Manoochehri S. Impact Fracture Behavior of Injection Molded Long Glass Fiber Reinforced Polypropylene. *Polymer Engineering and Sci-ence*, 1998, vol. 38, no. 1, pp. 79–89. doi: 10.1002/pen.10167
100. Lafranche E., Krawczak P., Ciolczyk J. P., Maugey J. Injection moulding of long glass fibre reinforced polyamide 6-6: guidelines to improve flexural properties. eXPRESS Polymer Letters, 2007, vol. 1, no. 7, pp. 456–466. doi: 10.3144/expresspolymlett.2007.64
101. Ogawa T., Mima M., Taya N. Change of fiber length in injection molding of carbon fiber reinforced Nylon 66. *Seikei-Kakou*, 1995, vol. 7, is. 5, pp. 315–320. doi: 10.4325/seikeikakou.7.315
102. Jacob A. Car makers increase their use of composites. *Reinf. Plast*., 2004, vol. 48, no. 2, pp. 26–32. doi: 10.1016/s0034-3617(04)00149-3
103. Steffens M., Himmel N., Maier M. Design and analysis of discontinuous long fiber rein-forced thermoplastic structures for car seat applications. *Transactions on Engineering Sciences*, 1998, vol. 21, pp. 35–44.
104. Pal'ke S. Lit'e pod davleniem steklovoloknistykh termoplastov [Injection molding of fiberglass thermoplastics]. *Polimernye materialy. Izdelija. Oborudovanie. Tehnologii* [Polymer materials. Products, equipment, technology], 2007, no. 3, pp. 26–31.
105. Zeyrek B. Y., Aydogan B., Dilekcan E., Ozturk F. Review of Thermoplastic Compo-sites in Aerospace Industry. *International Journal on Engineering Technologies and informatics*, 2022, vol. 3, no. 1, pp. 1–6. doi: 10.51626/ijeti.2022.03.00031
106. DeWayne Howell D., Fukumoto S. Compression molding of long chopped fiber ther-moplastic composites. 2009. Available at: https://www.toraytac.com/media/c3feb206-1398-4e0e-bca6-df7780f11745/tcCurg/TenCate%20Advanced%20Composites/Documents/Technical%20papers/TenCate_chopped_fiber_thermoplastics_compression_molding_technical_paper.pdf (accessed 18.04.2023).
107. Costa A. P., Botelho E., Costa M. L., Narita N. E., Tarpani J. R. A Review of Welding Technologies for Thermoplastic Composites in Aerospace Applications. *Journal of Aerospace Technology and Management*, 2012, vol. 4, no. 3, pp. 255–265. doi: 10.5028/jatm.2012.04033912
108. Davis Stephen J. Long fiber reinforced thermoplastic frame especially for a tennis racquet. Patent US, no. 5176868, 1993.
109. Manufactory in Xiamen China different contents long glass fiber and carbon fiber compound pellets. Available at: https://www.lfrt-plastic.com/ (accessed 18.04.2023).