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A REVIEW ON FABRICATION METHODS AND PRESENT SCENARIO OF APPLICATIONS OF PEEK.

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Abstract: PEEK, short for Poly Ether Ether Ketone, is an aromatic crystalline thermoplastic polymer. In order to meet the requirements of high temperature applications like aerospace, automobile etc., different types of fibers and nano fillers are reinforced with PEEK. The method of fabrication is one of the factors which affects the properties of composite materials. The aim of this review is to study the various fabrication methods used for PEEK and reinforcements so far and also the present scenario of application of PEEK with reinforcements.

Keywords: PEEK, Fabrication methods, Nano fillers, Reinforcements.

1. INTRODUCTION:

Even though metals tends to be more heat-resistant materials than plastic, there are many situations where engineers would get benefit from using heat-resistant plastics for their high-performance applications. In addition to being heat-resistant, these high performance thermo plastic materials are chemical-resistant, corrosion-resistant, and excellent electrical and thermal insulators. Common high-performance applications include piston components in the automotive industry, cable conduits in the aerospace industry, subsea connectors in the semiconductor industry, and more.

PEEK, short for polyether ether ketone is composed of repetitive units of polyaryletherketone and is an aromatic crystalline thermoplastic polymer That's resistant to chemicals, wear, fatigue, creep, and heat. This material is so strong and adaptable to harsh environments that manufacturers use it as a replacement for metal in many applications, no matter the temperature. PEEK can withstand temperatures as high as 310°C for short periods and has a melting point of over 371°C. And also it has the highest tensile and flexural strength of any high-performance polymer. The main limitation of this thermoplastic is its susceptibility to UV light and certain acids. And another main drawback is that difficulty in Fabrication when reinforced with fibers and nanoparticles. However, PEEK is still a highly versatile thermoplastic that all engineers should have in their repertoire.

Chunyang Chen and others [1] reported that the fiber distribution of short glass fiber reinforced (SGFR-PEEK) composites processed by extrusion was uniform compared to that processed by injection molding, which affected the strain-rate-sensitivity and fracture toughness. The injection specimen showed better fracture toughness than that of the extrusion specimen.

The mechanical properties of PEEK and PEEK composites has been extensively studied, in the aspects of damage characterization, analysis of failure mechanism, and analytical and numerical simulations [2–5]. The moderately reinforced system between un-reinforced PEEK and continuous fiber reinforced PEEK is short fiber reinforced PEEK, where carbon and glass fibers are commonly used as reinforced materials. Sarasua and coworkers [2] reported that the interface between carbon fiber and PEEK matrix revealed a higher adhesion to that of glass fiber-PEEK interface, under uniaxial tension. Rasheva and coworkers [3] studied the interaction between mechanical properties and tribological behavior for short carbon fiber reinforced PEEK composites. Li and coworkers [4] observed pulled-out fibers and smoother surface of pulled out fibers for PEEK composites stretched at cryogenic temperatures (20 K and 77 K), which indicates the transition of ductile-to-brittle bonding of fiber-matrix interface with the decreasing of testing temperature. Similarly, for the impact behavior of PEEK composites reported by Arias and coworkers [5], there is also a ductile-to-brittle transition resulting in a sudden decrease of impact energy absorption. Although thermoplastic polymer could get a lot of advantages after reinforced with short fibers, the reinforced inorganic fibers would have a serious negative effect on material damage due to the poor interfacial interaction between fibers and matrix [6–8]. The complexity of failure mechanism for PEEK composites comes from the microstructures of the material itself, like the heterogeneities and orientation of fibers due to injection molding process. For short fiber reinforced composites (SFRC), fiber breakage would result in material softening due to the weakening of bearing capacity of fibers, which may lead to the material failure.

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2. FABRICATION METHODS:

From the literature, the studies reveals that the fabrication method is one of the factors on which the properties of any composites is depends. Many fabrication methods can be employed to fabricate PEEK with fibers and/or reinforcements. These methods include Injection moulding method, Extrusion method, hot pressing method, FDM etc. depending on the properties which we need to tailored. In this study a light is thrown on the different PEEK composites fabrication methods with their benefits and challenges.

2.1 Injection molding Method:

Injection moulding is a manufacturing technology for the mass-production of identical plastic parts with good tolerances. In Injection Molding, polymer granules are first melted and then injected under pressure into a mold, where the liquid plastic cools and solidifies. The materials used in Injection Molding are thermoplastic polymers that can be colored or filled with other additives. Almost every plastic part around you was manufactured using injection molding: from car parts, to electronic enclosures, and to kitchen appliances.

Injection molding is so popular, because of the dramatically low cost per unit when manufacturing high volumes. Injection molding offers high repeatability and good design flexibility. The main restrictions on Injection Molding usually come down to economics, as high initial investment for the mold is required. Also, the turn-around time from design to production is slow.

2.2 Extrusion Method:

Extrusion is predominantly a thermos-mechanical processing operation that combines several unit operations, including mixing, coating, kneading, venting, shearing, heating, forming, partial drying or puffing, depending on the material and equipment used [9]. Extrusion processing involves a combination of transport processes, including flow of materials within the virtually controlled environment system, thermal energy transfer to and within the material, and mass transfer to and within the material during extrusion.

Extruders comes in a wide variety of shapes, sizes and methods of operation, but can be categorized into one of three main types: Piston, roller and screw extruders. Among these, twin – screw extruder is commonly used in extrusion of thermoplastic composites. Twin-screw extruder means that there are two screws inside the closed barrel (Fig. 1). The outcome of the extruder is pallets of required material composition. This pallets will be used to make the required test specimens by injection moulding process. In 1970s, twin-screw extruders were introduced to the food industry Moreover, twin-screw extruders have found a wide application in the chemical and paper industry due to their better process control and versatility, their flexible design permitting easy cleaning and rapid product changeover and their ability to handle a wide variety of formulations.

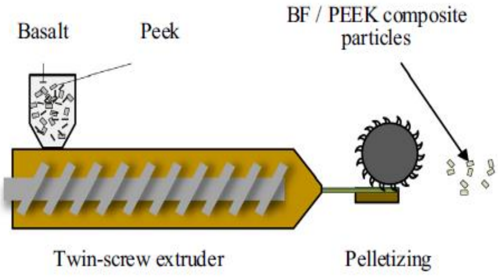

Fig.1 Twin-screw extruder

2.3 Hot pressing Method:

The molding process in this method is divided into two stages: pre-pressing and hot compression. The pre-pressing process removes a certain amount of air, which ensures full contact between the mold and the raw PEEK materials. Heat preservation before hot compression also ensures that the temperature of the material reaches a specified temperature of hot compression. To obtain products of the same size, during the hot compression process at the end of a certain period the pressure is maintained, and a certain pressure is applied on the melt to prevent the mold cavity from shrinking during the cooling process of the mold, which causes the product to shrink to a large dimensional error [10].

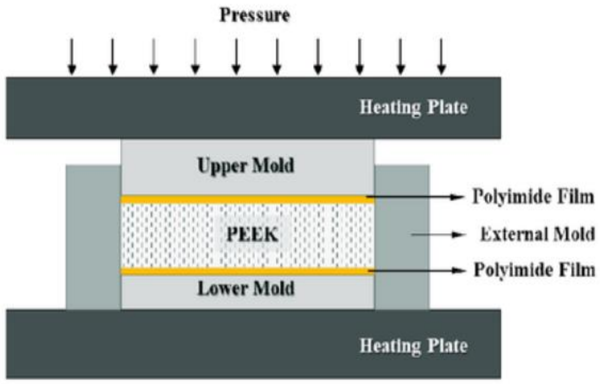

Fig.2 Hot Pressing process.

2.3 Fused deposition modelling:

Polyetheretherketone an emerging high-performance thermoplastic for FDM-3D printing. The density of PEEK is 1.3 g/cm^3 and the melting temperature of PEEK is 343 °C. The tensile strength, flexural strength and Charpy un-notched impact strength of PEEK are 107 MPa, 163 MPa and 136 kJ/m^2 respectively. Different types of chopped fibers such as carbon fiber and glass fiber were added into PEEK respectively as reinforcement to fabricate composites filaments. Prior to blending, these fibers were treated by anodic oxidation and silane coupling agent, respectively. Silane coupling agent and anodic oxidation methods are commonly used to improve fiber-matrix interfacial bonding [48-50]. The surface roughness of CF increases effectively through anodic oxidation treatment which also improves the amount of oxygen functional groups on the surface of CF.

Prior to preparing filaments, all materials were dried at 150 °C for 24 h to remove any moisture. Afterwards, PEEK and fibers were blended sufficiently in the high-temperature twin-screw extruder to fabricate composite filaments. During the extrusion processes, heater temperature, filament yield speed, and strand die diameter were set at 400 °C, 1.8

m/min, and 2.5 mm, respectively. Then the filaments were successively cooled down, pulled into strand cutter and chopped to pellets, dried for the second extrusion carried out by a single-screw extruder

After twice extruding, composite filament filled with well-distributed fibers was obtained consequently. The filament diameter and cylindricity was strictly controlled using a customized mold and an automatic tension control system. The prepared composite filaments were dried in a drying oven at 80 °C for 24 h in preparation for 3D printing. FDM-3D printer was used to fabricate test samples of Fiber/PEEK composites.

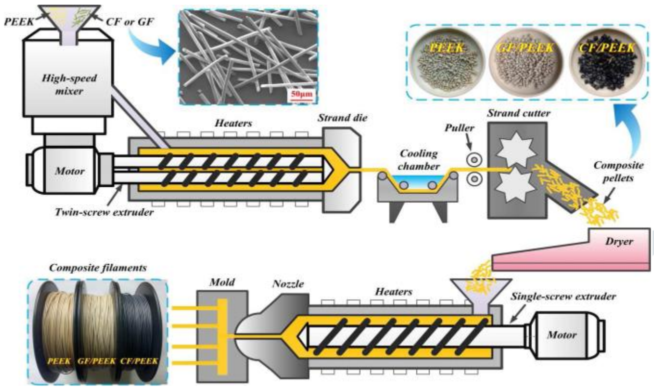

Fig. 3. Preparation process of composite filaments. [47]

3. APPLICATIONS OF PEEK:

Fig.4. Ball Bearing and screws made with PEEK.

3.1 Automotive Industry:

Environmental and safety standards are driving factors in the automotive industry, which also has a continual focus on lowering production costs and increasing efficiency and longevity in support of extended warranties.

There is a growing trend to replace more and more metal parts with plastic ones or other materials such as carbon fiber. PEEK's mechanical properties over a wide temperature range make it useful in the manufacture of car components such as seals, washers and bearings.

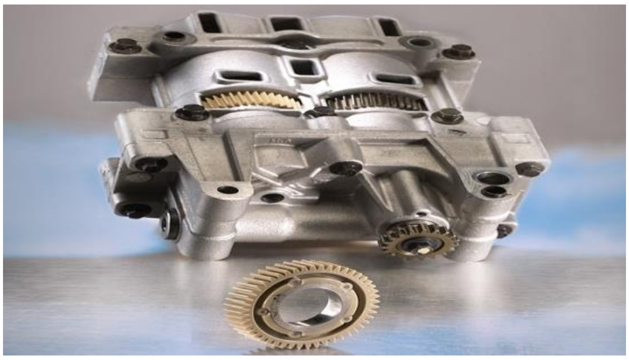

Fig.5. Balance shaft gear

3.2 Aerospace industry:

Even though aluminium is the material of choice for the aerospace industry, PEEK can still find application in some aircraft since it is lighter than aluminium. The only drawback is that PEEK is quite expensive to manufacture, yet it has even better recyclability than aluminium.

Fig.6. Aerospace component

3.3 Medical applications:

PEEK is insoluble in most polymeric solvents and also does not undergo hydrolysis, even at high temperatures. This, coupled with PEEK's relative inertness to chemical reactions, means that it is perfect for biomedical applications where constant sterilisation at high temperatures is important. It also finds application as dental implants when it is reinforced with carbon fibres.

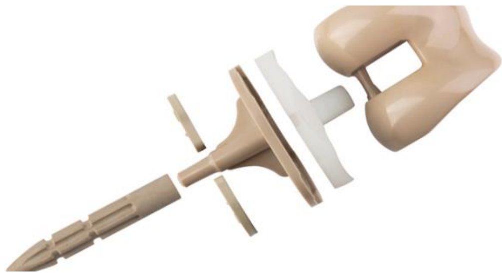

Fig.7. PEEK in Knee Implant

3.4 Electrical/electronic applications:

PEEK is an excellent electrical insulator and retains its mechanical properties at high temperatures. It can thus find application in electrical instruments that operate at high temperatures, such as soldering machines.

Fig.8. PEEK in Electrical applications

3.5 Future applications:

PEEK has potential in the food packaging industry after approval from the US Food and Drug Administration. It is also replacing stainless steel in impeller wheels for regenerative pumps because it offers less noise and improved wear resistance.

4. CONCLUSIONS:

From this review, we can conclude that, there are many fabrication methods to fabricate PEEK reinforced with various fibers and Nano – particles, and also the fabrication method has a strong impact on PEEK composite properties. The application prospects of PEEK material are broad and bright, and also there is a lot of scope for study, as still it is at the early stage of research.

5. REFERENCES:

1. Chunyang Chen, Chao Zhang, Zhenqiang Zhao, Yanpei Wang, Shing-Chung Wong and Yulong Li, "Effect of fiber reinforcement and fabrication process on the dynamic compressive behavior of PEEK composites" International Journal of Mechanical Sciences 155 (2019) 170–177, https://doi.org/10.1016/j.ijmecsci.2019.02.034.

2. Sarasua JR , Remiro PM , Pouyet J . The mechanical behaviour of PEEK short fiber composites. J Mater Sci 1995;30:3501–8 .

3. Rasheva Z , Zhang G , Burkhart T . A correlation between the tribological and mechan- ical properties of short carbon fibers reinforced PEEK materials with different fiber orientations. Tribol Int 2010;43:1430–7.

4. Chu XX , Wu ZX , Huang RJ , Zhou Y , Li LF . Mechanical and thermal expansion proper- ties of glass fibers reinforced PEEK composites at cryogenic temperatures. Cryogenics 2010;50:84–8 ..

5. Garcia-Gonzalez D , Rodriguez-Millan M , Rusinek A , Arias A . Low temperature ef- fect on impact energy absorption capability of PEEK composite. Compos Struct 2015;134:440–9 .

6. Chukov DI , Stepashkin AA , Maksimkin AV , Tcherdyntsev VV , Kaloshkin SD , Kuskov KV , Bugakov VI . Investigation of structure, mechanical and tribological prop- erties of short carbon fiber reinforced UHMWPE-matrix composites. Compo Part B 2015;76:79–88.

7. Singh, B., Sharma, C., Sharma, S. (2017) Fundamentals of extrusion processing. In: Novel Food Processing Technologies; Nanda, V. & Sharma, S. New India Publishing Agency, New Delhi.

8. Tong Li, Zhuoyu Song, Xiangfei Yang and Juan Du "Influence of Processing Parameters on the Mechanical Properties of Peek Plates by Hot Compression Molding", Materials 2023, 16, 36. https://doi.org/10.3390/ma16010036.

9. Cantwell WJ, Morton J. The significance of damage and defects and their detection in composite materials. A review. J Strain Anal Eng Des 1992;27(1):29e42. https://doi.org/ 10.1243/03093247V271029.

10. Jhaver R, Tippur H. Processing, compression response and finite element modeling of syntactic foam based interpenetrating phase composite (IPC). Mater Sci Eng, A 2009;499(1e2):507e17. https://doi.org/10.1016/ j.msea.2008.09.042.

11. Yao B, Zhou Z, Duan L, Chen Z. Anisotropic charpy impact behavior of novel interpenetrating phase composites. Vacuum 2018;155:83e90. https://doi.org/10.1016/ j.vacuum.2018.05.031.

12. Bishop SM. The significance of defects on the failure of Fiber composites. AGARD; 1981.

13. Friedrich K, Schlarb AK. Tribology of polymeric nanocomposites. 2nd ed. Elsevier; 2013. p. 458e82.

14. Xuanzhe Ling, Xishuang Jing, Chengyang Zhang and Siyu Chen "Polyether Ether Ketone (PEEK) Properties and Its Application Status" IOP Conference Series: Earth and Environmental Science, Volume 453, 2019, 5th International Conference on Green Materials and Environmental Engineering, December 27-29, 2019, Guangzhou, China.

15. Liu Liu, Linghan Xiao, Xiuping Zhang, Ming Li, Yanjie Chang, Lei Shang and Yuhui Ao, "Improvement of the thermal conductivity and friction performance of poly(ether ether ketone)/carbon fiber laminates by addition of graphene" RSC Adv.2015, DOI: 10.1039/C5RA10722A.

16. L. Ye, K. Friedrich, D. Cutolo and A. Savadori. "Manufacture of CF/PEEK composites from powder/sheath Fiber performs" Composites Manufacturing Vol 5 No 1 1994, 0956-7143/94/01/0041-10 @ 1994 Butterworth-Heinemann Ltd.

17. Peng Wang, Bin Zou, Shouling Ding, Chuanzhen Huang, Zhenyu Shi, Yongsheng Ma and Peng Yao, "Preparation of short CF/GF reinforced PEEK composite filaments and their comprehensive properties evaluation for FDM-3D printing" S1359-

8368(20)30681-8 JCOMB 108175, 17 May 2020, https://doi.org/10.1016/j.compositesb.2020.108175.

18. Dimitrios G. Papageorgiou*, Mufeng Liu, Zheling Li, Cristina Vallés, Robert J. Young,Ian A. Kinloch. “Hybrid poly(ether ether ketone) composites reinforced with a combination of carbon Fibers and graphene nanoplatelets” Composites Science and Technology 175 (2019) 60–68, 6 March 2019, https://doi.org/10.1016/j.compscitech.2019.03.006.

19. A. Martínez-Gómez, S. Quiles-Díaz, P. Enrique-Jimenez, A. Flores, F. Ania, M.A. Gómez-Fatou and H.J. Salavagione, “Searching for effective compatibilizing agents for the preparation of poly (ether ether ketone)/graphene nanocomposites with enhanced properties” Composites Part A 113 (2018) 180–188 21 July 2018, https://doi.org/10.1016/j.compositesa.2018.07.027.

20. J.A. Puértolas, M. Castro, J.A. Morris, R. Ríos, A. Ansón-Casaos, “Tribological and mechanical properties of graphene nanoplatelet/PEEK composites” S0008-6223(18)30850-9, CARBON 13464, DOI: 10.1016/j.carbon.2018.09.036.

21. Songtao Li, Wanchong Li, Jing Nie, Dongyan Liu, Guoxin Sui, “Synergistic effect of graphene nanoplate and carbonized loofah fiber on the electromagnetic shielding effectiveness of PEEK-based composites” Carbon 143 (2019) 154e161, https://doi.org/10.1016/j.carbon.2018.11.015.

22. Ángel Alvaredo-Atienza, Lu Chen, Verónica San-Miguel, Álvaro Ridruejo and Juan P. Fernández-Blázquez. “Fabrication and Characterization of PEEK/PEI Multilayer Composites” Polymers 2020, 12, 2765 24 November 2020; https://doi:10.3390/polym12122765.

23. Yu Jin Lin, Shi Qin, Bing Han, Cong Gao and Shu Ling Zhang, Preparation of poly(ether ether ketone)-based composite with high electrical conductivity, good mechanical properties and thermal stability” High Performance Polymers-2017, Vol. 29(2) 205–210.

24. Marianna Rinaldi, Federico Cecchini, Lucia Pigliaru, Tommaso Ghidini, Francesco Lumaca and Francesca Nanni “Additive Manufacturing of Polyether Ether Ketone (PEEK) for Space Applications: A Nanosat Polymeric Structure” Polymers 2021, 13, 11. https://dx.doi.org/10.3390/polym13010011.

25. M. Roux, C. Dransfeld, N. Eguémann and L. Giger “PROCESSING AND RECYCLING OF A THERMOPLASTIC COMPOSITE FIBER/PEEK AEROSPACE PART” EUROPEAN CONFERENCE ON COMPOSITE MATERIALS, Seville, Spain, 22-26 June 2014.

26. R. Hemanth, M. Sekar and B. Suresha “ Effects of Fibers and Fillers on Mechanical Properties of Thermoplastic Composites” Indian Journal of Advances in Chemical Science 2 (2014) 28-35.

27. L. Ye, K. Friedrich, D. Cutolo and A. Savadori “Manufacture of CF/PEEK composites from powder/sheath Fiber performs” Composites Manufacturing Vol 5 No 1 1994, Composites Manufacturing Vol 5 No 1 1994.

28. M. Rahail Parvaiz, Smita Mohanty, Sanjay K. Nayak and P. A. Mahanwar “Polyetheretherketone (PEEK) Composites Reinforced with Fly Ash and Mica” Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.1, pp.25-41, 2010.

29. Hongyun Ma, Angxiu Suonan, Jingyuan Zhou, Qiling Yuan, Liang Liu, Xiaoming Zhao, Xiaoxiao Lou, Chuncheng Yang, Dichen Li, Yin-gang Zhang, “PEEK (Polyether-ether-ketone) and its composite materials in orthopedic implantation” Arabian Journal of Chemistry, Available online on 5 January 2021, https://doi.org/10.1016/j.arabjc.2020.102977.

30. Jibo Zhang, Weiqun Tian, Jiayi Chen, Jin Yu, Jianjian Zhang and Jincao Chen “The application of polyetheretherketone (PEEK) implants in cranioplasty” Brain Research Bulletin, Available online 16 August 2019, https://doi.org/10.1016/j.brainresbull.2019.08.010.

31. Kanthan Theivendran, Faizan Arshad, Umar Khetaab Hanif, Aleksi Reito, Xavier Griffin, Clary J.Foote, “Carbon Fiber reinforced PEEK versus traditional metallic implants for orthopaedic trauma surgery: A systematic review” Journal of Clinical Orthopaedics and Trauma, Volume 23, December 2021, 101674, https://doi.org/10.1016/j.jcot.2021.101674.

32. Stober E J, Sefer J C and Keenan J D. Characterization and exposure of poly ether ether ketone (PEEK) to fluid environments [J]. Polymer, 1984, 25(12): 1845-1852.

33. Ren W.Q. The synthesis and property investigation of PEEK[D], Thesis, Fudan University 2011.

34. Wu Zhong-Wen, Situation of research and production and development for the special engineering plastic polyether sulfone and polyether ether ketone at home and abroad[J], New Chemical Materials,2002 30 (06):15-18.

35. Im J S, Lee S K and In S J. Improved flame retardant properties of epoxy resin by fluorinated MMT/MWCNT additives [J]. J Anal Appl Pyrolysis, 2010, 89(2): 225-232.

36. Sasuga T and Tagivara M. Mechancial relaxation of crystalline PEEK and influence of electron beam irradiation [J]. Polymer, 2011, 27: 821-826.

37. Liu Chao-Yan, The Progress of the World’s Plastics Industry in 2012-2013[J], China Plastics Industry, 2014, 42(03):1-41+93.

38. Chen Shuang-Fei, The progress of the world's plastics industry in 2008-2009[J], China Plastics Industry, 2010, 38(03):1-35+39.

39. Wang Xi-Mei, Qi Gui-Liang, Cai Jiang-Tao, and Zhang Yu-Long, Research progress of PEEK modification, Engineering Plastics Application, 2009,37(02):80-83.

40. Richard H. Investigation of the thermal decomposition and flammability of PEEK and its carbon and glass-Fiber composites [J]. Polymer Degradation and Stability, 2011, 96:12-22.

41. Chen Ya-Li, Application of thermoplastic composites on aircraft [J], Aviation Maintenance & Engineering ,2003(03):28-30.

42. Fu Guo-Tai, Liu Hong-Jun, Zhang Bai and Han Guang-He, Characteristics and application of PEEK[J], Engineering Plastics Application, 2006(10):69-71.

43. Zhang Yu, Thermodynamic simulation and experiment of 3D printing of bionic artificial bone with PEEK[D], Thesis, Jilin Univeristy, 2014.

44. Yang Li-Jun, Wang Zhe, Wang Tao, Research and progress in modification of PEEK and its composite coatings[J], China Plastics Industry, ,2017,45(02):15-20.

45. Wu Zhong-Wen, Research and development of PEEK resin at home and abroad and its production practice [J], Fiber Reinforced Plastics, 2014(02):25-29.

46. Tian Ai-Guo, Guo Qiang, Progress in the characteristics and application research of PEEK and its composites, Engineering Plastics Application, 2002(02):47-49.

47. Peng Wang, Bin Zou, Shouling Ding, Chuanzhen Huang, Zhenyu Shi, Yongsheng Ma and Peng Yao "Preparation of short CF/GF reinforced PEEK composite filaments and their comprehensive properties evaluation for FDM-3D printing", Composites Part B (2020), doi: https://doi.org/10.1016/j.compositesb.2020.108175.

48. Xie Y, Hill CAS, Xiao Z, Militz H. Silane coupling agents used for natural fiber/polymer composites: A review. Compos Part A-Appl S 2010; 41(7): 806-819.

49. Liu L, Jia C, He J, Zhao F, Fan D, Xing L, Wang M, Wang F, Jiang Z, Huang Y. Interfacial characterization, control and modification of carbon fiber reinforced polymer composites. Compos Sci Technol 2015; 121: 56-72.

50. Bismarck A, Kumru ME, Song B, Springer J, Moos E, Karger-Kocsis J. Study on surface and mechanical fiber characteristics and their effect on the adhesion properties to a polycarbonate matrix tuned by anodic carbon fiber oxidation. Compos Part A-Appl S 1999; 30(12): 1351–1366.