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Opinion

The Use of Additively Manufactured PEEK for Medical Implant Applications: A Short Review

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Opinion

Personalized medicine, also referred to as precision medicine, is poised to revolutionize the modern practice of medicine where implants must be tailored to individual patient's needs for ensuring highest safety margin and best patient care. Additive Manufacturing (AM), also known as 3D printing, has emerged in recent years as one of the most in-demand technologies for manufacturing of prototypes and components with complex geometries. AM is a novel tool of manufacturing components directly from digital model by using layer by layer material build-up approach [1]. AM has a high potential to be utilized for personalized medical implant applications [2]. Polyether Ether Ketone (PEEK) is a semicrystalline linear polycyclic aromatic thermoplastic containing ether and ketone linkages which was developed by US aerospace industry in the late 1970s. Its medical usage started in the 1980s due to its outstanding mechanical strength, thermal stability, non-toxicity, excellent chemical resistance, good wear resistance and compatibility with modern imaging technologies [2]. In particular, PEEK possesses excellent mechanical properties similar to those of human bone and is considered the best alternative material to titanium for orthopedic spine and trauma implants which has often been accused of stress shielding. However, PEEK suffers from poor integration with surrounding bone tissue after implantation as the hydrophobic nature of PEEK limits the cell adhesion and absorption of protein on the surface, thus reducing the wound healing capacity on osseointegration. The aim of this paper is to give a short review of recent progress in the use of the additively manufactured PEEK for medical implant applications. Surface modification is an efficient solution to improve the bioactivity of PEEK, which is capable of inducing osseointegration and primary stability of implant as well as of increasing cell proliferation according to the conditions after the implantation. In general, surface modification can be performed through physical and chemical approaches. Physical surface modification is performed through physical approaches such as by flame, laser, electron beam, plasma [2]. With respect to chemical surface modification, it is achieved by the chemical reactions, which are initiated on the surface of the sample by applying chemical solutions, e.g., chemical etching and grafting [2]. Among all these techniques, plasma surface modification is preferable as it provides better surface topography and wettability for biomedical applications as compared to simultaneous chemical etching processes. Proper surface topography can promote the absorption Extracellular Matrix (ECM) proteins (e.g., vitronectin, fibronectin among others) and benefit the adhesion of osteoblasts.

Another solution is the surface coating method with bioactive materials, such as Hydroxyapatite (HA) and titanium (Ti), chitosan/bioactive glass, Amorphous Magnesium Phosphate (AMP), calcium phosphate, titanium dioxide (TiO2), tantalum, tantalum pentoxide, niobium pentoxide among others [2,3]. Among these approaches, the coating of titanium on PEEK is a promising approach and has been widely used in conventionally manufactured PEEK samples, as it provides early bone on growth (Ti-bond). Numerous treatments including ion-plasma deposition, plasma vapor deposition and electron beam deposition among others can be performed for Ti-coating on PEEK. In [4], the authors have the processability of titanium-modified 3D-printed PEEK structures and also performed in-vitro and in-vivo tests in terms of cell adhesion, proliferation and osteogenic differentiation on the sample with or without Ti coating. It was revealed that the Ti-modified PEEK samples exhibit superior performance for cellular proliferation, differentiation and bone regeneration. Alternatively, fillers can be added into PEEK samples for improving not only the mechanical performance but also the bioactive properties. Under specific clinical conditions, the mechanical properties of PEEK implants need to be elevated. Carbon Fibers (CFs), Glass Fibers (GFs), Carbon Nanotubes (CNTs), and Graphene Nanosheets (GNS) have been added into the PEEK matrix for satisfying the requirements in load-bearing areas. The mechanical properties of PEEK can be tailored by adding different amounts or lengths of fibers to the composite. It has been also investigated that by adding bioactive fillers in the PEEK samples, their bioactive properties can be improved. The widely used bioactive additives are Hydroxyapatite (HA), Tricalcium Phosphate (TCP) ceramics, Bioactive Glass (BG) among others. Regarding more information on this topic, the readers can refer to [3]. As the abuse of antibiotics has contributed to the emergence of bacterial resistance, numerous ions and their nanoparticles have emerged as promising alternatives to antibiotics. For improving the antibacterial performance, different fillers can be added into PEEK, e.g., silver nitrate nanoparticles, ZnO nanopowder, Ag/ZnO, Si3N4, Zinc-magnesium silicate [3].

In recent years, a multi-material design and fabrication concept by allocating different biomaterials in a single component targeting a multi-functional medical implant, was exploited. In [5], multi-material Ti6Al4V-PEEK cellular specimens were manufactured by impregnating PEEK into the open-cells of the Ti6Al4V cellular structures which were fabricated by Selective Laser Melting (SLM) by means of hot pressing technology [5]. It was found that the multi-material design in this work, besides being able to withstand the loads occurring after implantation also enhances expressively the tribocorrosion performance, thus being a promising alternative fully dense metals currently used on these applications. A multi-material Nickel titanium (NiTi)-PEEK cellular structured solution was designed, produced and characterized targeting orthopedic applications [6].

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