

Review article

Scope of Polyether ether ketone (PEEK) material applications in healthcare industry: Review

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Abstract:

Polyether ether ketone (PEEK) is a high-performance thermoplastic polymer that has become increasingly popular in the medical field due to its excellent mechanical and biocompatible properties. PEEK is highly resistant to wear, fatigue, and creep, making it an ideal material for use in medical implants that requires high strength and durability. In addition to its intrinsic properties, PEEK can also be reinforced with various materials such as carbon fiber, glass fiber, or ceramic particles to further enhance its mechanical properties. These reinforced PEEK composites have been used in a variety of medical applications, including orthopedic implants, dental implants, cardiovascular devices, and drug delivery systems, among others. In conclude, PEEK with reinforced materials and modifications have shown promising results in various medical applications, offering improved mechanical properties, biocompatibility, and antimicrobial properties. Its unique combination of properties makes it a versatile material for medical devices and implants, and ongoing research continues to explore its potential in new applications.

Keywords: Polyether ether ketone, Orthopaedic implants, bioavailability

Introduction:

Polyether ether ketone (PEEK) is a high-performance thermoplastic polymer that has become increasingly popular in the medical field due to its excellent mechanical and biocompatible properties. ¹PEEK is highly resistant to wear, fatigue, and creep, making it an ideal material for use in medical implants that require high strength and durability.² In addition to its intrinsic properties, PEEK can also be reinforced with various materials such as carbon fiber, glass fiber, or ceramic particles to further enhance its mechanical properties. These reinforced PEEK composites have been used in a variety of medical applications, including orthopedic implants, dental implants, cardiovascular devices, and drug delivery systems, among others.³

PEEK can also be modified to incorporate antibacterial properties by embedding silver nanoparticles or other antibacterial agents into the material. ^{4,5}This modification has been shown to effectively reduce bacterial adhesion and prevent implant-associated infections, making it a promising solution for implant-related complications. Thus PEEK with reinforced

materials and modifications has a wide range of medical applications and has shown promising results in various studies.^{6,7,8} Present review article highlights applications of reinforced PEEK and modified PEEK in the medical field.

1. Orthopaedic implants:^{9,10}

PEEK can be reinforced with carbon fibers, glass fibers, or other materials to improve its strength and stiffness, making it an excellent material for orthopedic implants such as spinal cages, joint replacements, and trauma fixation devices. PEEK with reinforced materials and modifications has shown significant potential in the field of orthopedic implants. Orthopedic implants are devices used to replace or support damaged or diseased bones, joints, and tissues. The mechanical properties³ of PEEK can be enhanced by reinforcing it with materials such as carbon fibers, glass fibers, or other materials, making it a suitable material for orthopedic implants.⁹

PEEK implants have several advantages over traditional metal implants, including:^{8,9,10,11}

A. Biocompatibility: PEEK is a biocompatible material, meaning it does not cause an adverse immune reaction when implanted in the body.

B. Radiolucency: PEEK is radiolucent, which means it does not interfere with medical imaging such as X-rays or MRI scans, making it easier to monitor the implant.

C. Low density: PEEK is a lightweight material, making it suitable for use in implants that require low weight.

D. Corrosion resistance: PEEK is corrosion-resistant, making it suitable for use in implants that are exposed to body fluids.

PEEK implants are used in a variety of orthopedic applications, including spinal cages, joint replacements, and trauma fixation devices. Spinal cages made of PEEK are used to replace damaged discs in the spine and provide support to the spine. PEEK joint replacements are used in the knee, hip, and shoulder to replace damaged joints. Trauma fixation devices made of PEEK are used to stabilize broken bones and support the healing process.^{7,8,9}

Here are some of the specific applications of PEEK material in orthopaedic implants:^{8,9,10,11}

2. Spinal Implants: PEEK is widely used in spinal implants due to its radiolucency, which allows it to be seen on X-rays and MRIs. It is used in spinal cages, which are implanted between vertebral bodies to restore spinal alignment and stability. PEEK cages are designed to support spinal fusion and promote bone growth. PEEK is also used in spinal rods, screws, and other spinal fixation devices.

A. Joint Replacements: PEEK material is also used in joint replacements, including hip, knee, and shoulder implants. PEEK implants are often used as a femoral head alternative in total hip replacement surgeries. This is because PEEK is lightweight, strong, and durable, which allows it to withstand the stresses of weight-bearing joints.

B. Trauma Implants: PEEK implants are used in trauma cases to stabilize fractures, particularly in the extremities. PEEK plates and screws are used to secure bone fragments in place and promote healing. PEEK trauma implants are popular due to their high strength-to-weight ratio, biocompatibility, and fatigue resistance.

PEEK material is a versatile material that has many applications in orthopaedic implants. Its high strength, durability, and biocompatibility make it an ideal material for spinal, joint, trauma, and dental implants.

C. Dental implants:^{11,12}

PEEK can be reinforced with ceramic materials to improve its wear resistance and biocompatibility, making it an ideal material for dental implants.

PEEK with reinforced materials and modifications has also shown promise in the field of dental implants. Dental implants are artificial tooth roots that are placed into the jawbone to support replacement teeth or bridges. The use of PEEK in dental implants offers several advantages over traditional materials such as titanium, including biocompatibility, improved wear resistance, and enhanced aesthetics.¹³

PEEK dental implants are typically reinforced with ceramic materials such as hydroxyapatite or zirconia, which provide improved strength and wear resistance. The use of these ceramic-reinforced PEEK implants can lead to a reduction in inflammation and bone resorption, resulting in improved implant stability and longevity.^{14,15}

The use of PEEK in dental implants also offers improved aesthetics compared to traditional metal implants. PEEK is available in a range of colors, allowing for a closer match to the natural color of the patient's teeth.

In addition to traditional dental implants, PEEK can also be used in implant-supported overdentures, which are removable dentures that are anchored to dental implants. PEEK can be used in the framework of these overdentures, providing a lightweight and biocompatible alternative to traditional metal frameworks.¹⁵

Thus PEEK with reinforced materials and modifications is a promising material for dental implants, offering improved biocompatibility, wear resistance, and aesthetics compared to traditional materials. Ongoing research continues to explore its potential in new dental applications.

Here are some of the specific applications of PEEK material in dental implants:¹¹⁻¹⁵

D. Implant Abutments: PEEK abutments are used to connect dental implants to dental crowns or bridges. PEEK abutments have a similar modulus of elasticity to natural tooth structure, which can help to reduce stress on the implant and surrounding bone. PEEK abutments are also non-metallic, which can reduce the risk of allergic reactions in patients with metal allergies.

E. Temporary Implants: PEEK material is used to create temporary dental implants that can be used during the healing process. PEEK temporary implants are used in cases where the patient has

lost a tooth or teeth and the dentist wants to prevent the surrounding teeth from shifting. PEEK temporary implants are biocompatible and can be easily removed once the permanent implant is ready to be placed.

a. Guided Implant Surgery: PEEK material is used to create surgical guides for guided implant surgery. These guides are used to accurately place dental implants in the correct position and angle. PEEK surgical guides are biocompatible, radiolucent, and can be easily sterilized.

b. Customized Implants: PEEK material is used to create customized dental implants. PEEK implants can be made to fit the exact shape and size of the patient's tooth, which can improve the fit and function of the implant. PEEK implants can also be colored to match the patient's natural tooth color.

3. Cardiovascular devices:^{16,17,18}

PEEK can be modified with hydrophilic coatings or surface treatments to enhance its blood compatibility and reduce the risk of thrombosis, making it suitable for cardiovascular devices such as stents, catheters, and heart valves.

PEEK with reinforced materials and modifications has shown potential in the field of cardiovascular devices, such as stents, catheters, and heart valves. These devices require materials that are biocompatible, resistant to wear and tear, and have excellent mechanical properties. PEEK can be modified with various coatings or functional groups to enhance its blood compatibility and reduce the risk of thrombosis, making it an ideal material for cardiovascular devices.

PEEK can be modified with hydrophilic coatings, which can improve its blood compatibility by reducing surface tension and promoting blood flow. These coatings can also reduce the risk of clotting or thrombosis, making PEEK an attractive material for vascular grafts, catheters, and other devices that come into contact with blood.

PEEK can also be modified with surface treatments such as plasma, which can improve its adhesion to biological tissues and reduce the risk of delamination or separation from the tissue. This makes PEEK an attractive material for heart valves, which require a strong bond to the surrounding tissues to prevent leakage or detachment.

In addition, PEEK can be reinforced with materials such as carbon fibers or glass fibers to improve its mechanical properties, making it suitable for use in stents, which require high radial strength to maintain vessel patency.

PEEK with reinforced materials and modifications has shown promise in the field of cardiovascular devices, offering improved biocompatibility, wear resistance, and mechanical properties compared to traditional materials. Ongoing research continues to explore its potential in new cardiovascular applications.

4. Drug delivery systems:¹⁹⁻²²

PEEK can be modified with functional groups or coatings to improve its drug release properties and biocompatibility, making it an ideal material for drug delivery systems.

PEEK with reinforced materials and modifications has also been explored as a potential material for drug delivery systems. Drug delivery systems are devices or formulations that deliver therapeutic agents to specific locations in the body, such as tumors or injured tissues. The use of PEEK in drug delivery systems offers several advantages, including biocompatibility, excellent mechanical properties, and the ability to be modified to control drug release.

PEEK can be modified with various coatings or functional groups to control the release of drugs from the device. For example, PEEK can be coated with a hydrophilic polymer to promote drug diffusion, or it can be functionalized with chemical groups that can be used to attach drugs directly to the surface of the material.

In addition, PEEK can be reinforced with materials such as carbon fibers or nanoparticles to improve its mechanical properties, making it suitable for use in implantable drug delivery devices such as drug-eluting stents. The use of PEEK in drug delivery systems also offers several other advantages, such as its ability to withstand sterilization and its resistance to degradation from exposure to body fluids. These properties make PEEK an attractive material for use in long-term implantable drug delivery systems. PEEK with reinforced materials and modifications is a promising material for drug delivery systems, offering improved biocompatibility, mechanical properties, and the ability to be modified to control drug release. Ongoing research continues to explore its potential in new drug delivery applications.

5. Antibacterial implants:²³⁻²⁶

PEEK can be modified with antimicrobial agents or coatings to reduce the risk of infection in implants, making it suitable for orthopedic and dental implants.

There are several types of nanoparticles that can be added to PEEK to create PEEK bio composites, including but not limited to:^{27,28}

a. Carbon nanotubes (CNTs): CNTs can improve the mechanical properties of PEEK bio composites, such as stiffness, strength, and toughness. The optimal percentage of CNTs to add to PEEK depends on the specific application and desired properties, but typically ranges from 0.1% to 5%.

b. Graphene nanoplatelets (GNPs): GNPs can also enhance the mechanical properties of PEEK bio composites, as well as improve thermal conductivity and electrical conductivity. The optimal percentage of GNPs to add to PEEK varies depending on the specific application, but typically ranges from 0.1% to 5%.

c. Nanoclay particles: Nanoclay particles can improve the thermal stability and flame retardancy of PEEK bio composites. The optimal percentage of nanoclay particles to add to PEEK ranges from 1% to 5%.

d. Bioactive glass nanoparticles: Bioactive glass nanoparticles can improve the biocompatibility and bioactivity of PEEK bio composites, making them suitable for use in medical implants. The optimal percentage of bioactive glass nanoparticles to add to PEEK ranges from 5% to 20%.

The specific percentage of nanoparticles to add to PEEK bio composites depends on several factors, including the type and size of the nanoparticles, the desired properties of the composite, and the processing conditions. It is recommended to consult with a materials expert or manufacturer to determine the optimal percentage of nanoparticles for a specific application.

Methodology used for preparation of PEEK bio composite:²⁷

The preparation of PEEK bio composites typically involves the following steps:

A. Selection of reinforcement material: The first step is to select the appropriate reinforcement material based on the desired properties of the composite. This could be in the form of nanoparticles or fibers.

B. Preparation of reinforcement material: The reinforcement material is usually prepared by dispersing it in a suitable solvent, such as dimethylformamide (DMF) or N-methyl-2-pyrrolidone (NMP), and then sonicating it to break up any agglomerates.

C. Mixing of PEEK and reinforcement material: The PEEK resin is then mixed with the

reinforcement material in the solvent using a mechanical mixer or an extruder. The mixture is then dried to remove the solvent.

D. Molding or shaping of PEEK bio composite:

The PEEK bio composite is then molded or shaped using a suitable technique such as injection molding, compression molding, or extrusion.

The specific methodology used for the preparation of PEEK bio composites may vary depending on the type of reinforcement material, processing conditions, and desired properties of the composite. It is recommended to consult with a materials expert or manufacturer for specific instructions on preparing PEEK bio composites.²⁹

PEEK with reinforced materials and modifications has been explored as a potential material for antibacterial implants. Infection is a major concern in medical implants, as bacteria can colonize on the surface of the implant and lead to serious complications. The use of PEEK in antibacterial implants offers several advantages over traditional materials such as metal or ceramic, including biocompatibility, flexibility, and the ability to be modified with antibacterial agents. PEEK can be modified with antibacterial agents such as silver nanoparticles or antibiotics, which can be incorporated into the material or applied as coatings. These modifications can help to reduce the risk of infection by inhibiting bacterial growth and preventing colonization on the surface of the implant.³⁰⁻³³

In addition, PEEK can be reinforced with materials such as carbon fibers or nanotubes to improve its mechanical properties, making it suitable for use in load-bearing implants such as bone plates or joint replacements.^{2,5,6,7,8} The use of PEEK in antibacterial implants also offers several other advantages, such as its resistance to corrosion and its ability to withstand sterilization. These properties make PEEK an attractive material for use in long-term implantable devices that require resistance to bacterial colonization.^{1,2,3} PEEK with reinforced materials and modifications is a promising material for antibacterial implants, offering improved biocompatibility, mechanical properties, and the ability to be modified with antibacterial agents to prevent infection. Ongoing research continues to explore its potential in new antibacterial implant applications.²¹⁻²⁶

Conclusion:

In conclude, PEEK with reinforced materials and modifications have shown promising results in

various medical applications, offering improved mechanical properties, biocompatibility, and antimicrobial properties. Its unique combination of properties makes it a versatile material for medical

devices and implants, and ongoing research continues to explore its potential in new applications.

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