Mechanical properties of PEEK as an orthodontic fixed retainer after adding of reinforcing materials(A systematic review)

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Abstract

The aim of this systematic investigation was to provide a thorough analysis of the ways in which reinforcements effect on the mechanical properties of dental PEEK materials. A digital systematic review was undertaken in multiple databanks: searches were made in Science Direct, PubMed, Web of Science, and Google Scholar, combined with a manual search of scientific literature. Papers published between 2005 and 2024 were collected and reviewed, and relevant publications were selected to be included in this review. Studies established the influence of supplementary elements on the mechanical characteristics of polyetheretherketone. Conclusion: Incorporation of inorganic compounds into the PEEK matrix may enhanced its mechanical properties, thereby improving its suitability for high-load dental applications, particularly in the fabrication of fixed orthodontic retainers.

Keywords: polyether-ether ketone (PEEK) , reinforcement material , orthodontic fixed retainer.

Introduction

After receiving orthodontic treatment, teeth often revert to their original place. Every effort is taken to have them positioned as planned[1]. The method of applying orthodontic retainers to keep teeth throughout treatment is termed retention, and it's a significant component of orthodontic therapy[2]. The most frequent form of retention utilized by orthodontists is to construct retainers. Today, orthodontists employ metal straps and fiber-based composites (FRC) to build retainers. The negative characteristics of metal wire include a lack of aesthetics, the risk for metal allergy, and the distortion of MRI pictures. Additionally, little damaged wires or wires that do not adjust passively to the teeth might potentially contribute to undesirable tooth movement[3],[4]. Retainers should have features like aesthetics, biocompatibility, and the potential to adapt to the lingual surface[1]. Polyetheretherketone is used in the dentistry business as an alternative for metal alliances[1]. PEEK is a polycyclic aromatic hydrocarbon that is semicrystalline and was initially created by Victrex PLC in the early 80's[5]. The polyaryletherketone polymer family, including PEEK, is made of aromatic benzene molecules that are connected by functional groups like ether or Ketone[6]. PEEK is becoming increasingly popular in the dentistry and medical professions because of its exceptional mechanical qualities, including strength, resilience, elasticity, and flexibility. PEEK's elastic modulus is 3-4 GPa, and its flexural modulus is 140-170 MPa. These values are comparable to those of dental enamel and dentin, rather than to multi-stranded stainless steel wire[7]. PEEK has one of the best biocompatibility ratios in comparison to other materials, it is nontoxic, and resistant to hydrolysis[8]. Because PEEK is radiolucent, it helps decrease the artifacts of magnetic resonance imaging, and its flexural strength is 140-170 MPa[9]. It's an inert material that has no detrimental effects, and it's tolerated by the surrounding tissues. It's a full alternative for folks who have allergies to titanium and other metals. PEEK is more visually pleasing and has a beige, gray, and not metallic tone[10]. It's feasible to process it using numerous commercial techniques at temperatures between 350 and 420°C, including via injection molding, extrusion, compression molding, and additive manufacturing[11]. As a consequence, numerous compounds such diamond-like carbon (DLC), titanium (Ti), gold, and titanium dioxide (TiO_2) are integrated into the surface of PEEK. These coating materials have the potential to dramatically increase the bioactivity of PEEK[12]. Several changes have been made to its surface and chemical composition in order to increase the mechanical and biological capabilities of PEEK[13]. The mechanical hardness of PEEK is lower than other materials, which may lead it to shatter. To avoid this difficulty, PEEK may be enhanced with fibers like glass, carbon, and other particles that have a more appropriate ratio of strength to elasticity[14]. Recently, various research have directed their efforts to the production of PEEK-based biomaterials that have superior mechanical, physical, and barrier characteristics intended for application in restorative dentistry. spherical inorganic nanoparticles are introduced into the PEEK matrix[11]. By integrating inorganic components into the PEEK matrix, the thermal stability of the resultant nanocomposites may be increased[15]. This study aims to assess how fillers affect the physical characteristics of PEEK materials.

Materials and Methodologies

Study Methodology

Digital investigation in Google Scholar, PubMed, and Science Direct to find the related articles published between 2005 and 2024 through The Keywords: dental peek , reinforcement material and orthodontic fixed retainer .

Inclusion Criteria

The 2005–2024 research which applies reinforcement material to the peek and it is used in dentistry.

Exclusion Criteria

Case studies, literature reviews, pilot project research, and studies which used peek material in industries other than dentistry . . In addition to studies written in languages other than English.

Table : studied that discussed reinforcement materials used with the PEEK

Year & ref.	Title	purpose	Reinforcement	Conclusion
2023 [16]	The mechanical characteristics, safety and strength of the glass fiber as a matrix material and as a post in PEEK composites as well as the core of the material.	To study the bond strength of shear type, the mechanical properties of polyetheretherketone (PEEK-GF) cores and posts in terms of safety and efficiency.	varying amounts of glass fiber (0%, 30%, 40%, and 50%).	The mechanical properties of the composites were significantly improved, especially the elastic modulus of PEEK-GF50, which was compa

				rable to dentin.
2023 [15]	The characterization and evaluation of PEEK/ silica composites.	This study aims to increase PEEK's mechanical and physical qualities by an extra 3% weight. Nano-SiO_2	addition 3% wt. Nano silicon dioxide powder (SiO_2)	When nano particles are dispersed evenly over the PEEK matrix, the strength of the SiO2 /PEEK composite may be improved without diminishing its hydrophobic qualities..
202	Explorat	The goal	5% , 20%	The

3 [17]	ory investigation on the influence of polyetheretherketone (PEEK) content on the bond strength of various bonded composites.	of this study was to examine the binding strength between various PEEK materials and self-adhesive and traditional adhesives, the latter of which lacks components for filler..	titanium dioxide	average bond strength between the erasures of PEEK that is low in fill is the lowest , while the average bond strength between the erasures of PEEK that is unfilled is the highest..
2022 [18]	Enhancement of the Mechanical Qualities and Bioactivity of Silicate-Based Bioceramics in combination with Poly(eth	The goal of this study was to examine the impact of various nanoparticle kinds and quantities on the mechani	Two varieties of inorganic bioactive nanoparticles exist: forsterite (FT) has a chemical composition of Mg2SiO4 , and bioglass	Compared to the pure PEEK material, the addition of 20 percent BG

	er-ether-ketone) Nanocomposites for Prosthetic Dental Implantology.	cal capabilities, surface features, and biological aspects of these materials, their potential for usage in dental implants is exciting Implantology.	(BG) has a chemical composition of 45 percent SiO_2, 24.5 percent CaO, 24.5 percent Na_2O, and 6 percent P_2O_5.	and FT raised the elastic modulus of the material by 25% and 60%, respectively. Compared to the pure PEEK material, the addition of 20wt% BG and FT may boost the flexural strength by 5% and 40%,

				respectively..
2021 [11]	The surface characteristics and mechanical properties of nanosilica (SiO_2) integrated into polyetheretherketone (PEEK) composites for dental prosthesis and restorative dentistry have been researched.	The goal of this study was to examine the way that hydrophilic and hydrophobic nano-SiO_2 particles impact the mechanical and surface characteristics of PEEK-based composites intended for use in dentures and related disciplines of restorative dentistry ..	amorphous nano-SiO_2 particles.	The microhardness, stretchiness, and elasticity of the PEEK polymer were increased by 10% with hydrophobic nano-SiO_2..
2019 [19]	The utilisation of carbon fiber-	This investigation's objective was to	Carbon Fiber	The mechanical characteristic

	reinforced PEEK composites via 3D printing in orthopedics and dentistry.	analyze the microstructures and mechanical characteristics of FDM-made PEEK and CFR-PEEK samples.		s of the pure PEEK samples are equivalent to those of the regular PEEK pieces. The CFR-PEEK samples had a much larger tendency to display mechanical qualities that are superior to those of printed PEEK alone.
2019 [20]	The influence of the SiO2 concentration in polyetheretherketone	This investigation contrasted the experimental PEEK with	Different silicon dioxide(SiO2)contents 20%,40%,50% wt	This study shows that raising the SiO_2 concentration

	(PEEK) on the flexibility and tensile strength of resin cement joints.	different concentrations of SiO2 in conjunction with a control PEEK that had 20 percent TiO2, it demonstrated a greater capacity to reacts with saline agents that couple with silica. The effect of the SiO2 content in PEEK on its bondability.		in PEEK by pre-treating it with a saline agent that adheres to the resin may lead to a suitable connection between PEEK and resin cement, but, this may have an undesirable influence on the mechanical characteristics.
2019 [21]	The tribological and mechanical	The goal of this initiative is to build	graphene nano platelet	With greater concentrations of

	characteristics of graphene-based composites/PEEK are detailed in this section.	GNP/PEEK composites that have minimal wear and low friction while yet keeping their strength and uniformity.		GNP, the hardness and tensile modulus of elasticity increased.
2019 [22]	The influence of fiber supplementation and manufacturing technique on the dynamic behavior of PEEK composites.	In this work, the behavior of short fiber-reinforced polyetheretherketone (PEEK) composites under dynamic compression is examined. Specifically, the impacts of strain rate, fiber addition, and manufacturing process are	The short carbon fiber reinforced PEEK and the short glass fiber reinforced PEEK	The stress capacity of PEEK composites is improved by raising the strain rate. Shortening the fiber's length may boost the PEEK's tensile strength.

		explored.		
2017 [23]	The influence of dental light-curing technologies on the adherence of various components of PEEK.	The objective of this research was to explore the way different light-curing units influence the stretchiness of different PEEK combinations during the polymerization of the Visiolink adhesive system..	varying filler amounts of TiO_2	The presence of TiO_2 particles with different ranges of wavelength and PEEK may have an effect on the bond between PEEK and Visiolink.
2013[24]	Investigation of the tribological behavior of PEEK and glass fiber in PEEK composites.	In this research, the mechanical properties and tribological behavior of PEEK with 30% added glass fiber and pure	short-cutting glass fibers	Compared to pure PEEK, the GF/PEEK material has a greater tensile strength, modulus of elastici

		PEEK at room temperature were evaluated.		ty, strength and modulus of flexure. The temperature at which weight loss occurs in GF-RECs is roughly 75 degrees greater than that of PEEK alone.
2010 [25]	Fly ash and micas integrated into polyetheretherketone (PEEK) composites.	The purpose of this study is to examine the influence of filler particle form on the mechanical and thermal qualities..	Fillers are composed of fly ash with a diameter of 44 microns and micas with a diameter of 44 microns (hydrated).	The modulus of stretchiness of PEEK-fly ash and mica combinations was raised by adding 5-30 percent filler. The modulus of stretchiness of the filled composites with fly ash was larger than that of the mica. The incorporation of fillers led to a consistent increase in stretchiness.
2005[26]	PEEK composites composed of SiO2 and Al2O3 sized at less than 1 µm and integrated into the matrix.	The objective of this research was to explore the way the presence of silica or alumina particles affects the non-thermal condensation of	The SiO_2 and Al_2O_3 nanoparticles.	Whether using silica or alumina particles, the tensile strength, elastic modulus, and hardness of PEEK-

		PEEK chains and how to create PEEK composites with these particles by simple molding without altering the surface..		based nanocomposites can be increased by 20-50%, but the tensile elongation is decreased. The thermal stability of the PEEK matrix can be enhanced by adding inorganic additives.

Results and Discussion

160 studies were selected based on the tile and abstracts. However, only 33 articles were selected based on this study ,s aim, and 13 studies were included in the review that were published between the years of 2005 and 2024.
Reinforcing PEEK with various materials significantly enhances its mechanical properties, making it a strong candidate for orthodontic and dental applications.
Both carbon fiber and glass fiber (GF) improved hardness, flexural strength, and compressive strength; carbon fiber's strength improvements were comparable to those of human cortical bone.
• Titanium oxide and nano-SiO_2: 20% titanium oxide improved tensile strength, while 3% nano-SiO_2 improved transverse strength. When combined, these substances enhanced overall mechanical performance.
• Graphene Oxide and Bioglass/Forsterite: Bioglass and forsterite enhanced flexural strength by 5–40%, while graphene oxide enhanced tensile bonding, flexural modulus, and wear resistance. However, performance was decreased by excessive loading (30%) of forsterite and bioglass.
• Hydrophobic Nano-SiO_2 and Calcium Silicate: Higher calcium silicate concentrations reduced flexural strength, whereas nano-SiO_2 enhanced microhardness and flexural strength.
• Nano-TiO_2: Added additional functional benefits by contributing significant antibacterial activity when added to PEEK/PEI blends under UV light.
The purpose of this review was to establish whether the addition of PEEK to dental materials meets the essential requirements for dental applications. A total of 13 distinct research types were reviewed during this research . These studies demonstrated the positive impact of reinforcements on the mechanical characteristics of PEEK.
In one study using glass fiber as reinforcing agent, the results showed that the mechanical properties of the composites improved as the fiber content increased, indicating effective reinforcement of the PEEK matrix. SEM analysis revealed that the fibers were uniformly coated with PEEK resin, with no noticeable fiber clustering, and voids were formed due to fiber pullout during bending[16]. The length, diameter, and volume fraction of the fiber significantly influence the mechanical behavior of the composite[27]. The PEEK-GF50 group exhibit a compressive strength of 264±18.01 MPa, a flexural strength of 350±2.88 MPa, a Vickers hardness of 47.62±4.54 HV, and an elastic modulus of 17.4±0.49 GPa-values closely resembling that of dentin (18.6

GPa)[16]. In vitro cytotoxicity tests indicated all materials were safe. On the first day , PEEK-GF50 exhibited significantly higher cytotoxicity than pure PEEK($p > 0.05$), possibly due to short-term toxicity from exposed glass fiber fragment . By the seventh day, significant difference was observed($p > 0.05$),, suggesting minimal long-term cytotoxic effects from glass fiber addition[28]. Further testing on the flexibility of PEEK and SiO2/PEEK composites, following ISO178:2010 standard, showed that 3% of nano-SiO2 significantly enhanced the transverse strength of PEEK[15]. However, Wang et al. (2011) reported a decrease in average tensile strength with the addition of nano-SiO_2 emphasizing that mechanical strength is influenced by several factors including filler content, particle size , and load transfer efficiency . Dederichs et al.(2023) found that adding 20% of titanium oxide PEEK increased tensile strength more effectively than other concentration .SEM images revealed increased surface roughness when bioglass or forsterite was incorporated to the PEEK[18]. aligning with findings by [29]. Han et al.(2019) found that the mechanical results demonstrated that pure PEEK exhibited low strength in tensile , bending, and compressive tests. Adding 5% carbon fiber to the PEEK mixture improved its strength , making it similar to that of human cortical bone(14 GPa). Rikitoku et al., (2019) reported the outcomes of tensile bonding assessment indicated that an augmentation in the filler(Sio2) content resulted in a substantial enhanced the tensile bonding strength values were observed before and after aging, and the flexural modulus exhibited an increase with rise in the silica content. The augmentation noted in the tensile-flexural modulus and hardness increase with the addition of graphene . The concentration of Nano platelets (GNP) appears to pertain to the inherent mechanical properties of the graphene. Nonetheless, a resilience .The reduction is also a consequence of the GNP dispersion within the matrix. Notably, GNP fillers exert a beneficial effect on the coefficient of friction and more precisely on wear elevate this reported in Puértolas et al.,(2019). Chen et al., (2019) found that the neat PEEK matrix demonstrated negligible sensitivity to strain rate regarding its compressive strength. However, PEEK composite with short fibers showed stronger compressive strength when the strain rate went up, which means that adding fibers helps them perform better under sudden loads. The addition of 20% bioglass and forsterite improved flexural strength by 5-40% compared to pure PEEK , while 30% loading significantly reduced performance [30]. supporting earlier research suggesting lower filler concentrations are more beneficial [31]. Abd El-Fattah et al. (2021) demonstrated improvements in microhardness, flexural strength, and elastic modulus with 10% hydrophobic nano-SiO2 . Conversely ,Kim et al.(2009) reported a 20.84% drop in flexural strength with 30 vol% calcium silicate . Najeeb et al.,(2016) found that 5% carbon fiber addition achieved an elastic modulus (~14 GPa) comparable to cortical bone . Lümkemann et al.,(2017) noted that 20%TiO2 content resulted in the highest bond strength , indicating a correlation between filler composition and bonding performance . Antibacterial testing of nano-TiO_2 embedded PEEK/PEI blends showed significant bacterial suppression under 365 nm light , confirming pervious findings[32],[33]. Li et al (2013) found That adding 30 % chopped fibers enhanced mechanical properties . Parvaiz et al.,(2010) reported peak tensile strength at 20% filler (fly ash and mica) , followed by decline with higher content. Similarly , the inclusion of nano-SiO2 and Al2O3 enhanced tensile strength, hardness , and elastic modulus but reduced elongation[26]. Several studies have confirmed improved mechanical properties with reinforcement , others reported no significant effects .

Reinforcing PEEK with suitable materials significantly enhances its mechanical properties , making it a strong candidate for orthodontic fixed retainer . The improvements in strength , elasticity , hardness , and bonding performance align with the mechanical demands of long-term retention in orthodontics . However , the type and concentration of reinforcement must be carefully optimized to avoid compromising flexibility or biocompatibility . As a result, reinforced PEEK offers a promising metal-free alternative in orthodontic applications, particularly for patients seeking esthetic and biocompatible options.

Conclusions

•Moderate filler content (typically around 5-20%) optimized mechanical performance, with excessive filler loading may negative affect material toughness and flexibility .

•Reinforcements help tailor the elastic modulus of PEEK to match that of natural dental tissues, reducing stress concentrations and improving biomechanical compatibility .

•Surface morphology enhancements due to nano-fillers can improve bonding strength with adhesives, contributing to long-term retainer stability .

•Most reinforced PEEK composites exhibit good biocompatibility , with minimal cytotoxic effects and in some cases added antibacterial properties .

•Overall, reinforced PEEK combines the necessary strength, biocompatibility, and esthetic properties required for fixed orthodontic retainers, providing a reliable, metal-free alternative to traditional metallic appliances of reinforcement material must be carefully controlled to achieve the optimal balance between mechanical performance and biological safety.

•However , there are certain limitations that should be acknowledged . More clinical studies are needed to confirm the effectiveness and durability of reinforced PEEK retainers under real-life oral condition . The long- term effects on periodontal health, wear resistance, and patient outcomes remain insufficiently understood, and further in vivo research is necessary to establish clear clinical recommendations.

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