A Review on Bio-Composite Materials

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Abstract Composite material constitute of different materials to have better characteristics than traditional materials. Material properties such as physical, chemical and mechanical properties can be tailored in composite material based on requirements. This advantage extends the composite material applications in the field of human implants. Traditional metals or ceramics have certain limitations after the implantation in human body, because of its inheriting properties with biological tissue. These limitations can be eradicated by the composite material; it makes composites to fabricate implant for biomedical applications. The new research works enhance the composite materials to mimic the natural bone, biological functions and tissue characteristics. Human tissue and bone are naturally graded from the core side, functionally graded material (FGM) implant overcome some limitations of composite materials. FGM implants elastic modulus can be tailored as like a composite material, its biological functions similar with natural one. Other biological parameters such as corrosion, wear resistance and fracture toughness are considered when designing the implant. This article discusses composite material advantage and limitations of both composite and FGM implants.

Keywords- Composite Material, Implants, Functionally graded material, Wear, Fracture toughness.

I INTRODUCTION

The artificial implants are necessary to human body under certain circumstance to replace the functioning of human organs under certain circumstance. The natural and synthesis materials are best alternate for making artificial implants, which aid patients in healing, correcting abnormalities. Design and manufacturing of medical implants are very essential to prove their quality and durability, these parameters are important to consider before implanting into patient body to improve quality of life. Traditional materials were used earlier days after that composite materials were replaced the traditional materials. Traditional materials homogeneous property doesn’t meet certain parameters which are satisfied by inherit heterogeneous properties of composite material. Tailoring of material properties is not possible in traditional materials, but composite materials give opportunity to tailor material properties. Normally composite materials consist of two or more material combination, so it exhibits excellent specific properties in medical implants as required; it is more flexible in design than traditional material due to optimizing specific properties. Various combination of composite material is in practise in biomedical applications, the distinctive features of bio composite material is presented in this paper.
Enamel and dentine are important hard tissue in teeth, which is made up of natural composite materials like collagen and hydroxyapatite (HA). Mainly three types of composite materials used in the field of dentistry, polymeric based composites, metal matrix composites and ceramic based composites. Polymer and ceramic based composites are best alternate for the traditional metal based materials, these composites used to restore the dental growth and fill the cavities in fractured teeth. Mostly ceramic based composites are used to replace the damaged or missing teeth for giving natural appearance of teeth. Anterior and posterior of the teeth is restored by composite materials, Polymethylmethacrylate (PMMA) is in clinical purpose to fill along with amalgam for posterior teeth for providing better mechanical strength. Polymeric acrylic and methacrylic matrix reinforced with ceramic particles to maintain the dimensional stability. The main design aspect of dental composites is fracture under compressive force, shrinkage behaviour of resin under thermal environment and better wear resistance [1]. Mechanical properties of adhesive material make detrimental effect on restoration of dentine and longevity under tensile or shear stress. The recent research is aimed to eliminate the limitations of composite materials in the field of medical applications. Wear is a main concern in the high stress areas and delamination of composite parts also occur; that can be reduced by choosing suitable reinforcement particle [2]. The vitro and vivo test results are differ for patient’s conditions, wear, degradation and fracture performance results differ for patients especially patients who consume alcoholic beverages, alcoholic beverages make significant damage in composite implants [3]. Another problem in composite dental implant is internal stress due to polymerization shrinkage. The internal stress level is considerably high in light cured composite than self cured composite. This matrix shrinkage during curing is taken care by adding inorganic filler with matrix materials bisphenol-A-glycidylidimethacrylate (Bis- GMA), triethyenglycoldimethacrylate (TEGDMA). Optimum shrinkage of filler with monomers has not been investigated yet [4]. Adhesion between the matrix and filler is major factors in material behaviour under loading, different composition were investigated, which is made by Bis- GMA, TEGDMA and urethandimethacrylate (UDMA). The hardness of the composite also another issue in dental implants, suitable treatment is need for reinforced particle to maintain the stability of resin filler interface and harness increases with increase of volume fraction of salinated filler [5-6]. Silica-zirconia particles with UDMA resin composite was investigated for effect of moisture at interface and concluded that volume fraction of filler influence the moisture absorption ability [7]. Aligning of filler particles may improve the mechanical properties, this alignment of filler and reinforcement particle increase the elastic modulus along the alignment direction and compressive stress [8]. Bis-GMA composite mixed with an antibacterial monomer to enhance durability of implants, these composites are used to fill the posterior and multiple-unit restorations [9]. Adding fibrous reinforcement improves mechanical properties of the composites especially brittleness and toughness also it hasn’t sacrifice its antibacterial effect [10-11]. 50% Bis-GMA and 50% TEGDMA composite with silicon carbide and nitride whisker filler materials improve roughness and offer high elastic modulus, fracture toughness based on matrix materials [12]. HA-Ca polycarboxylate composites have better biocompatibility and mechanical strength. It has good adhesion to the bone wall [13].
Porous hydroxyapatite with PMMA has greater bone restoration [14]. Bis-GMA and TEGDMA matrix based composite reinforced with 25% alumina and 75% silica reduce polymerisation shrinkage and enhance wear resistance. Reducing the mismatch of elastic stiffness between dentine and post increase stress sharing under load and minimise the root fracture and helps restoration.

III FUNCTIONALLY GRADED MATERIAL IN DENTAL APPLICATIONS

Traditional metallic material doesn’t constitute property of mechanical strength and corrosive resistance, but composite materials fulfil the limitation of composite material. Especially functionally graded materials (FGM) are most appropriate composites for dental applications due to its bio degradation and change in elastic modulus in same design. Implant design with porosity gradation has significant impact in dental applications due to its bone restoration ability [15]. FGM material properties can be tailored along axial direction which makes the FGM implant to stand against occlusal force applied at the top and to have good bio compatibility at the bottom for better biomechanical bonding [16-18].

Fig 1. Tailoring of elastic modulus of FGM

Ti alloy is mostly preferred in field of bio medical applications due to its mechanical strength to retain the integrity of implant along with ceramics such as Hydroxyapatite (HA), cobalt (Co), silica (SiO$_2$), zirconia (ZrO$_2$) [19-25].

Fig 2. Distribution of material property in FGM dental implant
On one hand Ti/Co composite has good wear resistance, tissue connectivity and mechanical strength but on the other hand deprived bio compatibility [26]. FGM of Ti/ZrO$_2$ is more suitable for dental implant than Ti/Co in dental applications, but stimulation of inflammatory reaction and poor bone restoration was found [27]. Ti/SiO$_2$ FGM implant gets significant attraction in the field of dental applications, inherent properties of Ti/SiO$_2$ possesses better metabolic function and chemical reaction with bone tissue [28-30]. The studies show that Ti/HA combination more suitable for dental implant than other FGM implant, Ti/HA implant allows tissue growth into implant with limited mechanical strength of HA [31-33]. TiN is the excellent alternate for Ti in manufacturing of Ti/HA implant, which limits the drawbacks of HA [25].

**IV IN THE FIELD OF JOINT IMPLANT**

Composite materials play vital role in the field of joint prostheses, designing of material properties made composite implants inevitable in the field of joint implantation. Several investigations have been made to enhance the long term stability and biocompatibility. Bone graft techniques are more suitable to replace damaged cartilage tissue and wore joint, it has been done with aid of composite material added with high density polyethylene (HDPE) and HA particles [34]. Composites with 40% HA exhibit excellent torsional modulus, but low mechanical strength and low stiffness, which limit the application of HA in enduring of mechanical load [35-36]. Huge combination of HA allows the tissue growth after implantation and proper bonding has to be established by adding filler between matrix (HA) and reinforcement (polyethylene) to exhibit better mechanical properties [37-38]. Many researchers developed composite material, which characteristics are similar natural bone, HA/Alumina composite is a better replacement for injured natural bone. Elastic modulus similar with natural bone was developed with aid of P$_2$O$_5$ glass fibre with HA [39-40]. Porosity also another cause in developing bone implant, it has direct impact on stiffness of implant. Matrix porosity allows osteoblasts at vicinity of implantation, the studies are being carried out to enhance and optimise the properties without sacrificing of composite implant. Alpha-TCP and ployamnide attract researchers to compose composite for implant with good strength; which can be achieved by adding fibres [41]. TCP with 8% glutaraldehyde cross-linked gelatin implant produce less toxicity in vivo test during osteoblasts. The excess amount of gelatine produced toxic effect while releasing residuals [42]. Bio active glass, PMMA, PLA and 9% of antibiotic reduce inflammatory effects [43]. The PE matrix with 35% bio glass reinforcement composite implant was developed close to the properties of natural bone, but bonding between the matrix and reinforcement was weak. The HA and PE composite also had lower strength in bonding between matrix and reinforcement, the experimental results shown that good biocompatibility with nearby tissue in minimum time period after implant without any infection [37]. The carbon fibre reinforced composite material used to make fixation in bio medical applications, vitro and vivo experiments shown promising results with high mechanical strength and limited biocompatibility [38]. The coral (CaCO$_3$) and collagen composite implants were shown promising development in implant without any infection and tissue bonding.
V IN HIP JOINT REPLACEMENT

Bone grafting techniques are no longer in use, if injury is severe. The bone replacement is inevitable method to treat the patient. The composite materials implant is developed enough to meet such a requirement, but lot of research work has been carrying out to enhance the limitations of implant in joint replacement. Clinical experiments are guaranteed the composites implants in hip joint replacement for the past decay, it also induces some adverse effects which is commonly faced in post implantation. Metallic implants are no longer in use; it has weak corrosion resistance, stress shielding effect and biological reactions. Ultra high molecular weight polyethylene (UHMWPE) was chosen as alternative material for metallic implants, but it has poor mechanical characteristics. Lot of research works have been carried out to enhance the performance of UHMWPE by adding carbon fibre. Polyetheretherketone (PEEK) with carbon fibre was shown promising results in clinical results than UHMWPE composite. Acetabular cup made up of PEEK with 30% carbon fibre reduce wear damage paired with zirconia head than UHMWPE/meta and UHMWPE/ceramic pair [43-45]. Carbon fibre reinforced with epoxy resin cup with ceramic femoral head produced less wear debris in experimental results, which is 5-30 times less than polyethylene head [46]. Composite stem has an excellent advantage; its elastic modulus can be tailored. Elastic modulus of implant can be made close to the natural bone; this can be achieved in metal implants. Bioglass coating on titanium alloy head has shown good osteoconductive properties and stress shielding effect too [47-48]. Carbon and glass fibre reinforced with epoxy resin coating in cobalt chromium femoral head has proper stress transfer similar to natural load transfer. Carbon fibre reinforced with PEEK stem has good mechanical strength and bonding with near biological tissue after six months of clinical results [49-52].

Fig 3. Material gradation of stem from the distal end

Polyetherimide (PEI) is an another alternate for fabricating implant, it has promising results in vivo test. PEI has good boning with surrounding tissue and hasn’t produced adverse effects like metallic particles. PEI reinforced with carbon and glass fiber laminated implant guarantees load transfer, good mechanical strength and avert fracture [53-54]. One dimensional FGM prostheses has been developed to minimise stress shielding effects, the tailoring of elastic modulus of prostheses can be done by gradation in longitudinal direction [55]. FGM exhibits excellent characteristics of load carrying, resistance to fracture and bio compatibility [56-58].2D-FGM prostheses minimize the stress shielding effect without compromising interfacial stress between bone and implant, this investigation was carried out in finite element simulation model [59].
Titanium oxide mixed with HA functionally graded coating on titanium alloy head was shown promising results, which motivated the researcher to incline toward titanium alloy implants. HAP/Ti–6Al–4V coating has good fracture toughness and bone restoration [60-61]. HAP/Ti–6Al–4V functionally graded symmetrical and asymmetrical coatings were produced on stem using powder metallurgy technique, it was shown hopeful development in implant design in the view of bio compatibility and mechanical strength [62-63]. Titanium /HA and Titanium/Co implants were investigated, which was shown that HA allowed bone restoration, but Co debris particle due to wear made adverse effects on bone tissue [22]. Functionally graded Co–Cr–Mo coating on Ti–6Al–4V alloy was shown good surface hardness without changing stiffness of material at transition region [64].

Porous implant attracts the researcher to mimic the exact model of natural bone and skin tissue, core side of bone has meshed pore structure and outer region of bone has densed molecular structure. FGM implants were created with various pore size and its complications such as stress singularity due to crack, fluid flow were studied [65-66]. Porous Ti implant allows bone in-growth with 100–400 µm pore size [67]. The investigations have been carried out to make porous FGM implant, which must minimize the mismatch of stiffness between implant and natural bone and make the implant closer to the natural bone.

VI CONCLUSION

This article shows applications of composite material in the field of biomedical implant due to inherit properties. Lot of research works have to be carried out to enhance the properties of composite material to improve the life time of implant. Polymer and HA based composite material possessed greater mechanical strength and good wear resistance also. Application of composite material in bone grafting technique is inevitable, PE and Bio glass play vital role in this area. Evolution of functionally graded material application is enormous in human implant, its tailoring of elastic modulus make it to get characteristics closer to natural bone. Ti/HA FGM implant exposed good mechanical strength and bio compatibility, it ensures bone restoration also. Porous implant structures behaves like a natural bone, it allows fluid motion and has a good elastic stability closer to natural bone. Vitro and vivo tests show the successful enhancement in bio compatibility, that facilitates the patient for long term comfort in post surgical procedure. Fatigue and stress shielding effects are not considered and significant research works have not been carried out to improve those parameters.
Traditional manufacturing techniques may have limited the fabrication of implant to meet design requirements, but the evolution of powder metallurgy techniques promise the making of successful implants and compromising the limitations of material effects. Evaluation of composite and functionally graded materials are complicated than traditional material especially in the field of biomedical applications.

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