

A Review on Importance and Recent Applications of Polymer Composites in Orthopaedics

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Abstract:- The idea of using composite in bone implant came since 1980^[1]. Considering the observed problems and failures from the previous materials, using composite materials with higher strength and stiffness and more similarity to natural bone had started to develop. In medical composites at least one of the constituent materials should be bioactive (metal-polymer or ceramic). The name of composites is based on their matrix phase (metal-ceramic or polymer)^[2]. In manufacturing of medical composites, bioactivity is a main factor that should be considered in choosing the material. Bones as a hard tissue are strong and stiff and clearly have high elastic modulus. Human Bones are naturally and structurally composite material made of collagen fibers and Nano crystals of hydroxyapatite which are sediment in collagen fibers^[3]. The collagen fibers have low elastic modulus and hydroxyapatite is with high elastic modulus and contain almost 70% of bone dry weight and supports the stiffness of the bone. Regarding this fact, composite material could represent great biocompatibility. Nowadays it is proved that composite materials are a very good choice and substitute for bone implant in orthopedic surgeries.

Keywords:- polymer composites, biocompatibility, stiffness, bio inert, bone cements, polyetheretherketone

I. INTRODUCTION

Composite materials are made of two phases: Matrix and Reinforcement. The reinforcement fills the matrix phase and gives it more strength and stiffness. In orthopedic applications this two phases can mimic the natural bone and can be inserted inside the bone to support it from inside. Medical composites have a lot of applications in medicine and orthopedic. Biomedical / orthopedic composites belong to a group of materials called biomaterials (Biomaterial can substitute natural tissues in the body and perform their functions). Some implantable biomaterials at that age were made of natural material like: wood, some tissue of living organs, zinc, gold, iron. Regarding the fact that biomaterial medical composites perform their function in the body and in contact with tissues, their properties and structures should be as close to living tissues as much as possible. For example, in orthopedic composites the amount of stress that bones suffer is almost 4 MPa, but for other tissues like tendons, this can be more during daily work, up to 40-80 MPa. The average amount of load on the hip joint is almost 3000N and can increase during jumping up to 10000N. And clearly this amount of stress is not constant and can be changed in different kind of activities.^[3]

II. POLYMERIC COMPOSITE BIOMATERIAL

Polymeric composites are found to have fewer failures compared to other groups and are a better choice as alternative material which substitutes ceramic composites. They are variable and different in properties, performances and composition and found in different shapes and forms (films fibers...). They can be also used as fillers and absorb some liquid material. Using polymeric material which has a lower modulus is popular. The best choice would be reinforced polymeric material as composite material which has high strength and low modulus. Thermoplastic polymers form strong bonds, they are biocompatible and show resistance to wetting and moisture (due to strong bonds) (PEEK-PAEK)^[4]. Thermosetting polymers Such as Epoxy resins, they are different and vary in biocompatibility and durability. They are not so good in orthopedic applications. But they have found to be attractive in fracture fixation. Their processing characterization is much better than thermoplastics^[4].

III. APPLICATION AREAS OF POLYMER COMPOSITES

3.1 Bone fractures

The bone fractures are possible to repair in some different ways: external fixation and internal fixation. In external fixation there is no need to open the tissue. The bone fracture is kept in some devices and material such as casts-splints. The casting material consists of composite material made of woven cotton and a calcium sulphate matrix and some reinforcement material such as glass fibers and polyesters. In Internal fixation by using surgery techniques and implants the bone fracture is repaired. Depending on the bone fracture some different implants can be used such as wires, pins, screws, bone plates or intramedullary nails. Plates and screws are most common parts in internal fixation [1] and can be made of Steel-Ti alloys or Co-Cr alloys. Almost 1 or 2 years after the surgery the bone plates and bone screws are removed from the body. The bone can carry less stress and gets weak and easy to break after removing the plate. The bone weakening is less by using Ti alloy (due to less modulus of Ti); using plates from material with closer modulus to the bone is also preferred. As alternative material can be PA-PTFE and polyester in bone plate used. Their properties show that it has too low modulus and not enough strength. Therefore, as a material with high strength and suitable stiffness the polymeric composite is the best choice.

3.2 Polymeric composite materials as bone plates

In non-resorbable composite plates material is stable in the body and in vivo condition without any change in strength and stiffness. It can be made of thermoset or thermoplastic composite materials. CF/ epoxy- GF/ Epoxy (thermoset nonresorbable material). In partially cured epoxy material are some toxic monomers reported. Thermoplastic: CF/PMMA-CF/PP-CF/PS-CF/PE-CF/Nylon_CF/PBT-CF/PEEK- (this material is biocompatible and difficult to hydrolyze) it is also stiff enough and fatigue resistant and a rejection of carbon fibers by tissue has not seen to be much. (PLA) or polylactic acid-poly glycolic acid (PGA) can be degraded in the body, this material gets weaker after a certain period. Fully resorbable bone plates are composites of reinforcing fibers and resorbable materials. Example: poly-L lactic acid (PLLA) fibers and calcium phosphate based glass fibers. In partially resorbable, to improve their mechanical properties the resorbable polymers are reinforced by some material (non resorbable) such as carbon fibers- and polymeric fibers. Thus, they are called partially resorbable material, like CF/PLA composites.

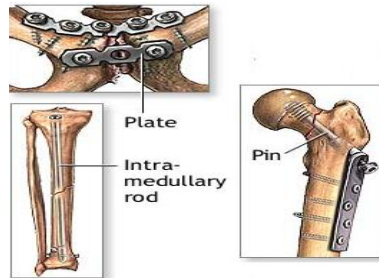


Fig 1 Polymeric bone plates

3.3 Polymeric composite materials as bone cements

The main functions of bone cement are to stabilize prosthesis by filling the gap between it and bone and to transmit loads from the prosthesis to bone (Kohn and Ducheyne, 1992). Polymethylmethacrylate (PMMA) has been used as a bone cement for nearly 40 years with little change in its composition and structure. PMMA is prepared in the operating theatre from powdered polymer containing an initiator / catalyst and liquid monomer containing an activator. Polymerization is initiated on mixing these components and proceeds by an exothermic free radical reaction. Barium or zirconium sulphate is usually added to the polymer powder to render the cement X-ray opaque and antibiotic is commonly added to reduce the risk of infection. Control of the exothermic polymerization reaction is essential to prevent thermal damage to the bone.

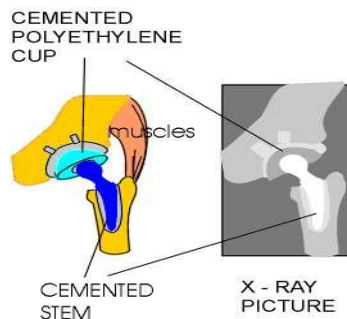


Fig 2 Bone cement

The thermal expansion and contraction of the polymer itself must also be limited to maintain good contact with the surrounding bone and implant surfaces. Acute exposure to high levels of monomer at operation is known to be dangerous, but there is also concern about chronic exposure to low levels of unreacted monomer leaching from the bone cement (Borzacchiello *et al.*, 1998). Mixing is carried out under vacuum to prevent the entrapment of air bubbles that would weaken the cement. However, significant porosity is always present in set material produced by polymerization shrinkage. The porosity of the set material, the presence of particles of barium sulphate and the roughness of the bone-cement interface all provide sites for crack initiation in bone cement.

3.4 Polymeric composites as intramedullary nails

They are used in long bone fractures and can be inserted inside the bone to fill it. The nail must be strong to support the weight of body. Intramedullary nails mostly are made of stainless steel or GF/PEEK composite, which was suggested by Lin *et al.* The reason for this is that composite materials show more biocompatibility and also better mechanical properties in contact with bone. After this discovery, the using of carbon fiber reinforced liquid crystalline polymers was continued by Kettune *et al* to be used as intramedullary nails. They have higher flexural strength and closer elastic modulus to the bone.



Fig 3 Intramedullary nails

3.5 Advanced polymer composites in bone replacements

There are many polymer composites that are made or are still under investigation. HA/HDPE (high density bio ethylene) the first bioactive composite, it is very biocompatible and used in orthopedic and HDPE is a liner polymer. Hydroxy apatite reinforced polysulfurHA/PSU is a new composite for bone replacement with almost 40%HA. PSU is polymer with high modulus and strength. It is applied in load bearing prosthesis [2]. It has better mechanical properties than HDPE and is resistant to oxidation and hydrolysis. Bio glass reinforced high density polyethylene in order to improve and increase bonding reaction between bone and implant, glasses are found to be better and more bioactive than HA. Calcium phosphate reinforced polyhydroxybutyrate and its copolymer are biodegradable composites TCP/ PHB. PHB is hydroxyacid and liner polyester. Chitin is natural polymer and also biodegradable PCHA/ chitin. Bioactive and biodegradable scaffolds have Chitin or poly(L-lactic acid) (PLLA) as the matrix polymer and HA, while containing 20% bioactive ceramic psHA/PLLA.

3.6 Polymers in total hip replacement

Polymers can fulfill two of the three requirements of joint replacement materials, providing load distribution and articulating surfaces. For load bearing applications such as THR femoral stems they are generally used in conjunction with metals as they have stiffness much lower than bone. However a polymer (e.g. PMMA) which can be moulded to the contours of bone and harden *in situ* will provide a good even load distribution. Polymers bearing counter faces have low friction and follow the traditional engineering design of using a hard material for the convex component bearing upon a concave component of less hard material. Polyethylene was first produced in low density form by ICI in 1939 and High Density Polyethylene (HDPE) was introduced in the 1950s (Dowson, 1992). Polyethylene has a simple $(C_2H_2)_n$ structure with no side groups. This structure and the mobility of the chain allow a high degree of crystallinity, the ratio of crystalline to amorphous regions in the material. HDPE has a lower degree of branching than Low Density PE (LDPE) producing more efficient packing and hence higher crystallinity and density.



Fig 4 Total hip replacement

Ultra High Molecular Weight PE (UHMWPE) although of lower density and crystallinity than HDPE has much larger mean relative molecular weight, ranging from 1 to 4 10^6 gmol⁻¹ (Kohn and Ducheyne, 1992). Increases in the degree of crystallinity increase stiffness and yield strength, but decrease toughness, while increasing molecular weight improves tensile and impact strengths. Polyacetal, also known as polyoxymethylene (POM) has the general formula $(OCH_2)_n$. Delrin is the trade name for the polyacetal homopolymer marketed by Du Pont. Its linear backbone structure is similar to that of polyethylene. However the shorter backbone (C-O) bond allows closer packing of the molecules, giving a harder polymer with a higher melting temperature.

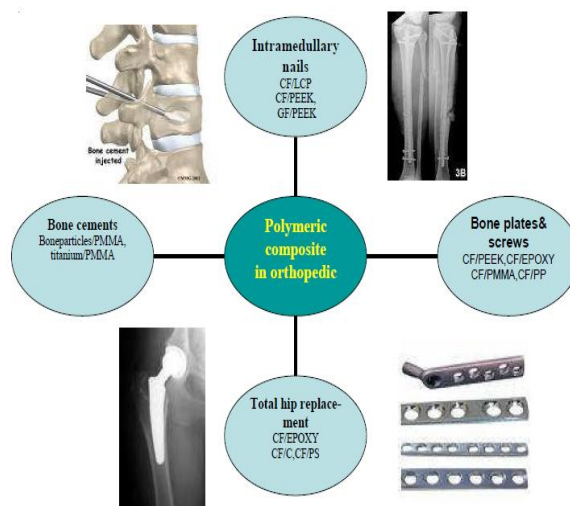


Fig 5 Application areas of polymeric composites in orthopaedics

IV. CONCLUSION

The military aircraft industry has mainly led the use of polymer composites. In commercial airlines, the use of composites is gradually increasing. Space shuttle and satellite systems use graphite/epoxy for many structural parts. Bridges made of polymer composite materials are gaining wide acceptance due to their lower weight, corrosion resistance, longer life cycle, and limited earthquake damage. Polymeric composite materials have shown high compatibility with many new diagnosis methods like: MRI because they are not magnetic as well as computed tomography (CT). Metals and ceramics can show some failures in X-ray radiography and are not totally radio transparent. But polymeric composites can be transparent by the help of some contrast material to the polymer. By changing and altering the fraction of reinforcement/ matrix phase it is possible to design and make the implants mechanically and physically suitable for different tissues. There is no corrosion like in metal implants. Reinforced composites have more fatigue resistance than un-reinforced composites, which is very important in knee joint replacement.

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