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BIOACTIVE COATING OVER POLYMER-CERAMIC COMPOSITE – AN IDEAL SYNTHETIC BONE SUBSTITUTE

S. BAG*[1] AND S. PAL[2]

[1]Department of Biomedical Engineering, JIS College of Engineering, Kalyani, Nadia, India
[2]School of Bioscience & Engineering, Jadavpur University, Kolkata, India.

*Corresponding author

S. BAG
Department of Biomedical Engineering, JIS College of Engineering, Kalyani, Nadia, India

ABSTRACT

A biologically active material enables implants to bond with bone, which could significantly extend the lifetime of the artificial implants or other medical reconstructive devices. The bioactive coating adhere to the surface of the implant, binds with both implants and bone, promotes formation of hydroxyapatite and lengthens the implant lifetime. Such implants are more durable and long lasting and will promote faster healing rates and should be accessible to wider range of patients. The coating provides a surface texture onto which bone cell could be deposited or a layer of additional material onto which bone could attach. Bioactive coating can defend the prosthesis against chemical attack and also separates the prosthesis from the surrounding to avoid inflammatory or other adverse reaction by making the prosthesis biocompatible.

KEYWORDS

Bioactive coating, Composite, Implant, Hydroxyapatite, Prosthesis.

INTRODUCTION

The human skeletal system has the unique capacity to regenerate and repair damages that occur below the critical condition. Local defects in bone are frequently restored by bone graft substitutes. Autografts being the most preferred, have some problems like limited blood supply, morbidity, increased operation time, blood loss and frequent insufficiency of bone graft [1]. Allografts on the other hand have the high risk of transmission of infections, develop adverse immunological reactions in the recipient's body, delay vascular penetration, slow bone formation and prevent incomplete graft incorporation when used as an accepted bone graft substitute.

Over the past decade, various artificial materials such as metals, polymers and ceramics, which are developed, as bone substitutes to overcome the common problems associated with natural bone grafts in reconstructive surgery [2]. It is now widely understood that synthetic bone grafts that possess the bioactive property, would aid in regaining shape and function of the defective bone by serving as a scaffold for bone growth and can contribute to the healing process [3]. Recently composite materials are being used in dental filling and orthopaedic implant applications [4]. So bioactive coating on the composite surface makes it most preferable bone graft substitute.

The objective of this work is to develop a coating technique which is suitable for polymeric as well as composite implant of polymer matrix and improve the Osseo integration of composite to achieve good fixation with bone. The bioactive coatings will be able to achieve faster early stage fixation and maintain long-term stability.

MATERIALS AND METHODS

A logical approach was taken into consideration to make the composite material more compatible with the bone and extends its life time and finds new application. The composite material used in this present work is coated alumina reinforced ultra high molecular weight polyethylene. The bioactive materials used for coating the composite were hydroxyapatite and bio-glass. As because hydroxyapatite and bio-glass ceramic of different forms and particle sizes are widely used as substitutes for bone augmentation and restoration [5] in orthopaedic, dental and maxillofacial surgery [6,7] and to assist in tissue engineering [8]. Such materials favour osteointegration and are biocompatible [9,10,11].

i) ***Preparation of Polymer-Ceramic Composite Plate:***

A special type of compression moulding system with temperature controlled heating arrangement was specifically designed and fabricated for preparation of polymer and composite plate. The top plate was used for pressing and bottom part for providing rectangular cavity for powder materials. The dimension of the mould was 205x 130x 20 mm^3. The ceramic powder was mixed uniformly with UHMWPE powder in 30 to 40 weight percent as it gave best possible mechanical characteristics as per a previous study [12]. The nearly uniform polymer and ceramic powder mixture (60 gm) was charged into the properly lubricated rectangular mould cavity. The powders were spread inside the mould cavity, leveled off with a straight edge level indicator and then top plate was fitted in the die cavity. The total assembly was placed between the two plates of the compression machine (ALMIL hydraulic compression testing press) (Fig-1). The powder was cold compressed repeatedly for 5-10 minutes under a pressure of 10MPa in order to expel the entrapped air between the particles. The temperature of the thermocouple-programmed controller of the mould was set to 160^{0}C and held constant for two hours. During heating the pressure was gradually reduced and maintained at 2 MPa. After plasticization the compression mould was subjected to air cooling. Finally the mould was taken out from the press and the top plate was removed and then a fabricated composite plate was obtained

.

Figure-1
Compression mould in ALMIL compression m/c.

ii) Deposition of Bioactive Coating on Composite Surface:

Before deposition of bioactive coating some surface modifications were performed using sand blasting and subsequent acid etching to increase roughness to help the coating adherence because mould plates were very smooth. The coating solution was prepared by pouring the powder in ethyl alcohol water mixture (1:1) and continuously stirred to get a homogeneous suspension. The suspension was sprayed in a thin layer over the composite surfaces with the help of a spray gun (spray gun was attached to the compressed air) and then dried at room temperature. Several fine layers were applied as per the required thickness. After that the spray coated composite material was placed in a compression mould box and compressed at 8 MPa pressure after heating at 95-100^{0}C for 30 min. The load is maintained constant until the total mass came back to ambient temperature. The mould was taken out form the press and finally we get a hydroxyapatite coated composite plate.

iii) Characterization of Bioactive Coating:

Since bioactive material coated implants are mainly used within the body, characterization of bioactive coating is a primary requirement prior to use. The surface properties and mechanical properties of the coating are important for biomedical application and depend mainly on chemical composition, size, shape and surface of the coating materials, phase state and microstructural characteristics.

a) Observation of surface topography using SEM study:

Surface topography of bioactive coating plays an important role in the bone bonding mechanism [13]. The coated and polished cross-sections were examined under scanning electron microscope (JSM-5200, Japan) with associated energy dispersive spectroscopy to analyze the surface morphologies and coating thickness of the hydroxyapatite and bio-glass (BG) coating over composite surfaces.

b) Coating Thickness measurement:

The coating thickness is a very important parameter to determine the uniformity in the thickness of the coating material on the substrate material. Ultra-sonic coating thickness gauge (Quintsonic PRO, Electro-Physik GmbH & Co., Germany) was used to measure the coating thickness of hydroxyapatite and bio-glass coated composite plate.

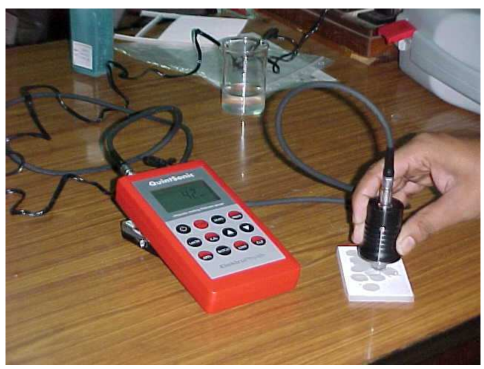


Figure-2

Quintsonic ultrasound coating thickness measuring gauge

c) Surface roughness measurement:

Surface roughness of the coated composite samples were measured using ultra compact portable surface finish measuring instrument, Handysurf E-30A, made by TSK, Japan

.

Figure-3

Surface roughness measurement using Handysurf

d) Coating strength measurement:

For coating to perform satisfactorily, they must well adhere to the substrates on which they are applied. To determine the coating strength, a qualitative scrape test was carried out to measure the adhesive strength of bioactive coating to the substrate after and before fatigue testing. This test measure the force needed to peel off the HA coating from the substrate under a contact load using an indigenously developed scrape test apparatus. The scratch testing apparatus was fixed in tensile grip of INSTRON mechanical testing machine. The coated plate was kept vertical and in touch with the scratch tool with a backing of a metallic plate to arrest bending. The scratching tool is capable of sensing the scratching as well as contact forces which were possible using a pair of strain gages and a strain measuring bridge. A complete set up is shown in Fig-4.

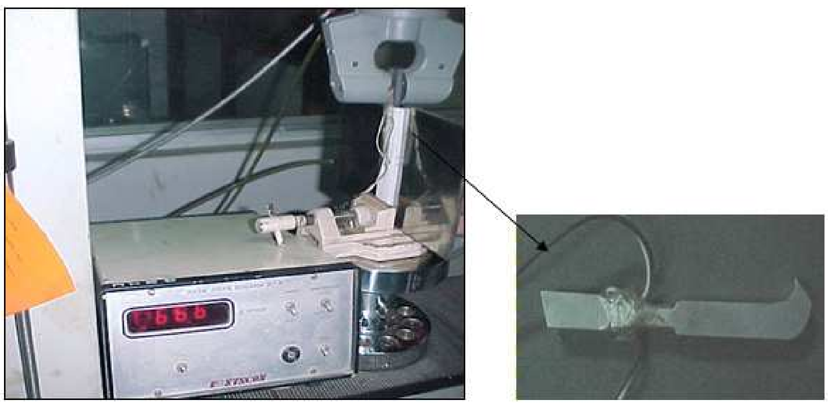


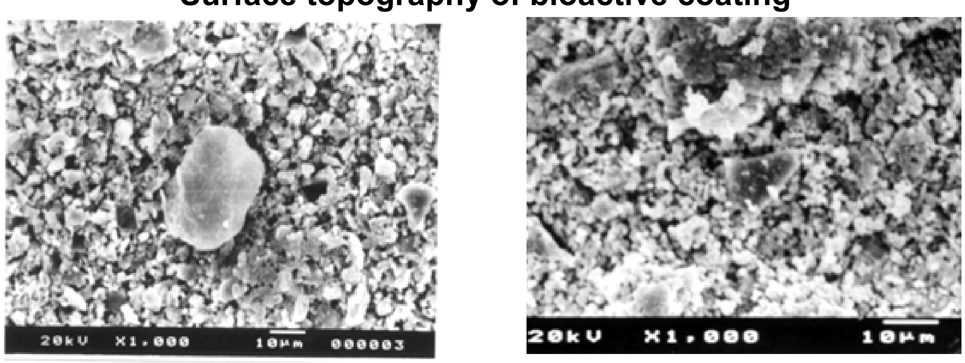
Figure – 4
Scratch test testing in INSTRON machine

RESULTS AND DISCUSSION

1. SEM study:

The morphological characteristics of HA and bio-glass coatings were shown in Fig-5 and the cross-sectional view and coating thickness were shown in Fig-6.

Surface topography of bioactive coating



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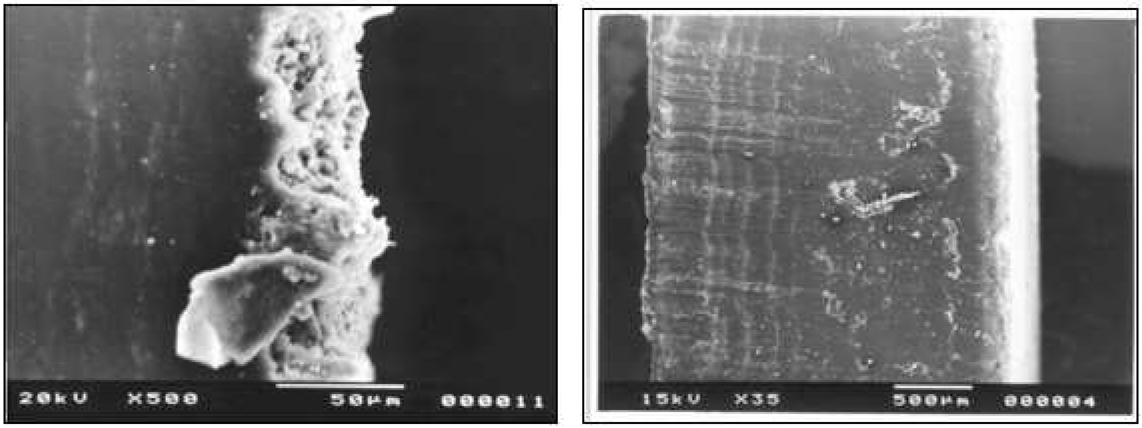
(a) (b)

Figure-5

SEM photograph of a) HA coating b) Bio-glass coating Cross Sectional view of bioactive coating



(a) (b)

Figure-6

Cross sectional view of a) HA coating (thickness of about 40µm) b) BG coating (thickness of about 30µm)

The cross-section morphology exhibited a clean, thin, uniform coating to the substrate interface. The surface morphology of HA and BG coating appeared homogenous and dense. The morphology of the coating consists of 1-5 µm droplet and grain like particles. From the cross-sectional images of the SEM study it was observed that the coating thickness is around 40 µm for HA and 30 µm for BG coating, which is effective in osteo-conductive activity.

2. ***Coating thickness measurement:***
   The mean coating thickness obtained from the gauge is shown in Fig-7.

Coating strength measurement

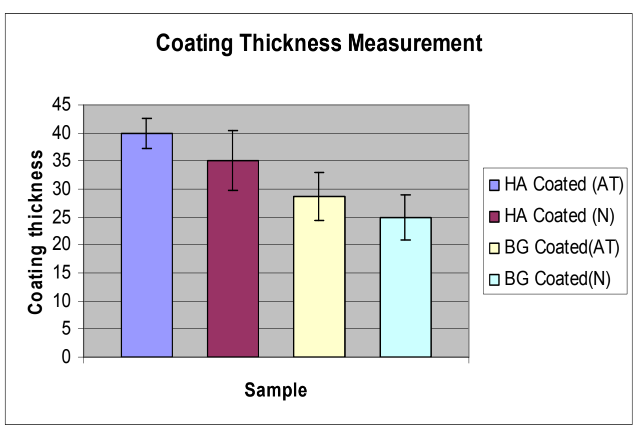


Figure-7

Comparison of coating thickness

From the results obtained by the coating thickness gauge the coating thickness of the different samples were in the range of 20-50 μm. the optimal thickness of hydroxyapatite coatings deposited for commercial use is typically between 40-60 μm [14]. The coating thicknesses of the composite plates were increased with surface modification.

3. *Surface roughness measurement:*

The surface roughness value obtained for different samples in this measurement were shown in the Fig-8.

Surface roughness measurement

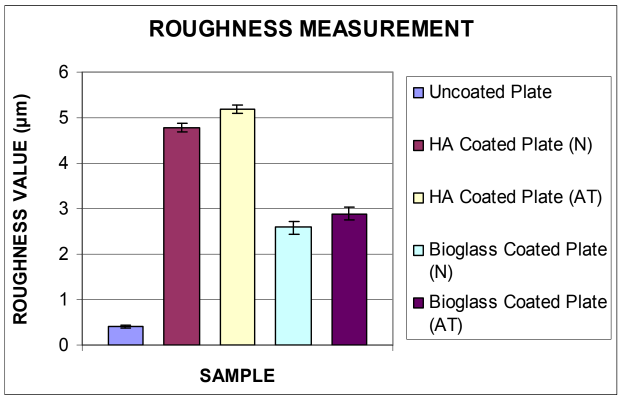


Fig-8
Comparison of roughness value of coated surface

4. *Coating strength measurement:*

The scratch test result was shown in the Fig-9.

Coating strength measurement

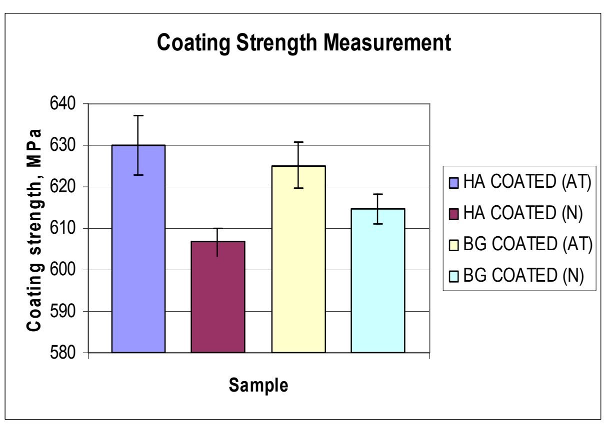


Figure-9
Comparison of coating strength

In scratch test, it was found that a sufficient force is needed to peel off the HA coating from the substrate. The mean coating strength was measured as 630.05 MPa for HA coated plate where as for BG coated plate it is 625.12 MPa.

CONCLUSION

The bioactive particles embedded on the surface of the polymer-ceramic composites permit new fabrication of coating methods. The quantity of the particles embedded in the coating is controlled by the concentration of the bioactive suspension and the applied layers and the treatment procedure. SEM studies revealed that the bioactive particles exposed on the surface were continuously and strongly anchored with the polymer matrix of the composite. The dense and fracture free coating improved the adhesion with the substrate and also act as barrier layer between implant surface and body fluid. Bioactive HA and BG are capable of interacting with the surrounding bone and produce direct attachment of the implant to bone without an interposed fibrous tissue layer because of the presence of free calcium and phosphate compounds at the surfaces [15,16]. The bioactive coatings on composite implants, able to form active layer in vivo, facilitates joining between the implants and bone and increases the long-term stability of the implants [17]. This type of coating has the potential advantage of producing intermediate region between bone and implant to enhance the smooth transition of stress between them.

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