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Characterization of nanobiocomposite functionally graded YSZ/HAP prepared by electrophoretic deposition for biomedical applications

Muhammed Jasim Kadhim **Nawal E. Abdulateef** **Makarim H. Abdulkareem**
Production and Metallurgy Dept./Uniuversity of Technology/Baghdad-Iraq

Abstract
This work describes preparation functionally graded coating of YSZ/HAP on stainless steel 316L as a substrate via electrophoretic deposition. Four layers (100%YSZ), (70%YSZ+30%HAP), (30%YSZ+70% HAP) and (100%HAP) were deposited on thin layer of chitosan. Also nano particles of chitosan was used as a binder material in all (FGMs) layers instead of sintering step. Ethanol with 5 % deionized water was used as a suspension for deposition procedure, pH value performed at 4 which fitted by using acetic acid. Four parameters were used in EPD procedure (time, voltage, concentration and temperature) Stability of solutions was measured by zeta potential that showed the high value of zeta potential for FGMs solution than the solution of single layer. The microstructure of surface coating and thickness of layers were characterized by optical microscopy and SEM that showed homogeneity and crack free. Thickness of single and FGM layers that obtained is varied between (12-85µm). Hydrophilicity property was investigated by wettability test which the result showed the super hydrophilicity for FGMs as compared with single coating layer.

Introduction
Stainless steel 316L was known as one of the most common metallic materials which was used for orthopaedic and dental implantation applications due to its excellent mechanical properties, ease of fabrication and availability at low cost [1,2]. But its applications were limited because of the, the low surface hardness, capability to pitting corrosion in body fluids, and poor wear resistance have limited their applications. It is of importance to improve corrosion resistance and surface hardness of austenitic stainless steels for their extended biomedical applications [3]. To overcome these problems, metallic implants are usually coated with bioactive materials, such as hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), it was a biocompatible ceramic material with high osseoconductivity. It was widely used an implant of bone replacement as a coating on tough substrate metals to promote bone ingrowth into prosthetic implants and to obtain both the mechanical properties of metallic substrates and the biological benefits of HA coatings [4,5]. HA has low fracture strength as compared with human bone. Therefore, HA alone cannot be implanted monolithic material for load bearing implants, such as: tooth and artificial bones. To enhance its mechanical properties many materials were used with HA such as ZrO2 because this material bas high strength, high toughness at room temperature, high compressive strength, high modulus, very good biocompatibility and the good compromise they represent between fracture resistance, therefore it was used in orthopaedic prostheses as a replacement for metallic material.

Functionally graded material could be mimic properties of human bone without affected on the mechanical properties of materials [7]. Functionally graded materials (FGM) are composites where the composition varies from place in order to effect the best performance of the structure. FGMs generally occur in nature. The human body contains many examples of complex FGM parts, such as bones or teeth [8]. wide variety of available processes have been reported for FGM production, such as plasma spraying, centrifugal casting, common powder metallurgy, PVD, CVD, and colloidal processing [9,10].
The goal of present work is to study the characterization of new functionally graded nanocomposite coatings of YSZ-HA-chitosan that produced by electrophoretic deposition for biomedical applications.

Experimental Procedure
Sand blast sheet of stainless steel 316L was used as a substrate to deposit coating layers. The sheets were cleaned with distilled water, followed by alcohol for 15 min by using an ultrasonic bath and then dried in oven before deposition. The coated area is 1 cm2.. Chitosan used as a binder material between single and FGMs layers instead of sintering step in electrophoretic deposition procedure. It was dissolved in 1% acetic acid and then ethanol with 5% deionized water as a solution which was used with chitosan deposit layer and the same solution used with subsequent layers. 3g/L of nano-ytrria stabilized zirconia and 3g/L of nano-hydroxyapatite were utilized in single and coating layers. Five layers were coated on substraite. The solutions of FGM are stirred for 5 hours while chitosan solution was stirring for 24 hours to obtain the best homogeneity. pH value for all solutions was performed at 4. The distance between the two electrode (anode and cathode) was 10 mm and EPD was performed at (30V, 6 min and 30ºC) for YSZ and (50V, 5 min and 30ºC) for hydroxyapatite. Cathodic deposition were performed in an acidic medium to obtain the highest positive zeta potential value. Zeta potential values for all solutions as shown in table 1.

Conclusions
- The chitosan exhibited good binder between components of layers so single and FGM layers appeared smooth, crack free with continuous morphology at optimum conditions and all layers are successfully fabricated on SS 316L.
- Higher layer thickness was obtained with four layers for two kinds of FGM.
- The composite and functionally graded layer obtained using EPD method are enabled to produce coating laminated layers with graded composition for YSZ/HA and chitosan.
- Water contact angles for samples are altered between 80.71° which considered as a hydrophilic to 22° which considered as super a hydrophilic. This is good results for cell attachment because the adherence of fibroblasts in initial stage needs super hydrophilic surfaces .

Type of sample	Thickness (µm)
One layer	12
Two layers	26
Three layers	40
Four layers	82
Five layers	65





