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Investigation of Wear Characteristics of Bio-Active Coating of Al_2o_3, Egg and Sea Shell Powder on Polyvinylchloride and Polyurethane

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Abstract

Polymers are used for implantation purposes in the medical field as implants due to its better corrosion resistance and mechanical properties. In the present work, in order to increase the life span of the implantation, coating process is applied on the polymer implants to form a thin film barrier. Since Hydroxyapatite(HAP) which is being used as coating materials is very expensive, an alternative coating material is developed by naturally derived powders like Seashell powder, Eggshell powder and Aluminum Oxide(Al_2O_3). Which are easily available and economical. These coating materials are used to protect the surface of the implant material and interface with biological system. The polymers namely polyvinylchloride and polyurethane are selected as substrate and coated with above powder by using thermal spray method. Wear test is conducted to determine the wear resistance of the coated specimen, to assure the wear properties which is essential requirements of implants. Selected Coating materials consisting of bio ceramics, extracellular matrix proteins, biological peptides or growth factors impart bioactivity and biocompatibility to the surface of conventional orthopaedic prosthesis that promote bone ingrowth and differentiation of stem cells into osteoblasts leading to enhanced osteo integration of the implant.

Keywords: Osteons, Implants, Bio Active, Egg Shell and Sea Shell

INTRODUCTION

S.BAG et al, 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 it is known widely understood that synthetic bone grafts that possess the bio active property, would aim in regaining shape and function of the defective bone by serving as a scaffold for bone growth and can be contribute to the healing process. Recently composite material are being used in dental filling and orthopedic implant application. So bio active coating on the composite surface make it most preferable bone graft substitute [1]. The design of these coatings must satisfy several important criteria: firstly the coating must be biocompatible and not trigger significant immune or foreign-body response; secondly, it must be "osteoconductive" in its promotion of osteoblasts (cells that make bone) to adhere to, proliferate and grow on the surface of the implant to form a secure bone-implant bonding; thirdly, the implant must also be "osteoinductive" and be able to recruit various stem cells from surrounding tissue and circulation and induce differentiation into osteogenic cells [2]. Currently, various implants used in clinical practice contain surface micro-pits and depressions. The surface features can be engineered through techniques such as grit-blasting, acid etching and plasma spraying [3]. Surface porosity impacts on osteo integration by allowing direct ingrowth of osteogenic cells into the implant, thereby strengthening the bone-implant interface [4]. Surface energy, also known as surface wettability, enhances both osteoblast adhesion and differentiation. Osteoblasts grown on high surface energy (hydrophilic) substrates display increased cell adhesion, proliferation and up regulation of various differentiation markers such as osteocalcin,type-I-collagen, osteoprotegerin, and glyceraldehyde-3-phosphate-dehydrogenase and raised ALP activity [5–7]. Infection is a main cause of implant loosening after joint arthroplasty. In some cases this necessitates removal of the original prosthesis followed by delayed revision procedure to re-implant a new prosthesis back into the bone. In such cases, the patient needs to endure periods of immobility and accept higher chances of reinfection and loosening associated with the revision procedure. Much research has focused on developing orthopaedic coatings with anti-infective properties. However in order to create bactericidal surfaces, the mechanism of bacterial colonization of metallic surfaces and the various factors that affect this process must be first elucidated. The environment surrounding newly implanted orthopaedic prosthesis predisposes it to infection. Upon implantation, the metallic surface of the prosthesis attracts protein adsorption, such as fibronectin, which facilitates bacterial adhesion [8]. Joint replacement is a major orthopaedic procedure used to treat joint osteoarthritis. Aseptic loosening and infection are the two most significant causes of prosthetic implant failure. The ideal implant should be able to promote osteointegration, deter bacterial adhesion and minimize prosthetic infection. Recent developments in material science and cell biology have seen the development of new orthopaedic implant coatings to address these issues. Coatings consisting of bio ceramics, extracellular matrix proteins, biological peptides or growth factors impart bioactivity and biocompatibility to the metallic surface of conventional orthopaedic prosthesis that promote bone ingrowth and differentiation of stem cells into osteoblasts leading to enhanced osteointegration of the implant. Furthermore, coatings such as silver, nitric oxide, antibiotics, antiseptics and antimicrobial peptides with anti-microbial properties have also been developed, which show promise in reducing bacterial adhesion and prosthetic infections[9]

SELECTION OF COATING MATERIAL

A coating is a covering that is applied to the surface of an object, usually referred to as the substrate. The purpose of applying the coating may be decorative, functional, or to protect the substrate surface. In case of implants the surface of material is usually coated with a bio active coating material as the direct use of substrate may cause undesirable reactions and ill effects. From the literature survey these materials were found to be effective and suitable for coating.

a. Aluminum oxide (Al_2O_3)

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium (III) oxide. It is commonly called alumina, and may also be called aloxide, aloxite, or alundum depending on particular forms or applications. It commonly occurs in its crystalline polymorphic phase α- Al_2O_3, in which it composes the mineral corundum, varieties of which form the precious gemstones ruby and sapphire.Al_2O_3 is significant in its use to produce aluminium metal, as abrasive owing to its hardness,and as a refractory material owing to its high melting point. The figure .1 shows industrial grade Al_2O_3 coarse powder.

Figure 2.1: Industrial grade Al_2O_3 powder

b. Egg Shell Powder

Egg Shell Powder is derived from Egg. It is a rich source of calcium. Egg shell is an easily available natural material, when eggs are consumed as food; a large number of shells are waste materials. Shell is mainly composed of calcite type calcium carbonate composition, which is about 95% of the whole shell quality. The figure 2 shows the egg shell powderused in the work.

Figure 2.2: Coarse Egg Shell Powder

c. Sea Shell Powder

Sea Shell Powder is derived from natural sea shell. It is a rich source of calcium. Sea Shell Powder has high absorption this can influence fast development of bone. Sea shell is an easily available natural material in coastal areas, when some seafood is fine finished; a large number of shells are waste materials. Shell is mainly composed of calcite and aragonite type calcium carbonate composition, which is about 95% of the whole shell quality, and also contains a small amount of SiO_2 and organic matter.

Figure 2.3: Coarse Sea Shell Powder

SUBSTRATES

a. Polyvinylchloride

PVC has high hardness and mechanical properties. The mechanical properties enhance with the molecular weight increasing but decrease with the temperature increasing. The mechanical properties of rigid PVC are very good; the elastic can reach 1500-3,000 MPa. The soft PVC (flexible PVC) elastic is 1.5–15 MPa.

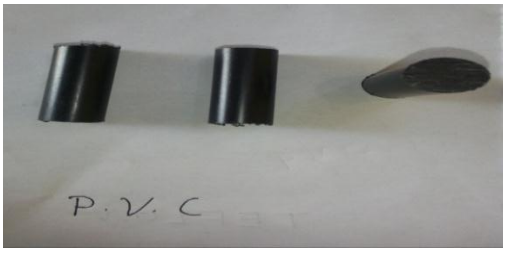


Figure 3.1: Polyvinylchloride

b. Polyurethane

Polyurethane has a high load capacity in both tension and compression. Polyurethane may undergo a change in shape under a heavy load, but will return to its original shape once the load is removed with little compression set in the material when designed properly for a given application. Polyurethanes perform very well when used in high flex fatigue applications. Flexural properties can be isolated allowing for very good elongation and recovery properties. Resilience is generally a function of hardness. For shock-absorbing elastomer applications, low rebound compounds are usually used i.e. resilience range of 10-40%. For high frequency vibrations or where quick recovery is required, compounds in the 40-65% resilience are used. In general, toughness is enhanced by high resilience.

Figure 3.2: Polyurethane

METHODOLOGY

A. Coating powder preparation

The organic materials i.e. egg and sea shell cleaned using distil water and boiled indistil water to remove all impurities and are dried in sunlight where as Al_2O_3 is used directly in ball mill.

Figure 4.1: Organic powders before ball milling

Figure 4.2: organic powders after ball milling process.

Coating Process

The Plasma Spray Process is basically the spraying of molten or heat softened material onto a surface to provide a coating. Material in the form of powder is injected into a very high temperature plasma flame, where it is rapidly heated and accelerated to a high velocity.

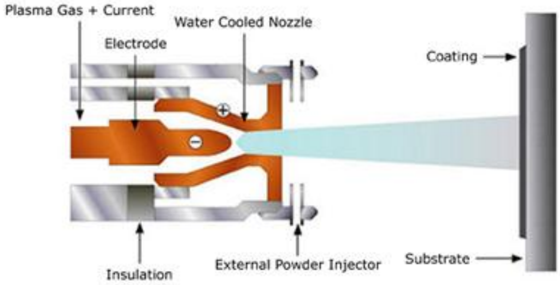


Figure 4.3: Plasma Spray process

The hot material impacts on the substrate surface and rapidly cools forming acoating. This plasma spray process carried out correctly is called a "cold process" (relative to.the substrate material being coated) as the substrate temperature can be kept low duringprocessing avoiding damage, metallurgical changes and distortion to the substrate material.

WEAR TEST

This test method describes a laboratory procedure for determining the wear of materials during sliding using a pin-on-disk apparatus. Single Materials are tested under nominally non-abrasive conditions. The principal areas of experimental attention in using this type of apparatus to measure wear are described. The coefficient of friction may also be determined. The values stated in SI units are to be regarded as standard.

Figure 5.1: Wear testing machine

Coating on PVC: Coating on PVC with 3 different samples were prepared

Sample A1: Al2O3

Sample A2: Egg Shell

Sample A3: Sea Shell

Figure 5.2: Sample A1

Figure 5.3: Sample A2

Figure 5.4: Sample A3

Coating On PU: coating on Polyurethane with 3 different samples were prepared

Sample B1: Al2O3

Sample B2: Egg Shell

Sample B3: Sea Shell

Figure 5.5: Sample B1

Figure 5.6: Sample B2

Figure 5.7: Sample B3

WEAR TEST SPECIFICATION

- Equipment Used : Wear and friction monitor
- Track diameter : 60 mm
- Disc speed : 380 rpm
- Applied load : 3 Kg
- Experiment duration : 15 minutes

Wear rate calculation: For this experiment for a every time period of 1 minute we captured the wear rate for a time of 15 minutes on both polyvinylchloride and polyurethane with different coating samples

Table 1: Wear rate of PVC and polyurethane (PU) with Al_2O_3, Sea shell and Egg Shell

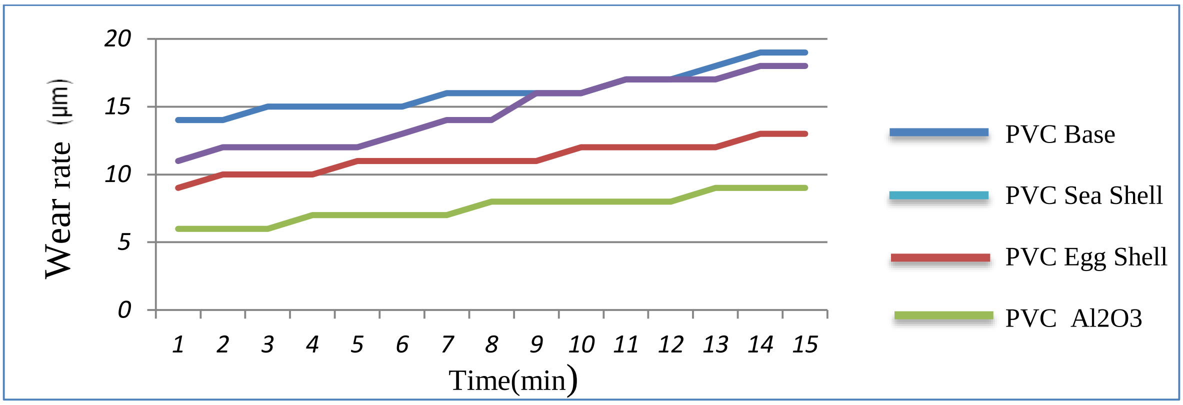
Time (min)	PVC Base material	PVC Coated withAl2O3	PVC Coated with Eggshell	PVC Coated with Seashell	PU Base material	PU Base material	PU Base material	PU Base material
1	14	11	6	11	40	40	40	40
2	14	12	6	12	41	41	41	41
3	15	12	6	12	43	43	43	43
4	16	13	6	12	45	45	45	45
5	16	13	7	12	46	46	46	46
6	16	13	7	13	47	47	47	47
7	16	13	7	14	48	48	48	48
8	17	12	8	14	50	50	50	50
9	17	14	8	14	52	52	52	52
10	17	14	8	15	54	54	54	54
11	18	15	8	15	55	55	55	55
12	18	15	9	15	57	57	57	57
13	18	15	9	16	58	58	58	58
14	19	16	9	16	60	60	60	60
15	19	16	9	16	61	61	61	61

Table 2: Initial and final weight of the (wear test) PVC and PU specimen with different coating samples

	PVC without coating	Al_2O_3 coated PVC	Seashell coated PVC	Egg shell Coated PVC	PU without coating	Al_2O_3 coated PU	Seashell coated PU	Egg shell coated PU
Initial weight(gm)	1.352	1.363	1.359	1.358	1.105	1.169	1.171	1.168
Final weight(gm)	1.212	1.349	1.338	1.345	1.056	1.162	1.168	1.166

RESULTS AND DISCUSSION

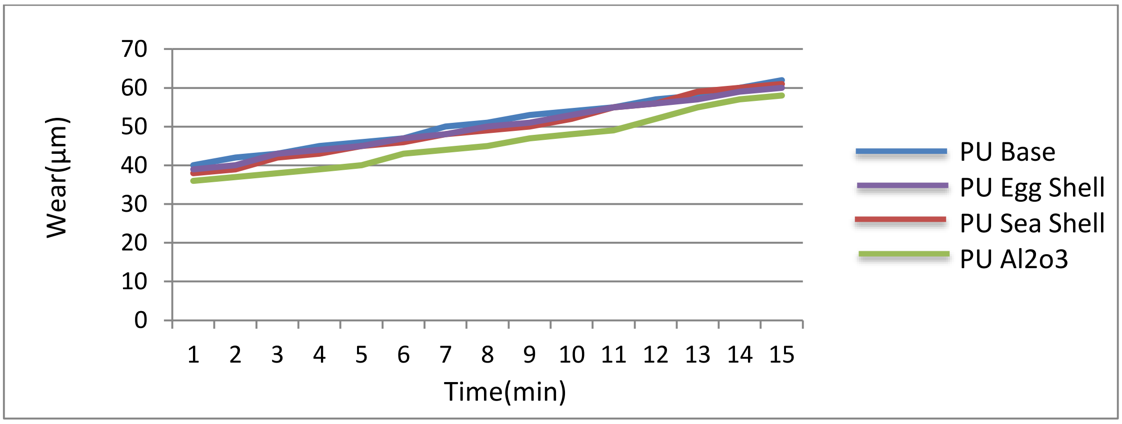
Comparison of Wear Rate (PVC with different samples)



Graph 1: Comparison of wear rate

Above graph shows the comparison of amount of wear taking place with respect to time when Polyvinylchloride is coated with different coating materials. From the above comparison we can conclude that PVC when coated with Al_2O_3 provides a better wear resistance compared to others coating materials.

Comparison of Wear Rate (PU with different samples)



Graph 2: comparisons of wear rate

The above graph shows the Time in ‘x’ axis and wear rate in ‘y’ axis. For above experiment we kept constant weight of 3kg and time 15 minutes. The above graph shows comparison of wear rate v/s time of Polyurethane with coating and without coating. From the above figure we can conclude that wear rate is very high for Polyurethane and it is soft material compare to other polymers. after coating wear rate slightly decreases.

CONCLUSION

From the experiment conducted, The following conclusions could be drawn:

- Plasma spray deposition gives proper coating thickness and phase purity of powder samples was maintained after deposition.
- The powders which were used to prepare coating materials are derived from a natural sources like Aluminiumoxide, egg shells and sea shell. The extracts are sources of calcium, fibres etc. So the coating materials are naturally bio-active and biocompatible.
- Among the coatings material used, PVC coated with Al_2O_3 provides high wear resistance.
  Among the coatings material used, PU coated with sea shell provides slightly better wear resistance compare to base material.
- As PU coating with all the three materials shows very poor wear resistance when compared to PVC.

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