ISSN: 0971-1260
Vol-22-Issue-16-August-2019

The Significance of Titanium and Its Alloys For Orthopedic Implants: A Review

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Abstract

The metallic materials, for example, titanium alloys, cobalt-chromium alloys, and stainless steels are predominantly utilized as implant materials.These materials possess good mechanical properties so these are capable for major load bearing applications.In this article, Ti properties, for example, metallurgy, mechanical properties, surface modification, and corrosion resistance in biomedical field have been discussed. Ti and Ti alloys have interesting properties, for example, high strength, low density and amazing corrosion resistance. These properties are essential for the production of lightweight and high quality parts for biomedical examinations. This review also highlights ample summary of different coating methods to improve the performance of Titanium alloys. Plasma spraying technique is reported as one of the best suitable method to coat different alloys using hydroxyapatite and other reinforced powders to boost corrosion resistance and biocompatibility. Other than the corrosion and mechanical properties, selection of materials in bioimplants also plays a major role depending upon the life span and human body environment. Several surface modification techniques are also discussed to enhance corrosion resistance of titanium alloys.

***Keywords**: Titanium alloys, bio-implants, corrosion, plasma spray, surface modification*

1. INTRODUCTION

Biomaterials are natural ingredients and are considered as artificial joints for the human body. These are employed instead of the damaged body parts or to reestablish the unhealthy part [1]. Inserts are generally implanted into a host tissue to activate preferred cell behavior as well as, to refurbish any weakened physical utilities [2-3]. The relevance of implants in a physiological situation orders that they have good biocompatibility, requiring satisfactory corrosion resistance, and good mechanical properties [4-5]. Subject to their applications, inserts can be of several sorts

ISSN: 0971-1260
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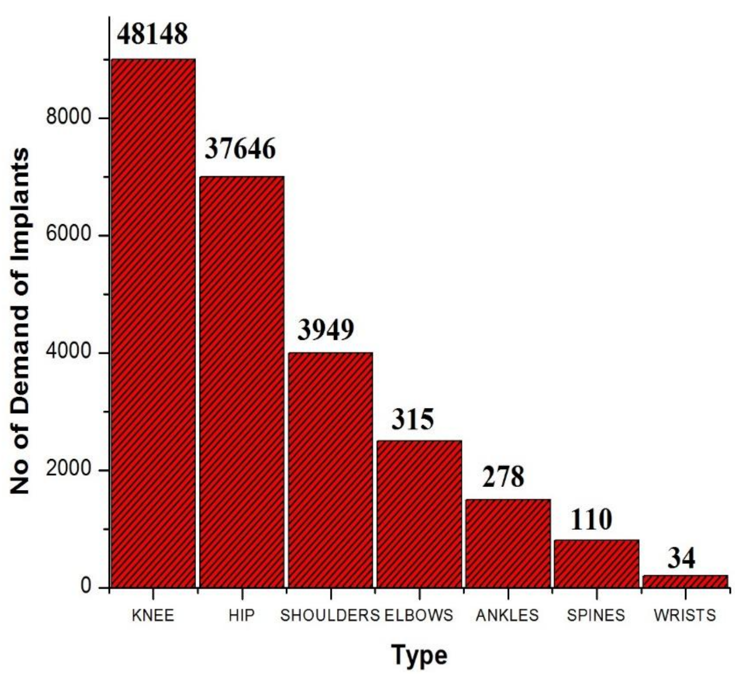
that are designed for various medical applications. Generally, the life of an implant also varies according to age limits as according to literature implant life of the older patients was around 15 to 20 years whereas more than 20 years for the younger patients [6]. The blood and other different constituents present in the corrosive condition of the human body unfavorably influences the biocompatibility and mechanical properties of the implants [7]. To avoid mechanical failure, high corrosion resistant biomaterials are required to escape the dissolution of surface oxide film that leads to supplementary ions in the body [8]. The accomplishment of the embed substitution doesn't consider uniquely on the medical procedure executed by a specialist, yet also, relies on the choice of the materials utilized as a replacement. The choice depends on the state of the patient identified with its health, weight, recovery time and age [9]. This implies appropriate information is required of replacement materials and the performance of the material. Notwithstanding these different factors, for example, design, surface properties and biocompatibility of the selected material were likewise considered [10]. An implant material ought to have great biocompatibility, ductile, compressive, shear strength to prevent fractures and improve functional strength. Electrical and thermal conductivity then again ought to be least to avert thermal development, contraction, and oral galvanism [11]. The embed material ought to have the capacity to form direct contact or association with the bone (osseointegration). This is to a great extent reliant on biocompatibility and surface composition of biomaterial. Fig. 1.Displays the demands of market for implants made by Ti and Co-based alloys in 2012 for Australia. Due to the weakening of bodyparts by growing human age the demand of using bioimplants has increased dramatically [12].



ISSN: 0971-1260
Vol-22-Issue-16-August-2019

Fig.1. Number of demand for bioimplants in Australia in 2012 [12]

2. BASIC IMPLANT MATERIALS

Since the nineteenth century the utilization of metallic inserts was presented for biomedical uses. Prior in the 1860's a surgical technique was created by Lister. After Lister, it was then altered by Lane in the 1900's by presenting a fracture plate of steel and further the stress concentration was decreased by Sherman [13]. From 1900s onwards metallic inserts end up being a fundamental piece of orthopedic industry and are utilized in the body for both permanent and temporary joints [14]. These are incredibly appropriate for bone repair because of improved properties. High rigidity alongside young's modulus makes them multiple times harder than ceramics. Metallic corrosion is one of the significant aspects and it tends to be decreased by appropriate selection of materials as some of the metals hold sound corrosion resistance [15-16]. The knack of alloys makes them fit for necessary uses as their properties, for example, wear, mechanical and corrosion behavior can be modified [17-18].

2.1. Magnesium and its alloys

Magnesium alloys have gained notoriety for being progressive in orthopedic applications because of their great biocompatibility and satisfactory mechanical behavior [19-22]. These alloys easily degrade in vivo because of the presence of Cl^- in the physiological condition, in this way taking out the requirement for auxiliary medical procedures to remove the implant. Mg^{+2}, a corrosion result of Mg alloy implants, doesn't cause unexpected complications in light of the fact that Mg cations are effectively eliminated in the urine [23-26]. Mg alloys are light in weight and have similar mechanical properties to bone [27-30]. Magnesium alloys significantly utilized as implant materials in the field of implants [31-34]. The leading downside of magnesium and its alloys that it corrodes swiftly in biological situation and loose its mechanical integrity [35-38].

2.2. Titanium and its alloys

In 1950-1960s titanium was firstly designed for aviation purposes and later it was produced for surgical implants. At present, 2% of titanium is utilized in medicinal appliances. Titanium has remarkable mechanical and biocompatible properties that make it's a well-known bioimplant [39]. Among the materials accessible for implants, the normal determination of Ti-alloys for implantation, is expected because of its exceptional attributes, for example, high strength, low density, good corrosion resistance, broad idleness to body condition, improved biocompatibility, low modulus and high ability to get together with human bone in corrosive environment [40]. Ti alloys, due to their lower modulus contrasted with 316 L steel and Co-Cr alloys, utilized in orthopedic field.PureTi and Ti–6Al–4V are most generally utilized titanium materials for embed applications. Disregarding the way that Ti6Al4V was initially produced for aviation field,but to its incomparable properties drove its entrance into biomedical applications. Ti alloys are also utilized in human services products, for example, wheel seats, artificial appendages, artificial legs and so forth inferable from theirexcellent similarity and non-hypersensitive nature [41-42].

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2.3. Stainless Steels

In many countries stainless steel (316L) grade utilized as a temporary embed. These alloys have high mechanical strength and malleability. Then again, it discharges ions and furthermore gets corroded in biological condition [43]. Because of these ion discharges, it impacts the body and causes incredible allergens. As indicated by the past examinations it was seen that around 90% of 316L implant failures are simply because of corrosion [44]. This leads to the loosening of the implants even for temporary use. In this way, it is feasible to employ some other improved materials for orthopedic inserts with good mechanical and biological properties [45].

2.4. Cobalt and its alloys

In Co-Cr alloys, CrO advances corrosion resistance while molybdenum provides strength. These alloys exhibit extraordinary mechanical strength, exceptional corrosion resistance and low ductility [46]. These combinations reveal balance among mechanical properties just as biocompatible nature. When contrasted with stainless steel, the two parameters for example corrosion resistance and mechanical behavior are predominant [47]. Then again these alloys are marginally expensive than steels however are much better in terms of corrosion behavior. For permanency of artificial joints in the field of dentistry, cast Co-Cr-Mo alloy was utilized as at the hour of medical procedure, these can't be molded in a specific structure [48]. On the other hand, increased incidence of crevice corrosion in these alloys tends to be the major drawback [49-51].

2.5. Other precious metals

Valuable metals comprise of gold, platinum, and palladium. These are noble metals unaltered via air, moisture, heat and most solvents. These don't rely upon surface oxides for their interness [52]. These materials hold high flexibility and have low mechanical properties. These are narrowly used because of significant expense per unit when paralleled to other embed materials [53].

3. HUMAN BONE

Human bone is a sort of soft tissue which promote inner sustenance and protection to the vital organs as the rib cage and furthermore fills in as a site for the attachment of the muscles. Moreover, the bone keeps up calcium homeostasis just as hematopoiesis. To aid these reasons, it is essential that the bone is inflexible. Actually, it should be flexible for energy absorption. Cortical and trabecular are the chief bone tissues in the human body. The function of cortical bone is that it shows high compressive quality as it has low porosity and conveys more quality and unbending nature deep down, while, trabecular bone offers high porosity [54]. Nevertheless, it delivers an enriched surface area to permit the contact of blood vessels and red bone marrow. To practice magnesium substrates in return of human bone, it must be confirmed the mechanical habits of both are similar. But on the other hand, the easy or quick degradation in corrosive

ISSN: 0971-1260
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environment results in weakening of the implants in a long run which results in infection in the human body [55]. Comparative properties of embed alloys are introduced in table 1. [56-58].

Table 1. Mechanical properties of metallic implants.

Property	Natural Bone	Magnesium Alloys	Titanium Alloys	Cobalt–Chromium Alloys	Stainless Steels
Density (g/cm^3)	1.8–2.1	1.74–2.0	4.4–4.5	8.3–9.2	7.9–8.1
Elastic modulus (GPa)	3-20	41-45	110-117	230	189-205
Yield strength (MPa)	130-180	85-190	758-1117	450-1000	170-310

4. SURFACE COATING TECHNIQUES

In the present period, different sorts of strategies are accessible in which the implant surface is smeared with various coatings which further amplifies the surface area and roughness. Besides, it improves biocompatibility and attachment quality at the bone-implant border.

4.1. Plasma spray

Electric arc builds a plasma flame over which an argon gas stream is flowed to heat the coating powder to a temperature of roughly 12000 to 16000°C as shown in Fig.2. This amount of heat delivered liquefy the particles which are additionally sprayed on the samples and solidify to make round interconnected pores between the bone and the implant which permits straight chemical bonding prompting a strong bond. Moreover, this supports the implant to accomplish better corrosion resistance and biocompatibility and quick recovery time after a medical procedure. To expand the weight-bearing capacity of the bone neighboring, the implant is prepared and mineralizer in a superior manner [59-60].

ISSN: 0971-1260
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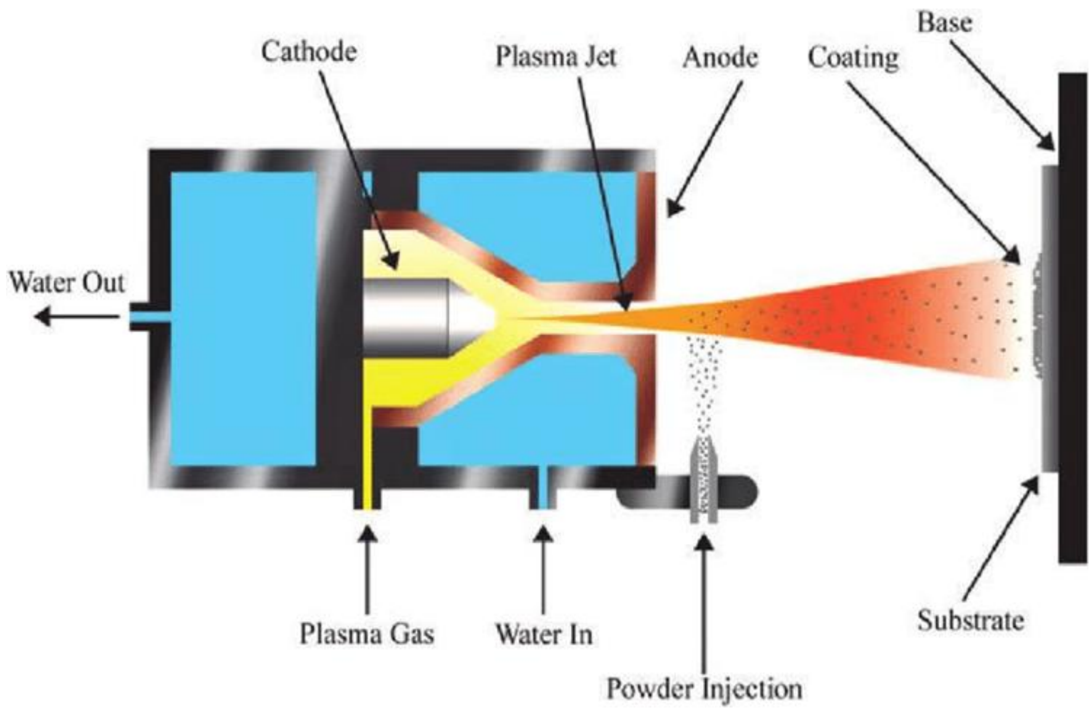

Fig. 2. Plasma Spray Technique [60]

4.2. Electrophoretic deposition

The first part of the procedure comprises of mineral ions dissolved in the electrolytic bath in which the electric current is applied and the particles get electrically charged that start traveling to one of the electrodes as shown in Fig.3. In the second part of the procedure, a coherent deposit is formed near to the electrode by the accumulation of the particles in the shape executed by the electrode which is acquired in the form of the green ceramic body by removing and drying it from the electrode. A ceramic component is designed by firing the green ceramic body. The only shape drawback is the likelihood to take away the deposit from the electrode after deposition [61-62].

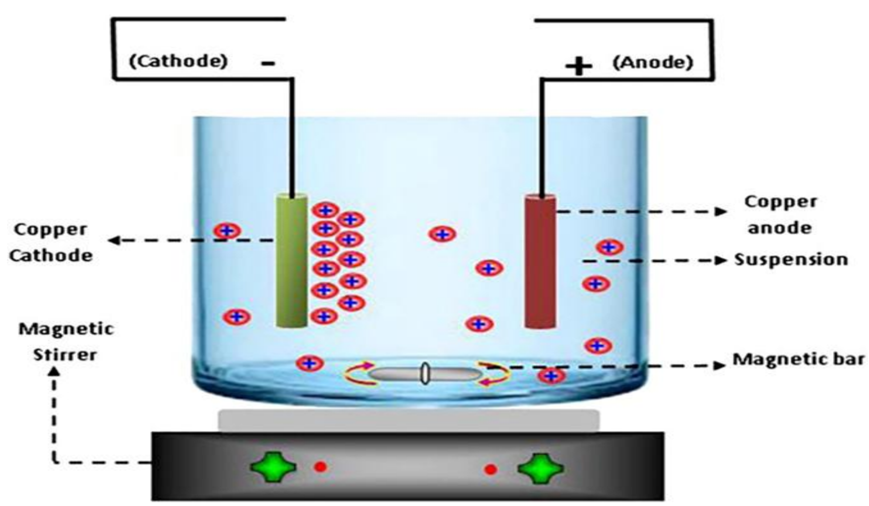

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Fig.3. Electrophoretic deposition set-up [62]

4.3. Sol Gel Deposition

This technique is applied for making solid materials from small molecules. The sol-gel deposition process is shown in Fig.4. The supreme materials for this advancement are oxides of silicon and titanium. Transformation of monomers was done into colloidal solution (sol) which deeds as the originator for a consolidated network (gel) of any discrete particles or system polymers. Minimal efforts, as well as easy control factors, makes this a favorable technique.

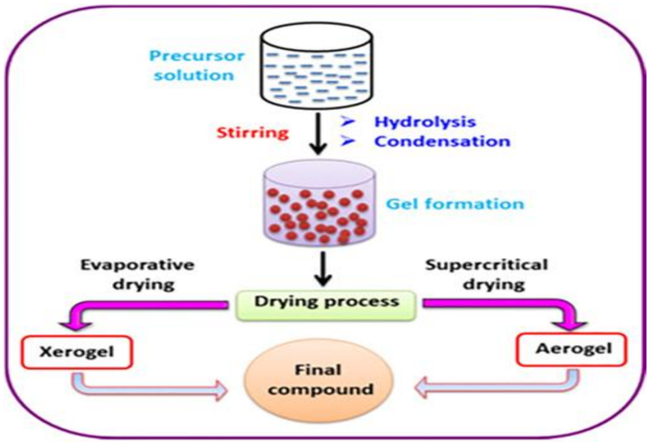

Fig.4. Sol-gel deposition [64]

On the other hand, thin films are prepared by sol-gel method, exhibit exceptional anti-wear and act friction reduction. Generally, it is used in methodical applications such as monolithic gels and thin films. Monolithic gels can be basically geared up by pouring sol into a flask. As soon as, the processes gelation and drying are completed, the primed piece is formed by the flask in which it was poured [63-64].

4.4. Hot Isostatic Pressing

The essential thing of this procedure is to drop the porosity of metals and upsurge the density of various ceramics ingredients, brings about improving mechanical properties just as workability. As shown in Fig.5, Initially, the material is engaged to a higher temperature and again raised at isostatic gas pressure in a controlled vessel. Argon is commonly utilized as pressurizing gas. To shield the material from chemical responses inert gas was applied. The pressure inside the chamber ascends to a substance that results in heating. Different frameworks utilize gas pumping to achieve the necessary pressure value. As the pressure is applied for entire directions it shows isostatic level. The powder is hot pressed around 850°C and a dense coating was made which brings about higher shear strength [65-66].

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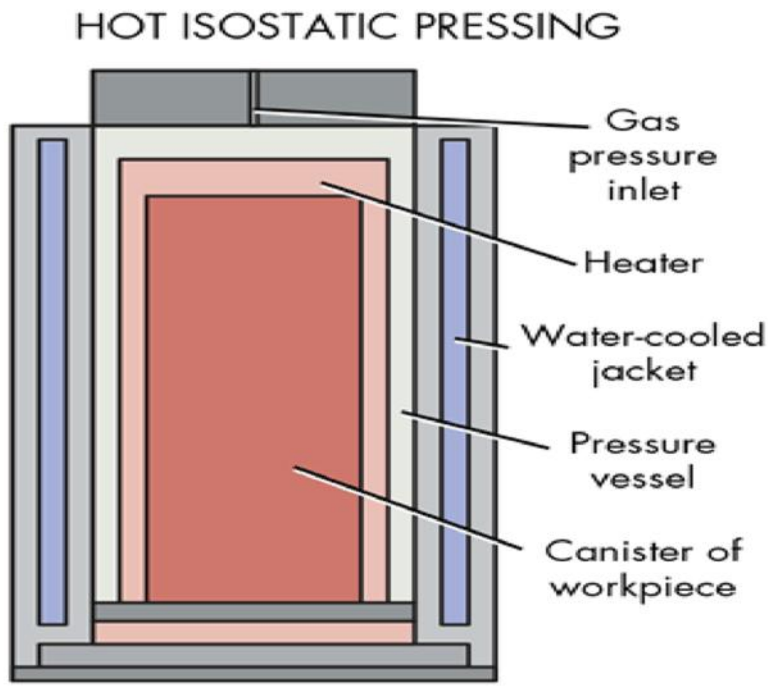

Fig.5. Hot Isostatic Pressing [66]

4.5. Pulsed Laser Deposition

For many years this procedure is accomplished of creating materials with higher quality films. As shown in Fig.6. High power laser pulses impact the material which melts or evaporates from the target surface. PLD works on an extremely plain procedure wherein material is expelled from the surface of the target by using pulses of laser energy. Laser produced plasma plume is a vaporized material comprising of neutrons, ions, electrons which rapidly becomes away from the objective surface in vacuum plume material recondenses and a film is formed upon the substrate [67-68].

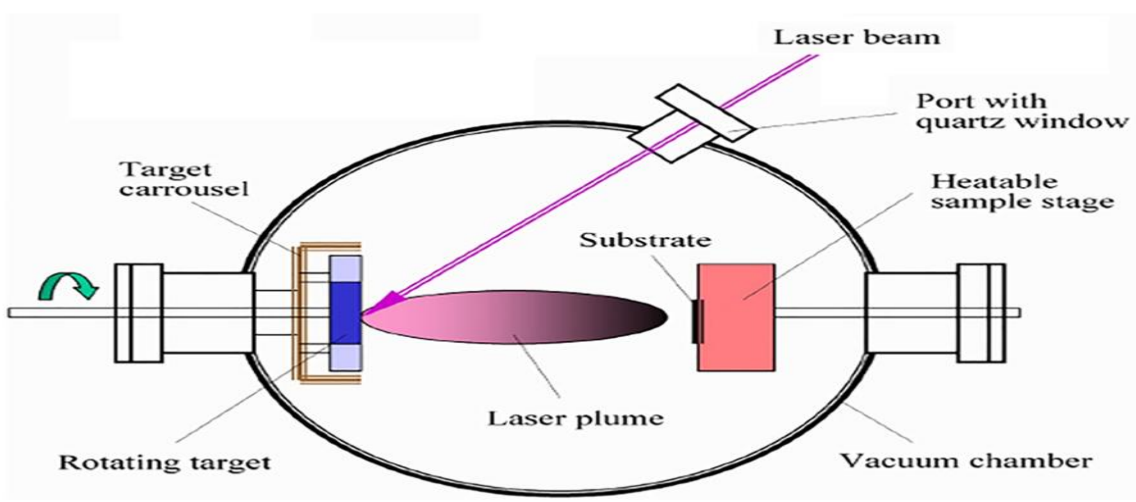

Fig.6. Pulsed Laser Deposition [68]

4.6. High-Velocity Oxygen Fuel

To accomplish better properties the procedure is done by heating the material and afterward quickened to a constituent's surface by a gas stream which is made in a combustion chamber by consuming the mix of oxygen and fuel as shown in Fig.7. It further permits the high-pressure gas to escape by means of a nozzle. A powder is heated and rushed towards the surface of the segment by carrying it into the steam. The subsequent thermal spray coating includes thin overlapping platelets. Almost perfect surface finish is obtained by dense spray coating made by spraying the molten or semi- molten matter on the surface through high temperature or high-velocity gas stream [69-71].

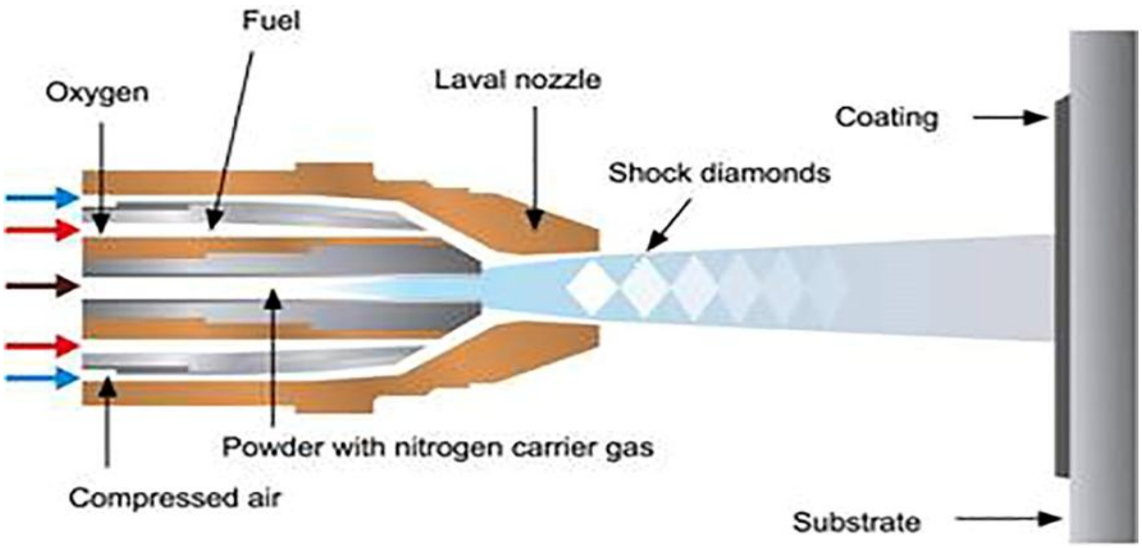

Fig.7. High-Velocity Oxygen Fuel [71]

5. STUDIES RELATED TO TITANIUM AND ITS ALLOYS

K.A. Khor et al. [72]This paper portrays an endeavor to advance coating mechanical properties by shaping a composite made out of HA and Ti-6A1-4V. Different percentage of (20, 33, and 80 wt % HA) were taken for plasma coating. The HA-rich areas seemed porous because of poor interparticle attachment, with the 80 wt% HA coatings having the most elevated porosity. The coatings would in general display expanded bond quality at thicknesses not exactly or equivalent to 60 μm. The phenomenal bond strength of the Ti-6A1-4V/HA composite is brought about by the unrivaled interfacial bond between the Ti-6Al-4V-rich splats and the alloy. The empowering advancement raises the probability of its utilization as a bond coat for plasma coated HA on titanium substrates.

Ming et al. [73]A straightforward rapid-heating strategy was effectively created for CaP coatings on Ti alloy by utilizing a sol–gel method. Total 5 reiterations of coatings wastreated around 600°C. XRD investigations were carried out for arrangement of HA has been affirmed by

XRD investigations and the coated Ti was seen as somewhat oxidized. On the other hand, at 400°C the coating may hinder the arrangement of CaP, in this manner just modest quantity of CaP is available. Now at 600°C, CaPdemonstrates the single phase as recognizable by XPS. The cement quality of all the 5 coatings layer on Ti alloy was determined to be near 60 MPa. Porous behavior was emerged for both the surfaces at 400°C as well as afterward solidificationof coating at 600°C.

R. B. Durairaj et al. [74]In this article, HA is used as a coating material for both substrates i.e. Ti6AL4V and AZ31. The coating is performed by electrodeposition system. The corrosion performance for both coated and uncoated were studied.According to the literature, in vitro assessment for HA coated Mg and Ti samples was experienced usingSBFto answer for distinguish the development of bio growth. The characterization was handled by SEM as well as EDS investigations. The outcomes obtained reveals HA coated substrates possesses slow degradation as well as corrosion rate when compared to bare alloys.

G. Singh et al. [75]The point of this study was to assess the corrosion behavior of the uncoated and coated Ti alloy. The coating material was used as CaPand HA and the coated samples are immersed in SBF. Three sorts of coatings: HA, HA + 10 wt% CaP, and HA + 20 wt% CaP onTi were made utilizing plasma spray procedure. SEM and XRD were utilized to examine the crystallinity, microstructure and morphology of the coatings. Electrochemical potentiodynamic test were performed to decide the corrosion performance of uncoated and the three coatings in Ringer's solution. The plasma coated substrates are found to have better corrosion resistance than uncoated substrate.

6. Conclusions

In this paper, the properties of different biomaterials are talked about with their mechanical and corrosion behavior. Previous studies on titanium alloys were likewise discussed for advanced bone-implant replacement. The data conveyed above explains that the design and selection of the materials are also key factors alongside the corrosion and other surface properties of the substrate. Different coating strategies alongside coating materials are discussed in this article that supports titanium alloys to improve their properties that are required in medical applications. It was noticed that the utilization of hydroxyapatite content in the coating, brought about improved corrosion resistance and upgrade biocompatible behavior. In addition, in the future, taking in thought with the expanding demand there is a need for higher life expectancy of orthopedic inserts. Hence, it is important to highlight the detailed examinations to decide the behavior of advanced biomaterials their clinical use and a point by point approach to upgrade the biocompatible behavior that follows trail implantation. Still convenient collaboration in dynamic order is required among orthopedic specialists, researcher and designers to reach an incredible accomplishment with this challenging future of bioimplant substitutions.

Funding: No specific grant from any sector for this study.

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