



## A Review on Surface Treatment of Stainless Steel Orthopedic Implants

Nishant Godbole<sup>1</sup>, Shajit Yadav<sup>2</sup>, M. Ramachandran<sup>3</sup>, Sateesh Belemkar<sup>4</sup>

<sup>1,2,3</sup>MPSTME, SVKM'S NMIMS, Shirpur, Dhule, Maharashtra, India.

<sup>4</sup>SPTM, SVKM'S NMIMS, Shirpur, Dhule, Maharashtra, India.

\*Corresponding author's E-mail: [sweetestchandran@gmail.com](mailto:sweetestchandran@gmail.com)

Accepted on: 02-12-2015; Finalized on: 31-12-2015.

### ABSTRACT

It is expected that in future, there will be an immense usage of implantable devices which will cause the number of infections to increase naturally because some patients are unable to autonomously prevent formation of bio film on implant surfaces. 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 orthopedic 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 orthopedic prosthesis that will promote bone growth and differentiation of stem cells into osteoblasts leading to enhanced osteointegration of the implant. Furthermore, several coatings such as silver, nitric oxide, antibiotics, antiseptics and antimicrobial peptides with anti-microbial properties have also been developed, which promises in reducing bacterial adhesion and prosthetic infections. In this paper, we are discussing various coatings provided on stainless steel. This review summarizes some of the recent developments in coatings for stainless steel orthopedic implants.

**Keywords:** Orthopedic implants, implantable devices, surface treatment.

### INTRODUCTION

Bone fracture and bone tissue injury are big medical problems<sup>1</sup>. An estimated 20 million bone fractures occur annually in the India. Bone defect caused by injury, infection, tumor and congenital diseases is one of the most common diseases in clinical orthopedics; sometimes injury is so severe that bone grafting has to be performed for further prevention. Preparation of ideal bone substitutes with good biocompatibility and biodegradability to repair bone defects has become the prime focus. So far artificial materials used in hard tissue repair and reconstruction most notably are metals and their alloys, then the ceramic materials and their composite materials. The elastic modulus of human bone is between 4.6 to 20GPa<sup>2</sup>. According to the structure, bone is divided into cortical bone and cancellous bone. Mechanical properties of cortical bone are: elastic modulus of 16–20GPa, and ultimate strength of 30–211MPa. Mechanical properties of cancellous bone are: elastic modulus of 4.6–15GPa, and ultimate strength of 51–193MPa. The density of cortical bone is about 1 990 kg/m<sup>3</sup> and cancellous bone is lower than it but more elastic. Cortical bone grafts are used primarily for structural support, and cancellous bone grafts for osteogenesis. For centuries, one goal of medical specialists has been the creation of a viable substitute to repair bone. Through the ages, substances such as leather, noble metals, plaster of Paris, directly transplanted hard tissues from other species, and other hard substances have been used in an attempt to repair bone tissues<sup>3</sup>. Ceramic is preferred over metal because the elastic modulus of ceramic is more close to the natural bone and scientists are focusing to improve its

brittleness for clinical use. Therefore, development of materials of proper mechanical properties without affecting biological compatibility has become a significant subject. One of the applications include internal fixation of fractures by bone plates, nails or intermedullary rods. In this work, we are using stainless steel 316L which is the most widely used bio materials for implants process, because of its capability to resist corrosion, mechanical properties and cheaper price according to other materials. Corrosion test is very important for any surgical implant to be used as a biomedical material because there will be a release of metal ion from the material if corrosion occurs<sup>4</sup>. The performance of a biomaterial is determined by its chemical, physical and biological properties. Metallic materials are widely used as biomedical materials because they have several good properties such as elasticity, rigidity, toughness and electrical conductivity are essential properties for metallic materials used in medical devices. Since our body has a complex environment, biomedical materials are subject to electrochemical corrosion mechanisms, with bodily fluids acting as an electrolyte<sup>5</sup>. Stainless steel after undergoing some Chemical and Physical Treatment can be used as temporary orthopedic implants to help bone healing, as well as fixed implants such as for artificial joints. But when we consider corrosion resistance in the human body, cobalt chromium alloys and titanium alloys are much better than stainless steel. However, large amounts of stainless steel are used for implant devices because they are less expensive than cobalt–chromium alloys, pure titanium, and titanium alloys. Generally, deep infection leads to implant removal and ensuing increased morbidity and even mortality. Aseptic loosening occurs



secondary to debris particles arising from wear products at the articulating surfaces or from cement disintegration at the cement-bone or cement prosthesis interfaces after long periods of repetitive mechanical stress associated with locomotion<sup>6</sup>. These wear particles lead to a biologic response characterized by an inflammatory response in the immediately adjacent bone that culminates in bone loss and loosening of the implant. Currently, most implants are made of metals such as cobalt chrome alloy, stainless steel or titanium alloy. However these metals generally lack a biologically active surface that either encourages osteointegration or wards off infection. Attention has thus been focused on developing various coatings to supplement the function of current implants. 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 "osteopromotive" 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 "osteopromotive" and be able to recruit various stem cells from surrounding tissue and circulation and induce differentiation into osteogenic cells<sup>7</sup>. Furthermore the coating must possess that much mechanical stability which when under physiological stresses associated with locomotion do not detach from the implant surface; finally, the implant coating should have anti-microbial properties minimizing the risk of prosthetic infection. Currently none of the commercially available prosthesis is able to satisfy all of the above criteria, further emphasizing the need for research and development of new biological coatings for orthopedic implants<sup>8</sup>. The aim of this review is to discuss recent approaches towards improving the integration of orthopedic prosthesis through novel implant coatings.

### Stainless steel orthopedic implants

Metallic surgical implants are structural components used to accelerate the bone consolidation after fracture. A group of implants consist of compression plates fixed to the bone by bolts and nuts. This is particularly useful when the excessively long period of consolidation by traditional methods (without implants) would probably provoke the atrophy of cartilages and articulations of the human body<sup>9</sup>. In recent years, many researchers have been made to study the behavior of metallic surgical implants in order to improve the biocompatibility of metals and alloys used in osteosynthesis implants. To study different parameters of surgical implants, they are subjected to aggressive working conditions such as static and dynamic mechanical loading and are exposed to the biochemical and dynamic environments of the human body that contributes to increase in wear. The load on implant varies differently with different types of action such as walking and cycling. Sometimes load reaches a peak of about four times the body weight at the hip and three times the body weight at the knee. And also, larger

loads are assumed by the hip and knee joints during some activities such as running and jumping<sup>10</sup>. Nowadays Austenitic stainless steel has been widely used as osteosynthesis implants because of the excellent mechanical properties: corrosion resistance and cost benefit. But, by using this type of steel, formation of Cl<sup>-</sup> ion in high concentration plus the regular temperature of the human body might create localized corrosions like pitting, crevice corrosion and fretting fatigue. In this work seven orthopedic surgical implants which failed in service were evaluated. The implants are made of austenitic stainless steel, and were used in Brazilian patients assisted by the national public health system (SUS). It was found that fatigue cracks were initiated because of machining imperfections and formation of crevice corrosion points. Different grain sizes and overall microstructures were observed in the seven specimens when analyzed. Some microstructures showed deformation induced martensite and presented slip bands, while others showed a hot deformation structure. The fatigue resistance of the AISI 316L stainless steel implants could be improved by a better surface finishing and surface nitriding treatment. Chemical assembly of silver nanoparticles on stainless steel is done to have good antimicrobial applications.

### Production of stainless steel implant materials

Stainless steel powder was cold-pressed with 800 MPa of pressure and then sintered at 1300°C for 30 min. The results indicate that the sintering temperature, atmosphere and time are important parameters that affect the porous ratio of materials produced by P/M. High temperature sintering can eliminate small pores and make the residual pores spherical. The wear tests showed that the wear of the AISI 316L stainless steel implants changed depending on the sintering temperature and load<sup>11</sup>. It was seen that presence of spherical pores in the samples increases the wear resistance of 316L stainless steel. Moreover, decreasing the porosity ratio of these materials improves all of their mechanical properties. Modern use of implants in dentistry and medicine began in 1960. Today many types of metallic and nonmetallic implants are used in the human body for different purposes. Artificial materials with appropriate physical, chemical, mechanical, and electrical properties are often used in orthopedic applications. The first implants produced from metallic materials by powder metallurgy (P/M) date back to the 1960s when a porous hip prosthesis was produced from Co-Cr-Mo alloy. These studies aimed at improving the mechanical and physical properties of P/M implants. Implants produced by P/M are specifically preferred in orthopedic and dentistry cases where a robust and reliable implant-bone connection and a high load bearing capacity are needed. In addition, P/M can produce fine grain size, improve the homogeneity of the material, and allow the production of final size, high quality implants in a cost effective manner<sup>12</sup>. P/M has been used to improve the microstructure and mechanical properties of implants as



well as avoid possible casting defects. Stainless steels produced by P/M play an important role in the machine industry because of their low production cost and reduced need for part processing. In current industrial processes, P/M stainless steels have a specific mass of 7.0–7.1 g/cm<sup>3</sup> while the theoretical specific mass of stainless steels today is about 7.9 g/cm<sup>3</sup>. Studies are being conducted to improve the characteristics of P/M stainless steels. P/M stainless steels are superior to other stainless steels because of their low cost, precise size control, and better wear and corrosion resistance, which are important quality indicators. The wear mechanism of P/M 316L stainless steel depends strongly on its microstructure, which is influenced by the sintering atmosphere. AISI 316L stainless steels have a low carbon and high nickel and chromium content. Low carbon content helps to prevent corrosion<sup>13</sup>. However, this kind of steel may experience internal wear and corrosion where the stress and oxygen consumption is high. Because weakness and failure of the prosthesis material will require the patient to undergo subsequent surgical operations, the material must have excellent mechanical, wear and corrosion properties. In this study, the effects of sintering 316L stainless steel produced by P/M at different temperatures on its microstructure, mechanical properties and wear behavior were investigated. In the third group of samples, use of a higher temperature resulted in better sintering, increasing wear resistance and micro hardness.

### Chromium coated stainless steel implants

Presence of Cr results in the formation of a thin, chemically stable, and passive oxide film on the surface of the stainless steels. The oxide film forms and heals itself in the presence of oxygen. The physical-chemical properties of this passive film control the material's corrosion behavior, its interaction with the body, and thus the degree of the material's biocompatibility. There have been numerous *in-vivo* and *in-vitro* studies focused on corrosion in metal implants. However, many of the *in-vitro* studies employed simulated body fluids such as Ringer's or Hanks' solutions. It has been reported that corrosion resistance of stainless steel is closely related to chromium concentration in the film formed by surface treatment methods. OCP of AISI 316 L display that, the PT is shifted to noble direction than CP+P, CP, MP respectively. While the value of OCP of AISI 310S display that the CP+P is shifted to noble direction than PT, CP, MP respectively. The passivation treatment significantly increases the corrosion resistance due to a high Cr content in the passive film and increased film thickness. From the results it can be concluded the AISI 310 S have higher corrosion resistance than AISI 316 L, so it can be recommended to use it in biomedical application as 316 L which widely used biomaterials.

### Biofilms Microbe repelling coated stainless steel

The biofilms consisted of more of cell ghosts than viable-looking cells. From the orthopedic usage point of view,

this is unfortunate as it means that biofilm adherence analysis done with one bacterial species does not necessarily predict the bio fouling tendency by another species<sup>14</sup>. The DLC coating reduced the accumulation of Staph. epidermidis biofilm on steel more efficiently than fluoro polymer coating. However, the situation was opposite for biofilms of *D. geothermalis* and *M. silvanus*. Thus, the functioning of the coated material for orthopedic implants depends on the microbial species causing the biofilm problem. High skewness value indicates lack of porosity. In addition, high value of kurtosis (Sku) indicated decreased tendency of bacterial adhesion. It is possible that the correlations to bacterial adhesiveness would have been different if pH or surface tension were different. *D. geothermalis*, Staph. epidermidis, *Psx. taiwanensis* and *M. silvanus* sensed the surface they were in contact with. This was indicated by ultra-structural changes when the cells attached to differently coated steel surfaces.

### Silver nanoparticles coated stainless steel implants

Since stainless steel was discovered in 1913, it has become one of the most commonly used materials in daily life. Furthermore, equipment requiring high quality construction that must provide a sterile environment in the food and pharmaceutical processing industry and that is designed to be free of all harmful contaminants typically utilizes storage containers and conveyor belts made of stainless steel. However, microbial adhesion to stainless steel surfaces followed by cell colonization and growth can result in the formation of bio film capable of protecting the micro-organisms from chemical and physical sterilization agents, such as ozone, AgNO<sub>3</sub> and its derivatives, ultraviolet light and radiation. This leads to increased chemical usage, more downtime, and higher labor costs in order to sterilize the equipment<sup>15</sup>. Recently, the Kawasaki Company has produced two types of silver-stainless steel using a similar method. Gaelle Guillemot and coworkers deposited silver nanoparticles onto stainless steel to reduce the adhesion of the model yeast. However, the methods mentioned above have not brought an enormous increase in the application of antimicrobial silver nanoparticles in the field because of the extremely complicated preparation procedure. Thus, a convenient, efficient, low cost and long-term antimicrobial method to prevent the adhesion of the bio film on stainless steel is needed. The antibacterial effects of metallic silver have been known for centuries. The silver ion exhibits broad-spectrum antimicrobial activity toward many different types of bacteria and is believed to be the active component in silver-based products. Previous work has shown that silver nanoparticles assembled on surface of glass, ceramic and TiN can provide strong antimicrobial properties. Therefore, silver nanoparticles also appear to be the best choice for coating the surface of stainless steel to restrain bacterial contamination and the formation of the bio film. It was also reported that passivation is an important surface treatment that protects the surface of stainless steel from



corrosion by forming thin, durable layer of chromium oxide at the surface. This oxide layer provides the possibility to connect silver nanoparticles onto the stainless steel surface through APTES. The antimicrobial effect of the composite is so good that it would appear to have enormous potential in antimicrobial applications. In this research, silver nanoparticles were chemically assembled on the surface of stainless steel by a coupling agent. According to the properties mentioned above, this antimicrobial stainless steel composite has low-cost and simple method for producing it leads to a promising future in antimicrobial applications.

### Failure of stainless steel implants

An orthopaedic implant stainless steel (SS) that failed prematurely was examined to determine the root cause for the fracture. Based on the results of extensive fracture surface analysis as well as the background information provided on the implant, it was determined that the implant failed by the mechanism of predominantly ductile fracture facilitated by the presence of non-metallic inclusions. An orthopedic implant is considered to have failed when it must be prematurely removed from the body<sup>16</sup>. Generally, there are two classes of failure-mechanical and biological. Once a foreign material is implanted; there are several ways in which the body may react unfavourably. The presence of the implant may inhibit the defense mechanisms of the body, leading to infection. Materials used in making implants must be inert or well tolerated by the body. The load on implant varies with position in walking cycle and reaches a peak of about four times the body weight at the hip and three times the bodyweight at the knee. Larger loads are assumed by the hip and knee joints during activities such as running and jumping. Orthopedic implants are exposed to the biochemical and dynamic environments of the human body; their design is dictated by anatomy and restricted by physiological conditions<sup>17</sup>. In every failure of an orthopedic implant, the concerned patient is made to experience the trauma of repeated surgeries, besides the severe pain experienced during the process of rejection of the device. The removal of the failed implant will cause great expense and hardship to the patient. Therefore, it is highly desirable to keep the number of failures to a minimum<sup>18</sup>.

The determination of the mechanism by which failure of an implant occurred is important, but it is also necessary to explore the event, or sequence of events, that had caused a particular mechanism or mechanisms to be operative. Furthermore, failure analyses can help improving the overall performance of implant devices through revision engineering. Only a few metallic alloys are in common use for implantation<sup>19</sup>. These are 316L stainless steel (SS), cast/wrought cobalt–chromium base alloys, and Ti–6Al–4V alloys.

### CONCLUSION

Various methods of surface modification or rough surface preparation in stainless steel and its alloys for implants were discussed with an emphasis on the methods based on the mechanical, thermal, chemical, and electrochemical and laser methods. It will be the ideal circumstance that the mechanical properties of bone substitutes are close to those of real human bone. But in consideration of too high strength of metal, the present artificial materials are rarely complete in conformity with human bone. Breakthroughs in fabrication techniques and new materials must be developed. Failure of SS nail for shinbones was predominantly by the mechanism of ductile fracture that occurred at the point of maximum bending in the SS nail implant.

### REFERENCES

1. Patil chetan Vitthal, Amrutkar Rupesh subhash, Bhavna. R. S, M. Ramachandran, Emerging Trends and Future Prospects of Medical Tourism in India, Journal of pharmaceutical sciences and research, 7(5), 2015, 248-251.
2. S.S.M. Tavares a, F.B. Mainier b, F. Zimmerman a, R. Freitas a, C.M.I. Ajus a, Characterization of Prematurely Failed Stainless Steel Orthopedic Implants, Engineering Failure Analysis, 17, 2010, 1246-1253.
3. Bill G. X Zhang, Damian E. Myers, Gordon G. Wallace, Milan Brandt, Peter F. M Choong, Bioactive Coatings for Orthopedic Implants-Recent Trends in Development of Implant Coatings, International Journal of Molecular Sciences, 15(7), 11878-11921.
4. Patil Chetan, Vitthal Chaudhary, Saurabh Sanjay, Bhavna R Sharma, M. Ramachandran, Need of Biomedical Waste Management in Rural Hospitals in India, Int. J. Pharm. Sci. Rev. Res., 35(1), 2015, 175-79.
5. Limei Chen a, Lin Zheng b, Yaohui Lv a, Hong Liu a, Guancong Wang a, Na Ren a, Duo Liu a, Jiyang Wang a, Robert I. Boughton c, Chemical Assembly of Silver Nanoparticles on Stainless Steel for Antimicrobial Applications, Surface & Coatings Technology, 204, 2010, 3871–3875.
6. Bhavna. R.S, M. Ramachandran, Need of Bhagavad Gita Concepts in the Present Scenario of Professional Education, International Journal of Applied Engineering Research, 10(11), 2015, 10570-10574.
7. M. Kiel, A. Krauze, J. Marciniak, Corrosion Resistance of Metallic Implants used in Bone Surgery, World Academy of Materials and Manufacturing Engineering, 30, 2008, 77-80.
8. MaxwellMurphy, Kang Ting, Xinli Zhang, Chia Soo, and Zhong Zheng, Current Development of Silver Nanoparticle Preparation Investigation and Application in the Field of Medicine, Hindawi Publishing Corporation, Journal of Nanomaterials, 2015.
9. Poushpi Dwivedi, Shahid S. Narvi and Ravi P. Tewari, Novel Scientific Appraisal of Elaeocarpus Ganitrus The Rudraksha: Nano Silver Synthesis with Aspects of Variation in Concentration Antimicrobial Activity and *in Vitro* Biocompatibility, Science Domain International, 4(7), 2014, 1059-1069.





10. LIU Wei, ZHOU QunFang, LIU JiYan, FU JianJie, LIU SiJin & JIANG GuiBin, Environmental and Biological Influences on the Stability of Silver Nanoparticles, Chinese Science Bulletin, 56, 2011, 2009-2015.
11. Kurgan Naci, Sun Yavuz, Cicek Bunyamin & Ahlatci Hayrettin, Production Of 316l Stainless Steel Implant Materials by Powder Metallurgy and Investigation of their Wear Properties, Chinese Science Bulletin, 57, 2012, 1873-1878.
12. M. Ramachandran, Benildus, Failure Analysis of Turbine Blade Using Computational Fluid Dynamics, International Journal of Applied Engineering Research. ISSN 0973-4562 Volume 10, Number 11, 2015, 10230-10233.
13. Feng XiaoJuan, Shi YanLong, Wang YongSheng, Yue GuoRen & Yang Wu, Preparation of Superhydrophobic Silver Nano Coatings with Feather-Like Structures by Electroless Galvanic Deposition, Chinese Science Bulletin, 58, 2013, 1887-1891.
14. Huang Qian-wei, Wang Li-ping, WangJin-ye, Mechanical Properties of Artificial Materials for Bone Repair, J. Shanghai Jiaotong Univ., 19(6), 2014, 675-680.
15. Ruggero Bosco, Jeroen Van Den Beucken, Sander Leeuwenburgh and John Jansen, Surface Engineering for Bone Implants: A Trend From Passive To Active Surfaces, 2, 2012, 95-119.
16. E. A. Ayob, D. M. El-zeer, and O. S. Shehata, Corrosion Protection of Stainless Steel used in Orthopedic Implants by Chemical and Physical Treatment, International Journal of Innovation and Applied Studies, 10, 2015, 1335-1349.
17. T. Sunder selwyn, R Kesavan, M. Ramachandran, FMECA Analysis of Wind Turbine Using Severity and Occurrence at High Uncertain Wind in India, International Journal of Applied Engineering Research. ISSN 0973-4562 Volume 10, Number 11, 2015, 10250-10253.
18. Bill G. X. Zhang, Damian E. Myers, Gordon G. Wallace, Milan Brandt and Peter F. M. Choong, Bioactive Coatings for Orthopedic Implants: Recent Trends in Development of Implant Coatings, International Journal of Molecular Sciences, 15, 2015, 11878-11921.
19. Rama Krishna Alla, Kishore Ginpalli, Nagaraja Upadhya, Mohammed Shammam, Rama Krishna Ravi, Ravichandra Sekhar, Surface Roughness of Implants: A Review, Trends Biomater. Artif. Organs, 25(3), 2011, 113-118.

**Source of Support:** Nil, **Conflict of Interest:** None.

