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Review Article

Corrosion Behaviour of Metallic Biomaterials in Simulated Ringer's Solution – An Overview

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Abstract

Corrosion of metal implants is critical because it can adversely affect the biocompatibility and mechanical properties. The materials used should not cause any adverse biological reaction in the body and, simultaneously, they must be stable retaining their functional properties. Several metals and alloys like tungsten, Ni-Ti, Ti-Al-V, Zr-Ti, Co-Cr-Mo have been used in bone defect fillings, tooth fillings. Hip joints etc, it is essential to know the corrosion resistance of this material in the presence of Ringer's solution. Usually the corrosion resistance of these materials is investigated by electrochemical studies such as polarization, AC impedance and cyclic voltammetry study. The nature of the film formed on the metal surface has been analysed by surface analysis techniques such as SEM, AFM, etc. Study of this review paper will be very useful and time saving to researchers who would like to investigate the corrosion resistance of biomaterials in synthetic body fluids. The research findings will be very useful to the medical field.

Keywords: corrosion resistance, metals, alloys, Ringer's Solution

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Introduction

The first requirement for any material to be placed in the human body is that it should be biocompatible and not cause any adverse reaction in the body. The material must withstand the body environment and should not degrade to a point that it cannot function in the body as intended. Corrosion and surface oxide film dissolution are the two mechanisms which introduce additional ions into the body. Extensive release of ions from prosthesis can result in adverse biological reactions leading to mechanical failure of the device. For example, release of nickel ion from 316LVM implant alloys may cause allergic effects in some patients. That is why metals used in the human body must have a high corrosion resistance. Corrosion is the destructive attack of a material by reaction with its environment. The serious consequences of the corrosion process have become a problem of worldwide significance. In addition to our everyday encounters with this form of degradation, corrosion causes plant shutdowns, waste of valuable resources, loss or contamination of product, reduction in efficiency, costly maintenance, and expensive over-design. It can also jeopardize safety and inhibit technological progress. Corrosion is an electrochemical reaction based on universal laws of nature. All metallic structures corrode. It is just a question of how quickly.

Steel, for example, is a man made substance produced from iron oxide. The energy added in the refining process is unstable. Given a suitable environment, steel will release this energy and return to its natural state of iron ore. When immersed in an electrolyte, such as soil, water, or concrete, metals produce a current which causes ions to leave their surface. The rate of current flow determines the life of the structure. One ampere of current consumes approximately 20 pounds of iron per year [1].

Biomaterial

Biomaterial is a material intended to interface with biological system to evaluate, treat, augment or replace any tissue, organ or function of the body. Biomaterials are used in dental implant, tooth fillings, vascular implants, bone defect fillings, Hip joint prosthesis bone plate, scaffolds for tissue engineering and contact lens [2].

Ringer's Solution

It is the name given to a solution of several salts dissolved in water for the purpose of creating an isotonic solution relative to the bodily fluids of an animal. Ringer's solution typically contains sodium chloride, potassium chloride, calcium chloride and sodium bicarbonate, with the latter used to balance the pH. Other additions can include chemical fuel sources for cells, including ATP and dextrose, as well as antibiotics and antifungal.

Table 1 Composition of Ringer Solution [3, 4, 5].

NaCl	6g/lit
KCl	0.075g/lit
$CaCl_2$	0.1g/lit
$NaHCO_3$	0.1g/lit

The influence of different artificial body fluids on metallic corrosion, all containing chloride ion, was investigated by measurements of open circuit potential, polarization curves and electrochemical impedance on high speed steel, chosen owing to its high rate of corrosion. Different artificial body fluids, all containing the aggressive chloride ion, can influence the metallic corrosion process. Body fluids, are aqueous solutions of organic and inorganic substances including mainly the Cations Na+, K+, Ca+ and Mg+ and Anions Cl-, HCO_3, SO_4^- and those of acids [6, 7].

Metals and Alloys

Many investigators have examined the corrosion rates of various metals exposed to different atmospheres [8-13]. Exposure studies were conducted to evaluate the relative corrosion resistances of various metals to different atmospheric environmental conditions. It is well accepted that the cost of material deterioration in an atmospheric environment is enormous, and that almost one-half of this cost is due to the corrosion of steel [4], [83-86]. Therefore, galvanized protective coatings are essential for the economic use of steel. Tungsten [19], Ni-Ti [20, 33, 42, 46, 63], Fe [21], Ti-Al-V [22, 24, 27, 51, 54, 66-69, 72], Ti-Mo [26], Zr-Ti [30], Ti [39, 41, 48, 52, 62], Co-Cr, MoTi [59], Stainless Steel [28, 29, 31, 64, 74], Pd-Ti [25], Hf-Zr Cr [23], Ti-Ta-Nb [45], Co, Cr, Mo, SS [32], have wide applications both contemporary and historic. These are the main materials used in electrical power lines because of their high conductivity. These materials also have several applications in the electronic and electrochemical industries. In addition, copper and its alloys have good resistance against atmospheric corrosion [16] and are resistant to bio-fouling [17]. Corrosion losses of Fe, Cu, Zn [15] and Al were found to depend on relative humidity, wetting time, amount of chloride and presence of SO_2 in the atmosphere. High corrosion rates in industrialized areas have therefore been related to the high SO_2 concentrations present in these areas [18].

Table 2 Biomaterials in Simulated Ringer's Solution

S. NO	Metals	Medium	Methods	Findings	Ref.
1.	Tungsten	Ringer's Solution	Weight loss method	Cytopathologic effects of tungsten on cultivated human arterial endothelial cells, human vascular smooth muscle cells and human dermal fibroblasts.	19
2.	Titanium nitride coated Ni-Ti	Ringer's Solution	X-Ray diffraction (X-ray), Scanning electron microscopy (SEM), Energy dispersive spectrometry (EDS) & Polarization study	An important point to be noted is that NiTi surgical devices can undergo significant deformations associated With the shape memoryeect or super elasticity.	20
3.	Fe based alloys	Ringer's Solution & 0.9 % NaCl+HCl	Electrochemical polarization analysis	The corrosion resistance of the amorphous alloys Fe55_xCr18-Mo7B16C4Nbx (x¼0 and 3at%) is much higher than that of nanocrystalline counterparts and 316 LSS. Besides, the presence of Nb plays an important role in enhancing the corrosion behavior of the alloys	21
4.	Ti-Al-V with Nitride	Ringer's Solution	X-ray analysis, Scanning electron microscopy (SEM), IPC Pro-Potentiostat, Polarisation study	Corrosion resistance of alloy increases with the content increase of TiN phase in nitride Coating. With increase of temperature from	22

				36 to 40_C the corrosion resistance of alloy is determined Significantly by quality of nitride coating.	
5.	Hf-ZrCN coatings	Ringer's Solution	XPS, X-ray diffraction analysis, atomic force microscopy (AFM) using an INNOVA (Veeco) microscope, Potentiodynamic polarization	Corrosion resistance, Tribological and biocompatible properties, in order to improve the performance and service life of the orthopedic systems	23
6.	Hydroxyapatite coatings on TiAlV	Ringer's Solution	Electrochemical impedance spectroscopy	The corrosion behaviour of surgical implant alloys, even when they are coated With a ceramic material such as Hydroxyapatite.	24
7.	Pd-Ti alloys	Ringer's Solution	X-ray diffraction, SEM, EDAX,	Corrosion resistance, biocompatibility and acceptable casting temperatures for porcelain fused-to-metal dental prostheses	25
8	Ti–Mo alloys	Ringer's Solution	EDX, XRF and SEM.XRD	Valve metal behavior and good corrosion resistance	26
9	Ti–Al–V alloy	Ringer's Solution	Potentiodynamic polarization measurements, Scanning electron microscopy	The effects of heat treatment on the weldment microstructure and corrosion properties	27
10	316L stainless steel	Ringer's Solution	SEM, weight loss method, EDX	Corrosion behavior of powder injection molded 316L stainless steel parts sintered in vacuum	28
11	Hydroxyapatite coatings on HNO3 passivated 316L SS	Ringer's Solution	Cyclic anodic polarization experiments and Impedance analysis	HNO3 passivation is found to have a tremendous impact on the corrosion resistance of 316L SS. 40% acid treatment is characterized by the increase in the corrosion resistance of 316L SS compared to the other treatment conditions.	29
12	ZrTi alloys	Ringer's Solution	Cyclic Potentiodynamic polarization (CCP), Electrochemical impedance spectroscopy (EIS), Scanning electrochemical microscopy (SECM), Scanning electron microscopy (SEM)	Potential use as biomaterials to replace Ti-based alloys containing Al and V	30
13	Hydroxyapatite coatings on borate passivated 316L SS	Ringer's Solution	Potentiodynamic polarization, Electrochemical impedance and cyclic Voltammetry (CV). Also X-ray diffraction (XRD) and Scanning electron microscopic (SEM)	Implant material in orthopedic surgeries & this method can be utilized in developing HAP coatings on Stainless steel biomedical implant materials.	31
14	Co Cr Mo and F138 316L stainless steel	Ringer's Solution	Deferential pulse polarography, atomic emission spectroscopy	The capabilities of the Microtox method for addressing biocompatibility issues beyond that demonstrated Previously.	32
15	NiTi	Ringer's Solution	Cyclic Potentiodynamic polarization	The electrochemical behaviors of thin film NiTi SMA prepared by sputtering have been investigated	33

				through a systematic comparison between thin film and the bulk metal	
16	Titania reinforced Hydroxyapatite with 316L SS	Ringer's Solution	FT-IR, XRD, Thermogravimetry and SEM, EDXS	The cold spray process can be an efficient technique to produce coatings from various chemical Compositions of powders with fine grain structure.	34
17	TiNbTaZr alloy	Ringer's Solution	Open circuit potential, Electrochemical impedance spectroscopy (EIS) and Potentiodynamic polarization methods	Corrosion resistance and cytotoxicity were evaluated	35
18	Co-Cr brazed with gold	Ringer's Solution	SEM, Dispersive Electron Microprobe, Optical microscopy.	Alloy is proved to be a suitable biodegradable metallic material with shape memory function	36
19	Tytin	Ringer's Solution	open circuit potential, polarization curves, cyclic voltammetry and Electrochemical impedance	All these factors demonstrate the importance of amalgam preparation and of choice of the artificial body fluids for in vitro studies in the detailed Investigation of corrosion process occurring in the oral cavity.	37
20	Mercury	Ringer's Solution	Ultraviolet spectrophotometer, polarization curves	Effect of corrosion and aging on the mercury vapor emission of dental amalgam	38
21	Ti alloys	Ringer's Solution	Plasma optical emission spectrophotometer, Open circuit potential (OCP)	In the present work exhibit passive Region in their Potentiodynamic behavior.	39
22	Zirconia coatings on AISI 316L	Ringer's Solution	X-ray diffract grams, Open-circuit potential (OCP) measurement, Impedance, Polarization Study.	The application of the coating and may be useful for implants and Surgical instruments to enhance corrosion and wear resistance.	40
23	Ti	Ringer's Solution	X-ray spectroscopy (EDX) and Raman spectra analysis	The main finding was that the galvanic combination of titanium and stainless steel did not accelerate the corrosion in the plating system.	41
24	NiTi	Ringer's Solution	Potentiodynamic polarization, Impedance spectroscopy	Electrochemical behavior of nickel titanium (NiTi) orthodontic wires in a solution Containing Streptococcus mutans oral bacteria.	42
25	Hydroxyapatite coated type 316L stainless steel	Ringer's Solution	Open circuit potential, Potentiodynamic cyclic polarization and Electrochemical impedance experiments, XRD	Biocompatible and bioactive ceramic, capable of interacting and bonding chemically with the surrounding bone. In clinical applications of dental reconstruction and hip replacement	43
26	S-phase	Ringer's Solution	Reciprocating wear test, Optical micro- scope.	S-phase hardened austenitic stainless steels could compete against more expensive alloys such as Co–Cr alloys in metal-on-metal wear applications in the biomedical industry.	44
27	Ti–Ta–Nb	Ringer's Solution	XRD, cyclic Potentiodynamic and the linear polarization methods	The melting process and thermo mechanical treatment under high vacuum or neutral atmosphere	45
28	NiTi	Ringer's	XRD and SEM,EPMA	PIRAC nitriding procedure can	46

		Solution		become an attractive surface treatment for NiTi surgical implants.	
29	CoCrMo	Ringer's Solution	Scanning electron microscopy, nanoindentation, AFM and Scratch test	Tribological and corrosion testing of surface engineered surgical grade	47
30	Ti	Ringer's Solution	Scanning Electron Microscope, High Resolution Optical Microscope, EDX	Bone–implant interface with fretting Contacts	48
31	Ti–Mo–Ta	Ringer's Solution	X-ray diffraction, open-circuit potential (OCP),linear Potentiodynamic polarization	As titanium alloys are to be used as implants or prostheses, they must be highly biocompatible and have essential properties such as a good resistance to corrosion	49
32	Alkali-manganese	Ringer's Solution	Electro-chemical reactions	Limited injury factor on the electric discharge in body	50
33	Ti-Al-V and Ti-Al-Fe	Ringer's Solution	EIS, open circuit potential	The effects of electrochemical and thermal oxidation on the behavior	51
34	Titanium	Hank's solution	High-resolution Transmission electron microscopy, Ion beam technology.	Artificial joints, bone plates, and dental implants	52
35	SUS316L stainless steel, Co-Cr alloy and Ti-Al-V	Ringer's, PBS(-) and Hank's solutions	Potentiodynamic method, electrochemical impedance experiments	Benefits the biomaterials against corrosion & effect of PH on the corrosion behavior of biomaterials.	53
36	Ti-Al-V	Ringer's Solution	Electrochemical polarization experiments	Improve its properties, such as microstructure, corrosion, and wear for biomedical applications	54
37	Bio-ceramic alumina	Ringer's Solution	SEM and AFM	Replacement parts in hip and knee operations. The inertness of the ceramic, its high wear resistance and its excellent biocompatibility make it the ceramic of choice. The high load-bearing properties of alumina also make it an ideal ceramic for dental implants.	55
38	Silica Glass Coatings on 316L SS	Ringer's Solution	Fourier transform infrared spectroscopy, X-ray diffraction studies, and scanning electron microscopy, open-circuit potential, electrochemical impedance spectroscopy,) cyclic polarization	Evaluation of its Corrosion Resistance Behavior	56
39	Mg–Zn–Mn	Ringer's Solution	Electrochemical impedance spectroscopy, scanning electron microscopy, X-ray spectroscopy	Formation of a partially protective $Mg(OH)_2$ surface film whose protective capabilities are increased by the alloying elements, development of degradable implants, such as screws, plates, and rods	57
40	Mg–6%Zn–$Ca_3(PO_4)_2$	Ringer's Solution	Electrochemical corrosion tests	To investigate the mechanical properties, powder-metallurgy	58

				sinter method and their corrosion properties are tested, composites obtain properties including density, Young's modulus, and strength similar to natural bone	
41	CoCrMoTi	Ringer's Solution	Potentiodynamic curves	Corrosion behavior of several experimental dental alloys, the influence of titanium alloying on corrosion behavior in two simulated body fluids	59
42	AISI 304 Grade Stainless Steel	Ringer's Solution	Surface mechanical attrition treatment (SMAT)	To improve the materials properties and performance, surface roughness, induced the formation of mechanical twins, strain induced martensite phase, and increased the defect density, which is a function of the size of the balls and treatment time	60
43	Zr-2.5Nb and Zr-1.5Nb-1Ta	Ringer's Solution	Open circuit potential and electrochemical impedance spectroscopy (EIS) measurements	Use as implant materials have been assessed and compared with those of Grade 2 Ti, which is known to be a highly compatible metallic biomaterial, crystalline alloys promising biomaterials for surgical implants.	61
44	Titanium base alloy	Ringer's Solution	Human fetal osteoblast cell line FOB 1.19. Cytocompatibility	self-passivation, with a large passive potential range and low passive current densities, namely, a very good anticorrosive resistance in Ringer solution of acid, neutral and alkaline PH values. Cell viability was not affected by the alloy substrate presence and a very good compatibility was noticed.	62
45	NiTi-based alloy	Ringer's Solution	Open circuit potential (OCP)	Importance of evaluating the corrosion resistance of Nitinol under realistic conditions (mechanical loads, wear and fatigue) in order to establish multifaceted mechanisms that might lead to accelerated dissolution and failure of implanted stents	63
46	Stainless steel	Ringer's Solution	Potentiodynamic polarization method and electrochemical impedance spectroscopy (EIS)	The formation of soluble complexes of metal ions with chelating agents, especially EDTA, which suppressed the formation of the outer Fe(III) layer of the passive film	64
47	MP35N	Ringer's Solution	Open-circuit potential, anodic polarization, potentiostatic control, electrochemical impedance spectroscopy, and linear voltammetry techniques, scanning electron spectroscopy, energy dispersive spectrum	Very high corrosion-resistant material and has been widely used in various medical applications	65

48	Stainless steel 316L and Ti–6Al–4V	Ringer’s Solution	Open circuit potential (OCP)	Laser surface engineering has been explored as a possible method for improving the functional surface properties of biomedical materials	66
49	Titanium (CPT), Ti-6Al-4V (TAV), Ti-Ni (TN), Co-Cr-Mo alloy (CCM), 316L stainless steel	Ringer’s Solution	Potentiodynamic polarization method and electrochemical impedance spectroscopy (EIS)	To investigate the corrosion behavior of dental metallic materials in the presence of Streptococcus mutans and its growth byproducts	67
50	Titanium and of the Ti-6Al-4V	Ringer’s Solution	Potentiodynamic polarization method and electrochemical impedance spectroscopy (EIS	Comparison with base metal, in solutions which reproduce the corrosion environment from the oral cavity (artificial saliva) and from adiacent tissues of the oral implants	68
51	Ti-6Al-4V and Ti-5Al-2.5Fe	Ringer’s Solution	Potentiodynamic polarization method and electrochemical impedance spectroscopy (EIS	PH changes which can generate the potential and current gradients like these simulated in this paper and so it exists the possibility of local acceleration of the corrosion on some areas of the implant.	69
52	Ti-5Al-2.5Fe	Ringer’s Solution	energy-dispersive X-ray (EDX) analysis	implant material not only for artificial hip joints but also for instrumentations of scoliosis surgery	70
53	commercial (GSP) and a prototype titanium	Ringer’s Solution	SEM	between the two designs suggest that the problem can be minimized or eliminated with an accurately designed taper fitting	71
54	Ti-6Al-4V alloy or 316L stainless steel	Ringer’s Solution	X-ray diffraction and glow discharge spectroscopy, wettability, nuclear reaction, electron spectroscopy for chemical analysis, attenuated total rejection IR spectroscopy and electron spin resonance measurements	The present study reports a wear rate decrease of the polymer cups, rubbing against metals, as a result of ion implantation (nitrogen, argon) of the polyethylene.	72
55	Co-Cr and Ni-Cr	Ringer’s Solution	SEM	The influence of heat treatments on the corrosion resistance of some base-metal alloys currently used in dentistry as a base for porcelain substrate systems has been investigated	73
56	Stainless steel	Ringer’s Solution	Instrumental neutron activation analysis	The extent to which the distribution patterns of steel-specific elements in animal (and human) tissues can be explained by the dissolution of the steel during the passivation process is discussed	74
57	316-L stainless steel	Ringer’s Solution	Anodic polarization and pulse- potentiostatic capacitance methods	The influence of surface preparation and, in particular, to the optimization of electro polishing time which acts to produce a microscopically smooth surface, free of debris and disarrayed material.	75

58	Titan-Based Alloy	Ringer's Solution	Potentiodynamic polarization method	The corrosion behaviour of high entropy in human physiological simulating media	158
59	Mg Alloys	Ringer's Solution	X-Ray diffraction (XRD) method and electron microscopy	The degradation behaviour of Mg alloys	159
60	Mg-based metallic glass	Ringer's Solution	TEM,SEM,XRD	To determine the amount of evolved hydrogen	160

Medium

The inhibition efficiency of various inhibitors on controlling corrosion of metals and its Alloys in artificial body fluids like Ringer's solution [19-51], [53-82] has been studied.

Temperature

Usually, the study is carried out at 37 ^oC.

Methods

Usually to measure corrosion resistance of biomaterials, electro-chemical studies such a Potentiodynamic polarization [20, 22, 23, 27, 30, 31, 35, 37, 38, 40, 42, 43, 45, 49, 53, 54, 62, 67, 68, 70-72], electro chemical impedance spectra [24, 29-31, 35, 37, 40, 42, 43, 46, 51, 53, 56, 57, 64, 67, 68, 70-86], and Weight loss method [19, 28], have been employed. From these studies, corrosion parameters such as corrosion potential, corrosion current, linear polarisation resistance, Tafel slopes, double layer capacitance, charge transfer resistance, phase angle value have been calculated and compared. When corrosion resistance increases, LPR value increases; corrosion current decreases; charge transfer resistance increases and double layer capacitance decreases [78].

Surface analysis

The film formed on the metal surface has been analyzed by surface analysis techniques Such as SEM [20, 22, 25-28, 30, 31, 34, 36, 46, 47, 48, 55-57, 68, 74, 76], EDAX [25, 26, 28, 34, 48, 73], X-Ray [20, 22, 23, 25, 31, 40, 41, 49, 56, 57, 75] and AFM [23, 47, 55], XRD [26, 34, 43, 45, 46], EDS [20, 68], XPS [23] XRF [26], OCP [35, 37, 39, 40, 43, 49, 51, 56, 64, 67, 68, 69], Differential Pulse Polarographic [32], FTIR [34, 56], Raman [41], Electrochemical Polarization analyse [21], Potentiostat [22], Cyclic Anodic Polarization [29, 33, 56, 68, 77], Cyclic voltammetry [31], [68], Dispersive Electron Microscope [36], Optical microscopy [36], UV–Spectroscopy [38], Plasma optical emission spectroscopy [39], Reciprocating wear test [44], Optical microscope [44]. IR [72], EPR [72] Electro pro micro analysis [54], Instrument neutron activate analysis [74], Wet ability [72] Surface mechanical attrition treatment [60], Nano indentation [47], High resolution optical microscope [48] Electrochemical reaction [50, 58, 72], High resolution transmission electron microscopy [52], Ion beam technology [52].

Conclusion

This review paper will be useful to a researcher who would like to select inhibitors to control of corrosion of metals and its alloys in body fluids. Especially this will be useful in contact lens, tooth fillings etc.

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