Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2012, 4(1):203-208

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Potentiodynamic polarization study of Type 316L and 316LVM stainless steels for surgical implants in simulated body fluids

Mohd Talha, C. K. Behera and O. P. Sinha*

Centre of Advanced study, Department of metallurgical Engineering, Institute of Technology,
Banaras Hindu University, Varanasi (U P), India

ABSTRACT

Corrosion of metal implants is critical because it can adversely affect the biocompatibility and mechanical integrity. The aim of this research is to compare the electrochemical corrosion behaviour of two biomedical alloys, 316L and 316LVM stainless steels in simulated body fluid (SBF) at 37°C. This temperature is equivalent to human body temperature. The SBFs used in this study were Hank's solution and Ringer's solution. This comparison is focused on passive behavior of the alloys using electrochemical potentiodynamic polarization study. Analysis of electrochemical parameters indicated that 316L stainless steel was more susceptible to pitting corrosion than 316LVM in SBF. It can be seen that corrosion potential (E_{corr}) for 316LVM is nobler(more positive) indicating that type 316LVM stainless steel is more corrosion resistant than type 316L stainless steel in SBF. The high corrosion susceptibility of type 316L was due to surface passive film with less protective to reveal high anodic dissolution rate.

Keywords: SBF, polarization, pitting, alloy.

INTRODUCTION

Biomedical materials play an important and a critical role in manufacturing a variety of prosthetic devices in a modern world. Prosthetic devices are artificial replacements that are used in a biological system, such as the human body in an effort to provide the function of the original part. These devices are generally made of polymeric, metallic and ceramic materials, or combinations of these materials, depending on the intended use [1].The demand for metallic materials in medical devices is large. Metallic materials are widely used as biomedical materials and are indispensable in the medical field. In particular, toughness, elasticity, rigidity, and electrical conductivity are essential properties for metallic materials used in medical devices. [2, 3]. Conventionally, metallic materials are essential for orthopedic implants, bone fixators, artificial joints, external fixators, etc. since they can substitute for the function of hard tissues in orthopedic. Specifically, stainless steels and Co-based alloys, pure titanium, and titanium alloys are widely used as orthopedic implants materials in clinical practice [2, 4].

The performance of a biomaterial is determined by its chemical, physical and biological properties [5]. 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 not degrade to a point that it cannot function in the body as intended [1]. One of the most important issues in the use of metallic biomaterials is their corrosion behaviour [6-9]. Corrosion is the first consideration for a material of any type that is to be used in the body because metal ion release takes place mainly due to corrosion of surgical implants [10]. Corrosion of metal implants is critical because it can adversely affect the biocompatibility and mechanical integrity [1]. Because of the high concentration of Cl^- and the temperature range of 36.7–37.2 °C, the human body fluid is considered a severely corrosive environment and localized corrosions such as pitting and crevice corrosion [11].

Specifically, stainless steels and Co based alloys are highly biocompatible biomaterials widely used as orthopedic implants materials in clinical practice [4]. Stainless steel is one of the representatives of metallic biomaterials. This is mainly due to their good corrosion resistant properties. The stainless steels typically used in medicine are austenitic stainless steels. These stainless steels contain 17–20%Cr, 13–15% nickel, 2–3% molybdenum and small amount of other elements [12]. The notation ‘‘L” indicates that the steel has a low carbon content (<0.03%) and is therefore not susceptible to intergranular corrosion due to precipitation of Cr-carbides at the grain boundaries. Stainless steel implants are used as temporary implants to help bone healing, as well as fixed implants such as for artificial joints. In terms of corrosion resistance in the human body, stainless steels are inferior compared to cobalt–chromium alloys and titanium alloys [13, 14]. 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 [15].

Presence of Cr results in the formation of a thin, chemically stable, and passive oxide film on the surface of the stainless steels [16]. The oxide film forms and heals itself in the presence of oxygen. The physico-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 [17]. 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 [18].

316LVM stainless steel is low carbon vacuum melted alloy. So it is more pure than 316 L stainless steel. The elemental composition of both the stainless steels is more or less same. So the need of present study is to compare the corrosion behaviour of these two stainless steels, which will provide an option for adopting a better orthopedic implant considering the cost of these two alloys.

The aim of this research deals with study to compare the electrochemical behaviour of two biomedical alloys, 316L and 316LVM in two different SBF solutions. This investigation has been performed using electrochemical techniques viz., potentiodynamic polarization study,

In this study, the potentiodynamic polarization tests in different simulated body fluids (SBF) at 37 °C were performed to evaluate the corrosion behavior of the 316L and 316LVM stainless steels.

EXPERIMENTAL SECTION

2.1. Specimens: Medical grade 316L and 316LVM stainless steels were obtained from Mishra Dhatu Nigam Limited (MIDHANI), Hyderabad, India. These steels were received in hot rolled & annealed condition in the form of 20 mm diameter and 300 mm long rod. The chemical compositions of 316L and 316LVM stainless steels are given in Table 1.

Table 1: Composition of Stainless steels

Steel	C	Mn	Si	S	P	Cr	Ni	Mo	N	Fe
316L	0.021	1.56	0.71	0.002	0.015	17.20	14.10	2.51	0.060	Bal.
316LVM	0.021	1.68	0.24	0.004	0.007	17.24	14.42	2.83	0.069	Bal.

Specimen with of 8.4 mm diameter and 0.554 cm^2 surface area was cut, abraded up to 800 grit emery paper and mirror polished with alumina, washed with distilled water followed by acetone before testing the materials.

2.2. Electrolytes**:** The SBFs used in this study were the Hank's solution and Ringer’s solution that were prepared by mixing the analytical grade reagents and triple distilled water, with pH value of 7.4±0.2. Compositions of the SBFs are listed in Table 2. The electrolyte of about 900 ml was used and temperature was maintained at 37 ºC (98.4 F) open to air by a water-bath throughout the whole investigations. This temperature is equivalent to human body temperature [19-21]. The accuracy of temperature maintained in the present investigation is ± 0.5 ºC.

Table 2: Composition of SBF (g/L) [1, 22]

Components	Hank's solution	Ringer's solution
NaCl	8.0	9.0
KCl	0.40	0.40
$CaCl_2$	0.14	0.25
$NaHCO_3$	0.35	0.20
$Na_2HPO_4.2H_2O$	0.06	
KH_2PO_4	0.60	
$MgSO_4.7H_2O$	0.06	
$MgCl_2.6H_2O$	0.10	
Glucose	1.0	

2.3. Polarization Tests: The polarization tests were carried out using a three-electrode cell assembly at 37 ºC steel specimen with 0.554 cm^2 surface area to study the corrosion behavior of 316L and 316LVM stainless steel in SBFs. All electrochemical experiments were performed in Gamry electrochemical cell with three electrodes connected to Gamry Instrument Potentiostat/Galvanostat with a Gamry framework system based on ESA 400. Gamry applications DC 105 software that is controlled by a computer was used to measure the polarization curves of the steels. The standard calomel electrode (SCE) was used as reference electrode, graphite electrode was used as a counter electrode and stainless steels samples were the working electrodes. All potentials were measured versus SCE.

The specimen was immersed into the solution for about 30 min to make its open circuit potential (Eocp) become stabilized and then the potentiodynamic polarization was performed. Potentiodynamic polarization curves were obtained by changing the electrode potential automatically from -150 to +150 mV versus E_{OC} with scan rate of 1 mV s^{-1}. All the measurements were repeated at least three times, and a new solution was used if a new polarization test was performed.

RESULTS AND DISCUSSION

3.1 ***Open circuit potential (OCP):*** One simple way to study the film formation and passivation of implants/alloys in a solution is to monitor the open-circuit electrode potential as a function of time. A rise of potential in the positive direction indicates the formation of a passive film and a steady potential indicates that the film remains intact and protective. A drop of potential in the negative direction indicates breaks in the film, dissolution of the film, or no film formation.

An open-circuit potential as a function of time for two materials tested in SBF in the present investigation is given in Figure 1(a) and Figure 1(b). It is clear that, the evolution of the OCP with time is same for both the tested materials i.e. 316L and 316LVM stainless steels in both the solutions, showing a continuous shifting towards more positive values with time which clearly indicates the formation of a protective passivation layer on their surfaces. Further, more shift in the positive direction for Type 316LVM stainless steel has observed. This suggested that Type 316LVM stainless steel is more corrosion resistant in SBF.

3.2 ***Potentiodynamic polarization study:*** Fig. 2(a) and Figure 2(b) show the typical polarization curves of 316L and 316LVM stainless steels in Ringer's and Hank's solution. These polarization curves can be divided in several potential domains. The cathodic domain includes potentials below -475 mV(SCE) where the current can determined by the reduction of water and partially of dissolved oxygen. The potential domain comprised between -475 mV(SCE) and -350 mV(SCE) is characterized by the transition from cathodic to anodic current at the corrosion potential. The another domain corresponds to the passive plateau and ranges from -300 to -150 mV(SCE), before passivity was broken due to pitting corrosion. In the passive region, 316LVM shows the pitting potential shifted towards more positive values and 316L produces the same effect in a lesser extent.

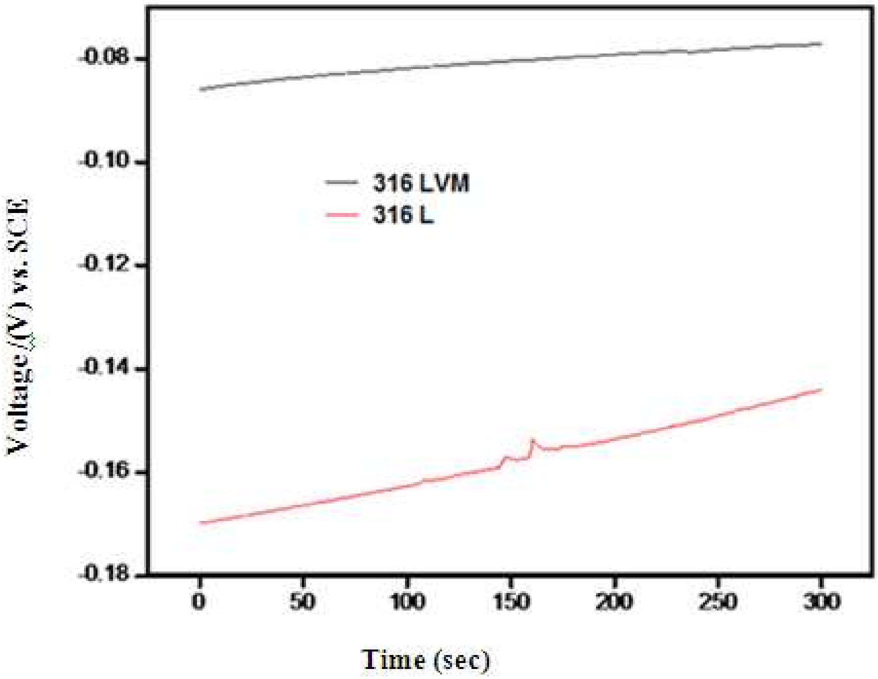

Figure 1(a): Open circuit potential as a function of time for 316 L and 316 LVM stainless steel in Ringer's solution at 37°C.

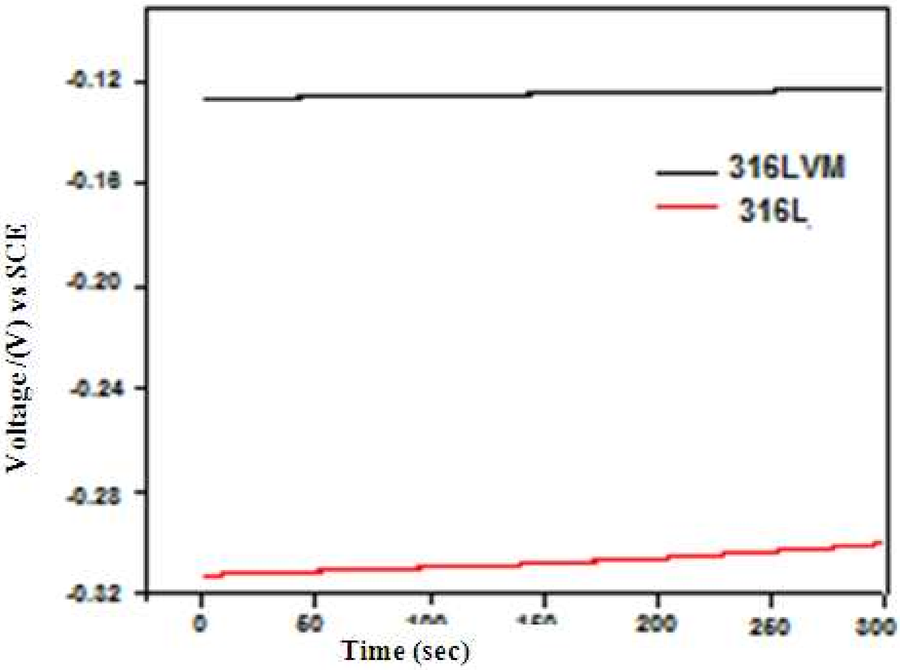

Figure 1(b): Open circuit potential as a function of time for 316 L and 316 LVM stainless steel in Hank's solution at 37°C.

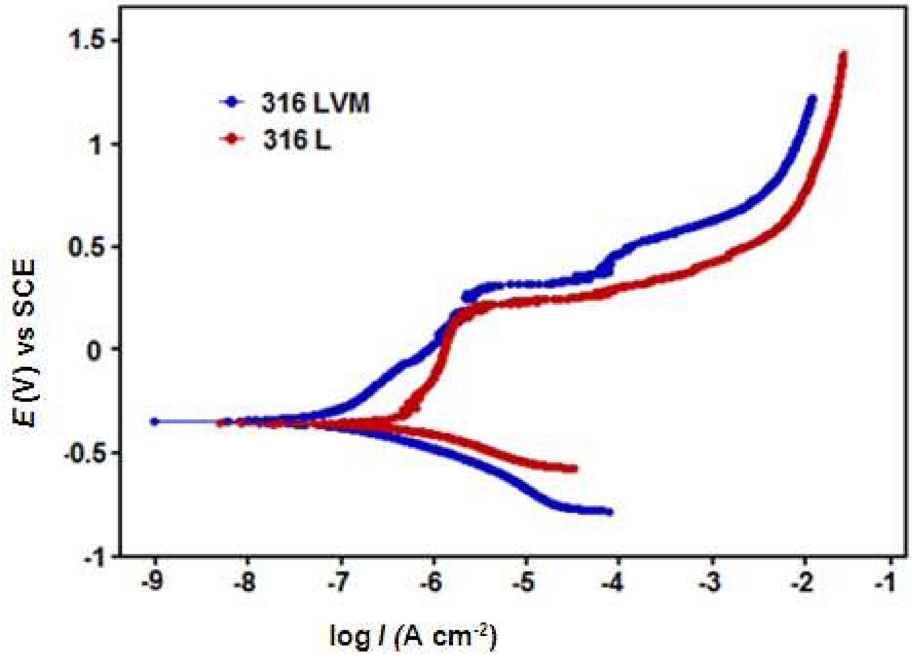

Figure 2(a): Polarization curve for 316L and 316LVM stainless steel in Ringer's solution at 37°C

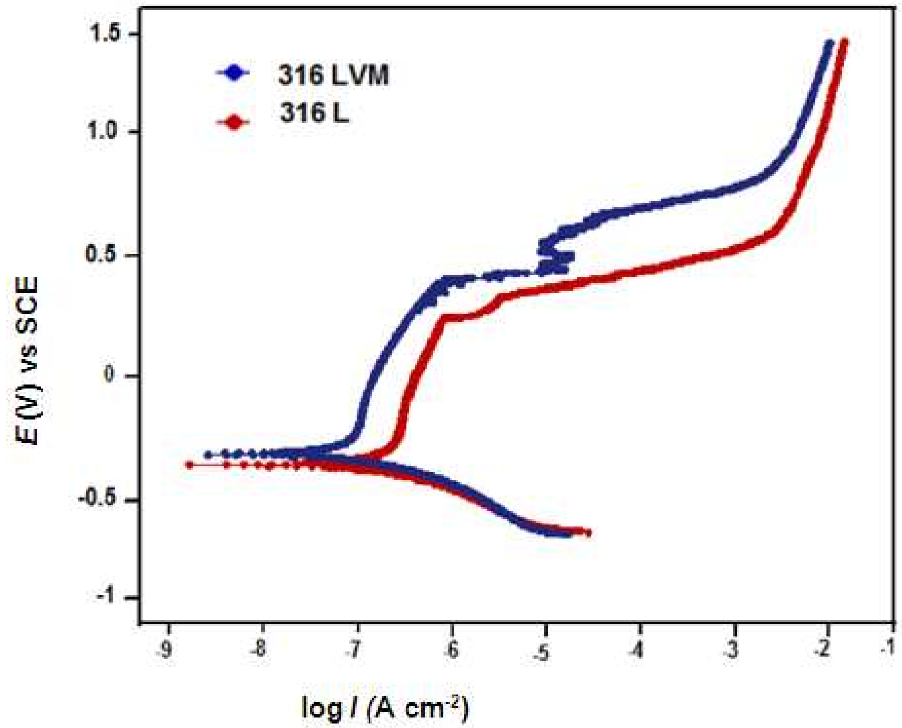

Figure 2(b) Polarization curve for 316L and 316LVM stainless steel in Hank's solution at 37°C

Table 3 shows the electrochemical parameters of the 316L and 316LVM stainless steels in SBFs. It can be seen that corrosion potentials for 316LVM is nobler (more positive) than 316L in both the solutions, indicating that former is more corrosion resistant than later in SBF. The values of corrosion current densities also support this observation.

Table 3: Polarization parameters for 316LVM stainless steel in SBFs

Steels	Ringer's solution			Hank's solution		
	E_{corr} (mV/ SCE)	I_{corr}(nA cm^{-2})	Corrosion Rate (mpy)	E_{corr}(mV / SCE)	I_{corr}(nA cm^{-2})	Corrosion Rate (mpy)
316L	-359	103.6	84×10^{-3}	-356	288.0	5.98×10^{-3}
316LVM	-346	96.3	73×10^{-3}	-342	76.60	1.5×10^{-3}

CONCLUSION

1. More shift of OCP in the positive direction for 316LVM stainless steel than 316L stainless steel was observed in SBFs. Shifting towards more positive values with time clearly indicates the formation of a more protective passivation layer on surface of 316LVM stainless steel, indicating that it is more corrosion resistant.
2. Polarization measurements reveals that corrosion potential for 316LVM stainless steel is less negative than 316L stainless steel, indicating that former is more corrosion resistant than later in SBFs.
3. The higher corrosion susceptibility of 316L stainless steel was due to less protective surface passive film, results in high anodic dissolution rate. The values of corrosion current densities also support this observation.

Acknowledgements
One of the authors, Mohd Talha is pleased to acknowledge the financial support as Junior Research Fellowship provided by the University Grant Commission (UGC), New Delhi, India.

REFERENCES

[1] J. *Materials Characterization*, **2002**, 49, 73– 79.
[2] C.V. Vidal, A.I. Muñoz *Corrosion Science*, **2008**, 50, 1954–1961.
[3] M. Sumita, T. Hanawa, S.H. Teoh, *Mater. Sci. Eng. C*, **2004**, 24, 753–760.
[4] K.S. Katti, *Colloids Surf. B Biointerfaces*, **2004,** 39, 133–142.
[5] B.D. Ratner, A.S. Hoffman, F.J. Schoen, J.E. Lemons, Biomaterials science: an introduction to materials in medicine. San Diego: Elsevier/ Academic Press, **2004**.
[6] A.C. Fraker, Corrosion of metallic implants and prosthesis devices. In: ASTM metals handbook (9th ed.). Corrosion. Metals Park, OH: ASM International, **1987,** 13, 1324–35.,
[7] M.F. Leclerc, Surgical implants. In: ASTM metals handbook (9th ed.) Metals Park, OH: ASM International, **1987**, 2, 164–80.
[8] J.J. Jacobs, J.L. Gilbert, R.M. Urban. *J Bone Joint Surg* **1990**, 80-A, 268–82.
[9] S.G. Steinemann, *Metal implants and surface reactions, Injury* **1996**, 27:SC, 16–22.
[10] M. Donachie, Biomedical alloys. *Adv Mater Process* **1998**, 7, 63– 65.
[11] H. Yang, K. Yang, B. Zhang, *Mater. Lett.* 61, **2007**, 1154–1157.
[12] A.J. Sedriks. Corrosion of stainless steels. New York: Wiley, **1996**.
[13] Y. Nakayama, T. Yamamura, Y. Kotoura, M. Oka, *Biomaterials*, **1989**, 10, 420.
[14] M. Morita, N. Nakamura, Y. Tsukamoto, T. Sasada, *J. Jpn. Soc. Biomater.* **1992**, 10, 209.
[15] M. Sumita, *Orthop. Surg*., **1997**, 48, 927.
[16] Y. Okazaki, E. Gotoh, *Corros. Sci.,* **2008**, 50, 3429–3438.
[17] A. Shahryari , S.Omanovic , J. A. Szpunar , *Materials Science and Engineering* C, **2008**, 28, 94–106.
[18] C. Tang, S. Katsuma, S. Fujimoto, S. Hiromoto, *Acta Biomaterialia*, **2006**, 2, 709–715.
[19] I. Gurrappa, M. Kiran Kumar, Proceedings of Global 2000 Corrosion Meet, Mumbai, India, Quest Publications, Mumbai 1, **2000,** 561– 72.
[20] P. Kumar, A.J. Hicki, A.I. Asphahani, A. Lawley, *ASTM Spec Tech Publ* 859, **1985**, 30-41.
[21] I. Gurrappa, *Corros. Prev. Cont*., **2001**, 48, 23–37.
[22] Rare metals, Feb **2010**, 29(1), 37.