The Quantification of Corrosion Damage for Pre-stressed Conditions: A Model Using Stainless Steel

Selin Munir^{1,2} · William R. Walsh¹

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Abstract Stainless steel is used extensively within orthopaedics as part of varying surgical procedures such as trochanteric osteotomy, sternum closure, patella tendon repair and reconstruction, patellofemoral ligament reconstruction and internal fracture fixation. This study examines the changes in corrosion behaviour after applying plastic and elastic stresses. Furthermore it analyses how a tensile and a compressive load can affect the corrosion susceptibility of a material. Stainless steel test specimens were divided into three groups of seven to determine how corrosion susceptibility will change when a material is pre-stressed. Potentiodynamic testing was performed to investigate the pitting behaviour of ss304 after being exposed to pre-stressed conditions. All images graded exhibited both area and pit corrosion scores, which significantly differed between the 3 groups ($p < 0.001$). The samples that were destructively stressed under compression had a mean of 35.5 % corrosion damage (SD 14.5) which is significantly greater ($p = 0.001$) compared to a mean of 11 % (SD 4.5) corrosion damage present with a material destructively stressed under tension. This study has shown that a material's corrosion susceptibility changes significantly after being pre-stressed regardless, whether this is mechanically loading it within its yield strength or destructively loading.

Keywords Pitting corrosion · Stainless steel · Potentiostat · Stress-induced corrosion

1 Introduction

Corrosion is a complex phenomenon with multivariate implications and factors that can lead to the degradation of metallic materials [1, 2]. The local environment, metallurgical processes and mechanical performance are factors that may accelerate corrosion [1, 3, 4]. Stainless steel is susceptible to pitting corrosion, which is a localised form of corrosion that generates pits on the surface of the material due to corrosive attack [5]. In an effort to reduce the susceptibility to pitting corrosion, the interface of the steel and environment has been vastly studied [4, 6–13].

Stress-induced corrosion behaviour is vastly studied with focus on the effects of crack formation under stress and the rate of crack propagation and their implications on corrosive attack [6, 14–16]. The stress alteration of a material and the implication on the corrosion susceptibility is vital to the dental and orthopaedic industries [2, 17, 18]. Cyclic loading of a material accelerates stress-induced corrosion cracking [14, 16]. A stress-induced material being exposed to a corrosive environment does not necessarily result in catastrophic failure however the alterations to the material can be sufficient to increase corrosion susceptibility [19, 20].

Stainless steel products are diversely used for different applications, which vary based on the type and magnitude of mechanical stress exerted on the material. Coronary stenting, sternal wires, Kirschner wires, trauma plates and Cerclage wires are all potentially susceptible to corrosion with research commonly focusing on the improvement of surface treatment, tissue biocompatibility and cytotoxicity to assess the implication within the local environment [21–23]. Biomedical wires have a diverse application range within orthopaedics. Kirschner wires are commonly used to hold fractures in place in small joints commonly associated

✉ Selin Munir
selin.munir@gmail.com

¹ The Surgical and Orthopaedic Research Laboratories, Prince of Wales Hospital, UNSW, Sydney, Australia

² The Graduate School of Biomedical Engineering, UNSW, Sydney, Australia

with hand and wrist surgery. Cerclage wires are applied in trauma cases, which have resulted in bone fracture, periprosthetic fracture or in sternal closures. Understanding the possible increased effect of corrosion damage, which can be induced in a material having been mechanically pre-conditioned under different loads, will allow a better understanding of how static loading relates to the corrosion susceptibility of a metal.

Corrosion in biomedical alloys is an important issue with unanswered questions regarding corrosion phenomena relating to the implementations of mechanical loads. This study will assess the corrosion parameters, rate and how they differ amongst the different loading conditions. It will attempt to quantify the corrosion damage on the surface of each sample to determine the severity of corrosion damage after the specimen has been exposed to the different stresses. Understanding the possible increased effect of corrosion damage, which can be induced in a material having been mechanically pre-conditioned under different loads, will allow a better understanding of how static loading relates to the corrosion susceptibility of a metal.

The use of an idealised model to analyse the mechanical implications to a material can provide a contribution to various applications such as orthopaedic surgery, cardiothoracic surgery and trauma cases which use stainless steel products that undergo varying degree of mechanical loading or initial material manipulation prior to insertion during surgical procedure.

2 Methodology

2.1 Test Material and Sample Preparation

1.6 mm diameter, stainless steel (304) tie wire (Whites wires Australia Pty Ltd) was cut into 40 mm length test samples. Each group contained 7 samples to follow [G 61 - 86] ASTM standard for material characterisation. The elemental composition of the material was identified using inductively coupled plasma laser ablation (ICP-LA) and is shown in Table 1. There were three groups resulting in a total sample size of twenty-one ($n = 21$). The samples were divided into three groups to determine how corrosion susceptibility will change when a material is pre-stressed. The two test series assessed both permanent deformation (group 3) and elastic deformation (group 2) and compared to a control (group 1). A schematic illustration of the samples within each of the groups is represented in Fig. 1.

Fig. 1 A representation of the three groups. Group 1 is the control group. Group two underwent cyclic loading within the elastic region. The blue arrows represent the contact points. Group three underwent permanent deformation. The blue arrows represent the regions, which were analysed for corrosion damage after being exposed to compression or tension (Color figure online)

The samples within group 2 are maintained straight and placed on the 3-point test rig. Blue arrows in Fig. 1 represent the position of the exerted forces. The samples within group 3 are bent into a ‘u’ shape as illustrated in Fig. 1.

The rationale for testing both series was to determine if large loads, which resulted in permanent deformation, had increased corrosion damage in comparison to cyclic stresses applied within the material’s elastic region. Taking into consideration the materials used in joint replacement surgery that are constantly under cyclic loading, the implication on how aggressive the corrosion is in comparison to the control can be analysed. The permanently deformed samples were analysed for compression and tension as these were the samples to show the highest magnitude of corrosion based on other studies looking at stressed conditions and would allow for clear results on how the two different load conditions affect corrosion severity [6, 16, 17, 24].

Group 2 was loaded using a cyclic load within the elastic region of the material, using a 3-point bend test for duration of 1000 cycles. A sinusoidal waveform was selected and all testing was done under displacement-controlled condition. A 90/9 amplitude configuration was used to set the amplitude parameters, providing the maximum usage of the liner range. The sinusoidal waveform applied to each test sample had an amplitude of 121.5 μm .

Table 1 Elemental composition of 304 stainless steel using ICP-LA

Element	Cr	Fe	Mn	Ni	P	S	Si
Concentration (% wt/wt)	17.41	58.37	0.6674	9.51	0.0284	0.0329	0.1707

The cyclic load ranged from 264 to 4834 N. Benchtop micro mechanical testing system (MACH-1) controlled through computer run software (mechanic analysis), using a 10-kg load connected to an actuator (850F Actuator) was used for all test. The frequency was set to 1 Hz and all samples were tested under dry conditions.

All samples within group 3 experienced plastic deformation. This was achieved by bending the sample to form a 'u' shape, using a stencil for reproducibility, and pliers. The arc was kept constant for each sample indicative of having the same load applied to subsequent samples. Additionally each wire was of set length providing consistency of the arc and bending strength required. The rationale behind creating a 'u' shape sample was to provide both a compressive and tensile side for the determination of corrosion damage on each. Analysing the corrosion damage on the same sample for both tensile and compressive loads allows for direct comparison between the two results with any inter-sample bias removed.

2.2 Potentiodynamic Corrosion

The electrochemical analysis of all the samples was conducted using a cyclic potentiodynamic polarisation technique at 37 °C using a USB controlled potentiostat (PG 101, Metrohm). A schematic representation of the corrosion setup is shown in Fig. 2. The computer interface uses Autolab NOVA software (Eco Chemie, Netherlands), an electrochemical software package. The corrosion cell consists of a three-electrode configuration, including a working electrode, a reference electrode (Ag/AgCl Coleman electrode) and counter electrode. The counter electrode used is a large platinum mesh, chosen for the high stability of platinum. All electrodes are immersed into the electrolyte within the corrosion chamber. The electrolyte used for this study is phosphate buffer saline (PBS) with a pH of 7.445. The chemical make-up of the PBS (10L) electrolyte used throughout this study is 80 g NaCl, 11.5 g Na₂HPO₄, 2 g KCl and 2 g KH₂PO₄. The total amount of electrolyte placed into the reaction chamber was 700 mL. Prior to commencing potentiodynamic polarisation the OCP measurement was taken after aerating the medium with N₂ gas for 3600 s. The cathodic potentiodynamic polarisation scan was initiated from OCP to 100 mV below the OCP, followed by potentiodynamic anodic polarisation initiated 100 mV below the OCP and terminated at 800 mV above the OCP. The potential for the polarisation scan commenced from 100 mV below the OCP to 800 mV before reversing and terminating at the OCP minus 300 mV at a scan rate of 0.001 (V/s). The medium was aerated with nitrogen gas throughout the procedure. The output was a polarisation scan represented by a semi-logarithmic plot of the logarithm of current density versus potential. The polarisation scan was used to determine

the protection potential, the passivation current and the breakdown potential.

2.3 Scanning Electron Microscopy (SEM)

A Hitachi benchtop SEM was used under different magnification settings to observe the surface and corrosion damage. The raw images of all specimens following potentiodynamic testing were captured at $\times 50$ and used for qualitative and quantitative analysis. All the corroded specimens were measured for the cumulative corrosion damage in the regions of interest.

2.4 Qualitative Corrosion Analysis

The grading system used for qualitatively identifying corrosion damage was based on the visual analysis of pit formation, discolouration or change in surface topography. Two blinded independent observers assessed the corrosion damage on each sample, using the 4-point scoring systems shown in Tables 2 and 3. The grading criteria assessed both the spread of corrosion damage and the severity of pit formation.

A score of 0–3 was assigned for the corrosion damage seen across the surface of each sample using Table 2 adopted from Golberg and coauthors [25]. Table 3 addressed the severity of pit formation using a score of 0–3 to determine the size of pits. The rationale behind two orthogonal grading systems allows for a quantitative measure of both the surface coverage of corrosion damage, indicated by surface area modification, and the ferocity of the corrosion damage, indicated by the nucleation of pits.¹

2.5 Quantitative Corrosion Analysis

The corrosion damage was quantitatively assessed using 'histomorph', a MATLAB-based programme, which provides a ratio of the selected area (corroded) in comparison to the total area of interest. The data were tabulated using Microsoft Excel 2010 to provide quantitative data on the corrosion damage on the surface of the material.

2.6 Statistics

All statistical analysis was conducted using SPSS (IBM). The test used to determine statistical significance was a Kruskal–Wallis with a significance level of $\alpha = 0.05$. The Mann–Whitney U test was used to determine statistical significance across individual groups with the significance level of $\alpha = 0.05$.

¹ For each of the scores in Table 3, a minimum of 5 pits needs to have been observed to achieve the score. This ensured that any outlying pits did not affect the score.

Fig. 2 A schematic diagram showing the layout of the corrosion setup. The corrosion cell including all three electrodes labelled working, reference and counter are included

Table 2 The qualitative grading criteria for assessing corrosion damage of the sample

Severity	Score	Criteria
None	0	No visible corrosion
Mild	1	Corrosion occupying 1–25 % of the regional area
Moderate	2	Corrosion occupying 25–50 % of the regional area
Severe	3	Corrosion occupying 50–100 % of the area

Table 3 The visual grading criteria for assessing the pit diameter of a sample

Severity	Score	Criteria
None	0	No pit formation
Mild	1	At least 5 pits less than 50 μm diameter
Moderate	2	At least 5 pits greater between 50 and 200 μm diameters
Severe	3	At least 5 pits greater than 200 μm diameter

3 Results

3.1 Pitting Characteristics

The variation in pit geometry and nucleation resemble the different degrees of corrosion damage observed within the study (Fig. 3a). Small pits were found to be concentrated in

localised regions commonly surrounding a large pit (Fig. 3c). Under high magnification the depth of the large nucleation can be seen in Fig. 3b. The localised surface topography changes due to pitting corrosion can be observed under high magnification as micro-clusters of shallow pits, forming at pre-existing active corrosion sites (Fig. 3d).

3.2 Corrosion Grading

There was no significant difference between intra-observer variability for both the area corrosion ($p = 0.936$) and pit severity ($p = 0.825$) across the three groups. Similarly there was no significant difference between the 3-blinded graders when grading the compression and tension regions for both the corrosion area ($p = 0.886$) and pit severity ($p = 0.772$) scores. All images graded exhibited both area and pit corrosion scores, which significantly differed between the 3 groups ($p < 0.001$) (Fig. 4a–d). The visual corrosion damage score for the non-stressed (control) samples had the lowest median grading of 1 and 1 for the area and pit formation, respectively, which was significantly different to both the stressed groups ($p < 0.001$). The median visual area corrosion score of 2 for the non-destructive group was significantly lower ($p < 0.001$) than the group that underwent a destructive load, with a median value of 3.

The difference between the corrosion damage due to a compressive destructive load in comparison to a destructive tensile load is presented for the same sample in Fig. 4c, d. The compression region presented severe corrosion damage, showing damage across the entire region in addition to localised pit formation (Fig. 4c). The corrosion damage within the tensile region was similar to the non-destructive samples in Fig. 4b, d. Both the compressive and tensile regions had the same median visual area and pitting scores of 3 and 2, respectively. There was no significant

difference in the median values between either regions ($p = 0.59$).

3.3 Quantified Corrosion Score

The quantified corrosion damage for the three groups is shown in Fig. 5a. The control group had the lowest corrosion damage out of the three groups with a mean of 5 % (SD 1.6) surface alteration. The non-destructive samples presented a mean of 9.6 % (SD 1.7) surface alteration. The plastically deformed samples showed the most corrosion damage with a mean of 23.3 % surface alteration as well as significantly higher corrosion damage compared to both the control ($p = 0.001$) and elastically deformed ($p = 0.001$) samples. The non-destructive samples presented a statistically significant ($p = 0.001$) increase in the corrosion damage ratio by 4.6 % compared to the non-stressed (control) samples. The samples that were destructively stressed presented a mean of 35.5 % corrosion damage (SD 14.5) that is significantly greater ($p = 0.001$) compared to a mean of 11 % (SD 4.5) corrosion damage under tension.

3.4 Electrochemical Analysis

The mean open-circuit potential (E_{oc}) for the non-stressed samples was lower in comparison to both the pre-stressed samples, this indicates that mechanical stress changes the initial electrophysical stability of a material (Fig. 6). The permanently deformed samples had a significantly different

Fig. 3 The SEM images representing the variation in corrosion damage observed on the surface. **a** ($\times 150$) Shows the overall variation of pitting corrosion on the surface of a sample. **b** ($\times 1000$) Represents a large pit formation, which has deep depth. **c** ($\times 150$) Shows the different rates of pit formation where a large central pit is seen surrounded by multiple smaller pits. **d** ($\times 1000$) Shows the multiple nucleation of pit formation across a surface

Fig. 4 The SEM images representing the variation in corrosion damage observed on the surface. **a** ($\times 50$) Represents the corrosion damage observed within the control group. **b** ($\times 50$) Represents the samples in group 2. **c, d** Both represents the corrosion severity of the samples within group 3. Specifically **c** is the region, which underwent a compressive load and **d** is the region that underwent a tensile load

Fig. 5 Representation of the corrosion damage value for each test group. From left to right on the x-axis is the non-stressed, non-destructive load and destructive load (**a**). The corrosion damage value for both permanently deformed regions that underwent a compressive (left) and tensile (right) load (**b**)

($p = 0.0056$) E_{oc} in comparison to the non-stressed samples. The E_{oc} was more positive for the samples which underwent non-destructive stresses, however the change in the E_{oc} was not statistically significant ($p = 0.19$) in comparison to the control. Comparing both the mechanically stressed sample groups resulted in a small increase in the E_{oc} for the samples exposed to a destructive load, however the change in E_{oc} did not show a statistical significance ($p = 0.13$).

The mean breakdown over-potential ($E_{bd} - E_{oc}$) is greatest at 0.904 V for the non-stressed samples in comparison to the elastically deformed and plastically deformed samples, which presented mean breakdown over-potentials of 0.538 and 0.318 V, respectively. The corrosion rate was significantly higher for the plastically deformed samples compared to both the non-stressed and elastically deformed samples. The plastically deformed presented more than double (2.2) the corrosion rate of the elastically deformed samples and nearly four times (3.63) as high in comparison to the non-stressed samples. Corrosion resistance was affected by the magnitude of the applied stress however this change was not statistically significant ($p = 0.99$) between both the groups. The pitting potential for the destructively stressed samples (0.15 V) was lower in comparison to both the control (0.46 V) and non-destructively stressed samples (0.23 V). The mean re-passivation potentials for the non-stressed samples and the elastically deformed samples were -0.21 and 0.37 V, respectively. Group three did not re-passivate for 3 samples, however the samples that underwent re-passivation had a mean re-passivation potential of 0.23 V.

Fig. 6 The potentiodynamic polarisation scans for control group (blue), group 2 (red) and groups 3 (green) are shown (Color figure online)

4 Discussion

Corrosion is a fundamental phenomenon in most metals with the exception of gold and platinum, which exist naturally in the metal state and have thermodynamic stability. A protective oxide, enhanced manufacturing and surface treatment techniques can alter the severity of corrosion in different metals [26]. It is well accepted in the literature that stainless steel is prone to pitting corrosion where nucleation of the surface is directly related to the breakdown of the oxide layer [7, 13, 27, 28]. All the samples within this study were susceptible to pitting corrosion after potentiodynamic testing. Macroscopically small pits were observed along the entire area exposed to the corrosive environment, which concurs with in vitro corrosion studies conducted on stainless steels.

The control group had the highest pitting over-potential in comparison to both the mechanically stressed sample groups, in which group three showed the least positive value. This showed that a material exposed to no mechanical stress has the best resistance to corrosion. In addition, the protective over-potential was highest for the control group indicative of it possessing the highest resistance to pitting corrosion. A study conducted by Bundy et al. showed that static stresses affect the corrosion behaviour of metals where he found that the corrosion parameters were lowered [17]. The significant difference between both the pitting over-potential and the protection over-potential between the control and the plastically deformed group suggests that plastic deformation significantly increases the corrosion susceptibility of the material. Wu et al. tested SS304 in 5 % HCL and found that

the pitting over-potential was 131 mV, which is lower in comparison to this study [13]. The high pitting over-potential signifies an increased resistance to pitting, whereas high protection over-potential relates to a higher probability of re-passivation if damage to the oxide film occurs.

The variation in pit nucleation across the surface was only seen under high magnification with both sporadic and numerous pits observed. The large pits were found in localised regions either isolated or surrounded by smaller nucleation of pits, which occurred in spawns [13]. The extent of pit formation is due to multiple factors with studies showing that the formation and severity of pits is related to an increase in temperature, increases in chloride concentration, material composition and surface topography [9, 24, 29]. In this study the chloride concentration and testing temperature was kept constant therefore are not considered as factors explaining the difference in corrosion damage observed on the surface between sample groups. A leading factor responsible for pit formation is insufficient film stability, which leads to chemical dissolution at the oxide–electrolyte interface [2, 26]. This is a well-documented phenomenon and is commonly related to inaccurate surface preparation such as deep scratches, and defect formation during surface preparation. This study has shown a higher percentage of pit formation within the control group in comparison to other studies conducted using SS304, which potentially could contribute to the higher degree of corrosion in the observed results.

The variation of the OCP for the control group is likely due to surface defects observed prior to testing resulting in a

deformed oxide layer producing different electrochemical conditions within the surrounding cell. The OCP is an indicator of the corrosion susceptibility of a material where a more positive reading relates to a lower susceptibility to pitting corrosion. The more positive OCP seen for the mechanically stressed samples are indicative of an increase in localised corrosive attack for pre-stressed materials. The different sizing of pit nucleation across the surface of a material exposed to pitting corrosion can be identified by the different rates at which pit growth and re-passivation occur.

All the samples showed pit initiation commonly due to the breakdown of the oxide layer, this is referred to as phase one of the corrosion process. The large pits seen on the surface are most likely due to the generation of an aggressive chemical environment within the pit which includes excess Cl^- ions or other halide ions causing a thermodynamic imbalance leading to an autocatalytic process of corrosion [14]. Figure 2 shows that the pit sizes were larger for both the mechanically stressed groups indicative of an increased risk of localised attack. The larger pits seen on the surface are a result of early erosion and faster decay of material or lower physiochemical stability, which result in extended duration of time before re-passivation can occur [11, 14].

Comparison between both the pre-stressed groups showed that plastically deformed had a significantly lower OCP in comparison to the elastically deformed indicative of a higher susceptibility to corrosion damage once a material's yield point is surpassed. Stress corrosion cracking studies have shown that materials, which have been permanently deformed, result in an increase in corrosion severity of the material [30–32]. The change in the microstructure and rearrangement of grain boundaries due to mechanical changes is responsible for the increase in corrosive attack seen on materials, which have been mechanically loaded passed their yield point. The increase in corrosion is commonly due to the weakened grain boundaries however, for naturally oxidised metals the in-homogeneity of the protective oxide coating as a result of mechanical testing is also a contributing factor. The damage to the oxide layer can be severe which limits the re-passivation process resulting in a deformed coating, leaving more of the bulk metal exposed, correlating with a much higher corrosion rate for the material. The plastically deformed samples showed similar sized pit formation within the tensile region compared to the elastically deformed samples. The similar findings show that the material has a similar corrosion resistance if either fatigued within its elastic region or destructively loaded under tension.

The elastically deformed samples did not significantly differ from the control group, indicating that cyclically fatiguing a material within its elastic region does not significantly affect the corrosion damage, due to not permanently altering the microstructure. However there is still a

higher percentage of corrosion seen in this study where the quantitative results show an increase from 4.9 % for the control to 9.6 % for the cyclic samples [15, 33].

Within the group of plastically deformed samples both the regions that had a tensile load or compressive load applied were analysed. This revealed that most of the corrosion damage occurred within the region that experienced a compressive load in comparison to the region which experienced a tensile load. The compressive and tensile regions analysed showed that the compressed regions had a 3 times increase in corrosion, which was an interesting observation as many studies which correlate mechanical stress to accelerated corrosion commonly reference crack initiation and propagation under tensile loads or fatigue [14, 16, 24, 34]. Studies which focus on mechanical corrosion have commented extensively on tensile testing and increasing hair line cracks which can lead to crack propagation that is accelerated under a corrosive environment [24]. However, few studies have done a comparative analysis within the sample to determine a quantitative measure; therefore it is difficult to make direct correlation with these results.

Compressive loading is commonly related with improving the corrosion resistance, however this behaviour is contradicted by the findings of this study. Xx et al. examined intergranular corrosion (IGC) and the affects of a compressive load. It showed that a stress halfway to yield along the through-thickness direction reduced the growth kinetics of IGC. The higher corrosion severity found within the compressive region cannot be explained by excessive damage at the grain boundaries.

A study examining the effects of compressive stresses on corrosion were conducted on SUS304-coated nitride film. This study showed that compressive stresses influenced both the corrosion resistance and corrosion protective quality. Miura et al. showed that compressive stress increases with increasing radius of curvature. Secondly they showed that the number of pores increases with increasing compressive stress. They concluded that corrosive damage progressed more rapidly as the compressive stress increased. Considering the samples had a high curvature the physical geometry of the sample could be a possible reason why the compressive region had greater corrosion damage. Considering the samples had a higher degree of curvature, the physical geometry of the sample could be a possible reason why the compressive region displayed greater corrosion damage. In addition to this Miura reported that higher compressive loads lead to the creation of a higher number of pores. Plastically deforming the samples and creating the u-shaped geometry can both be contributing factors as to why the compressive region has severely higher corrosion damage compared to the tensile region.

From the SEM images the compressive region also showed regions of surface removal as a result of corrosion damage. The delamination of the material during the

corrosion process exposed large regions of raw material, hence accelerating the process of corrosion within that region and leading to greater corrosion damage.

Within the plastically deformed sample group the region that underwent a compressive load had very aggressive surface damage with large areas of the surface removed in addition to sporadic pit formation. This could be a result of two factors; the first being due to the stress and formation of small cracks in high stress points which disrupt the oxide coating resulting in more severe corrosion. Secondly the local environment based on the geometry of the sample can form a temporary 'crevice like' effect where a higher concentration of chloride or halide ions can congregate, leading to a more corrosion-prone environment resulting in more aggressive corrosion damage. The application of orthopaedic wires are commonly plastically deformed by surgeons, in lieu of this, this model has shown that design consideration must be applied to ensure the material is corrosion resistant after it has undergone plastic deformation. This is critical as they are used in a corrosive environment; the human body.

5 Conclusion

Stainless steel is used extensively within orthopaedics as part of varying surgical procedures such as trochanteric osteotomy, sternum closure, patella tendon repair and reconstruction, patellofemoral ligament reconstruction and internal fracture fixation. Common products used in these procedures are metal plates, Kirschner wires or Cerclage wires, which are generally mechanically manipulated either elastically or plastically stressed intra-operatively to aid in the surgical procedure. This study has shown a material's corrosion susceptibility changes significantly after being pre-stressed regardless, whether this is mechanically loading it within its yield strength or destructively loading. The quantification of the corrosion damage shows that a material exposed to a corrosive environment after undergoing a destructive compressive load will corrode significantly more in comparison to a material that has undergone destructive loading under tension. Therefore the intra-operative manipulation of these products for surgical applications can potentially increase the corrosion susceptibility due to mechanical alteration of the manufactured material. The potential consequences may lead to extended wound healing, inflammatory tissue response to corrosion particles or premature implant failure.

6 Limitations

Stainless steel test specimens were used for this study, as they were a cheaper material choice in comparison to a medical grade material. The use of a medical grade

material is not an important factor as the parameters under investigation are mechanical and the results of interest are in relative between the samples tested. Therefore for the purpose of this study the use of medical grade material was not required. A second limitation to the study is the use of the Goldberg grading system. This grading system is extensively used in corrosion studies to provide analysis to the affect of corrosion. However, the grading system is subjective and relies on the graders judgement to identify and distinguish between corrosion and corrosion products. It has been pointed out in the literature that the reproducibility of the Golberg scoring system has not been evaluated.

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