Faculty of Mechanical Engineering

INFLUENCE OF MECHANICAL PROCESS ON THE STRESS CORROSION CRACKING OF 316L STAINLESS STEEL FOR IMPLANT APPLICATION

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DECLARATION

I declare that this thesis entitled “Influence of Mechanical Process on the Stress Corrosion Cracking of 316L Stainless Steel for Implant Application” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……

Name : ……

Date : ……

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature : ……

Supervisor Name : ……

Date : ……

DEDICATION

I dedicate this thesis to my beloved mother, father, wife and sons

ABSTRACT

316L stainless steel (SS) is very synonym as a metal implant in medical application. This 316L grade is widely used at various implant divisions and makes it beneficial to the medical treatment of several injuries and diseases. However, their usage is slightly limited by the corrosion problems during implantation in the body. In this study, experiments are aimed to evaluate the stress corrosion cracking (SCC) of 316L SS in the simulated body environment. The 2.0 mm thick of 316L SS test specimens was undergone two steps mechanical processes; rolling and bending. The specimens were cold-rolled to 10%, 30% and 50% reduction in thickness and bent up to the U-bend shape using special bending equipment. The processing properties like plastic strain and springback after both processes were measured. The mechanical properties and structural modifications of cold worked specimens were assessed using tensile, hardness, bending and metallurgical tests. The corrosion tests were done in phosphate buffered saline (PBS) solution at temperature and pH of 37 ^{o}C and 7.4. The XRD and EDS methods were used to identify the corrosion products. Whereas, the morphology of SCC failed specimens was observed under microscopic method. From the results, the occurence of SCC has been evaluated as follows. The 316L SS was strain hardened after two steps mechanical processes. The strain hardening effect was clearly seen from the resulted processing properties and structural modification. It was indicated by a higher plastic strain and springback. The structural modification from coarse to dislocated and dense grain structures also makes the steel harder and stronger. Then, the bending process produced transversal cracks in the outer U-bend surface. The crack, which formed at the existing grain boundaries, was identified as the initial stage of SCC. Consequently, the chloride ions penetrate the crack during the corrosion process and facilitate the crack growth. The crack was propagated along with the previous rolled marks, under transgranular mode. In this work, SCC was clearly found on the U-bend 316L SS with 10% reduction in thickness. However, the steel with higher thickness reduction produced a greater strain hardening which then prevented the occurrence of transversal cracks. From the finding, this work shows the mechanical process greatly influenced the SCC rather than the corrosion process. The steel must be strain hardened by two steps mechanical processes to initiate the SCC failure.

ABSTRAK

Keluli tahan karat 316L (SS) sangat sinonim sebagai implan logam dalam aplikasi perubatan. Gred 316L digunakan secara meluas dalam pelbagai divisyen implan dan menjadikannya bermanfaat untuk rawatan perubatan untuk beberapa jenis kecederaan dan penyakit. Bagaimanapun, penggunaan implan sedikit terhad kerana masalah kakisan semasa implantasi dalam badan. Dalam kajian ini, eksperimen bertujuan untuk menilai retak hakisan tegasan (SCC) bagi 316L SS dalam persekitaran simulasi badan. Keluli 316L SS sebagai bahan spesimen dengan ketebalan 2.0 mm menjalani dua peringkat proses mekanikal; iaitu gelekan dan lenturan. Spesimen-spesimen telah disejuk-gelekan kepada 10%, 30% dan 50% pengurangan tebal sebelum dilenturkan kepada bentuk lentur-U denagn menggunakan alat lentur khas. Sifat-sifat pemprosesan seperti terikan plastik dan springback selepas kedua-dua proses diukur. Sifat-sifat mekanikal dan ubahsuai struktur ke atas spesimen dikerja sejuk telah dinilai menggunakan ujian regangan, kekerasan, lenturan dan metalurgi. Ujian-ujian kakisan telah dibuat dalam larutan phosphate buffered saline (PBS) pada suhu dan pH adalah 37 ^{o}C dan 7.4. Kaedah XRD dan EDS digunakan untuk mengenalpasti produk-produk kakisan. Kemudian, morfologi spesimen yang gagal secara SCC telah diperhatikan melalui kaedah mikroskopik. Daripada keputusan, pembentukan SCC telah dinilai seperti berikut. 316L SS telah dikerasterikkan selepas melalui dua peringkat proses mekanikal. Kesan pengerasan terikan jelas kelihatan daripada hasil sifat-sifat pemprosesan dan pengubahsuaian struktur. Ia ditunjukkan oleh terikan plastik dan springback. Pengubahsuaian struktur daripada kasar kepada struktur butiran terkehel dan padat juga menjadikan keluli lebih keras dan kuat. Kemudian, proses lenturan telah menghasilkan retakan melintang pada pemukaan luar lenturan-U. Retak berkenaan, yang terbetuk pada sempadan butir sedia ada, telah dikenalpasti sebagai peringkat permulaan SCC. Akibatnya, ion klorida dapat menembusi ke dalam retak semasa proses kakisan dan memudahkan pertumbuhan retak. Retak telah merambat melalui tanda gelekan sebelumnya, yang berada di bawah mod transgranular. Dalam kajian ini, SCC jelas dijumpai pada 316L SS berbentuk lenturan-U dengan 10% pengurangan sejuk. Bagaimanapun, keluli dengan pengurangan sejuk yang lebih tinggi mewujudkan pengerasan terikan yang lebih besar yang kemudiannya dapat mencegah daripada berlaku retakan melintang. Daripada penemuan yang diperoleh, kajian ini telah menunjukkan proses-proses mekanikal sangat mempengaruhi SCC berbanding proses kakisan. Keluli mesti dikeras terikkan melalui dua peringkat proses-proses mekanikal untuk memulakan kegagalan SCC.

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