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INFLUENCE OF MECHANICAL DAMAGE ON CORROSION RESISTANCE OF PLATES USED IN FUNNEL CHEST TREATMENT

The paper presents influence of mechanical surface damage on corrosion resistance of plates made of Cr-Ni-Mo stainless steel, used in funnel chest treatment. The surface of the steel was electrochemically polished and fitted. The surface damage is induced in the given deformation regions and is a potential reason of corrosion. The corrosion tests were realised by recording of anodic polarization curves with the use of the potentio-dynamic method. The VoltaLab® PGP 201 system for electrochemical tests was applied. Additionally, the tests showed that the structure of the steel the plates were made of, met the PN-ISO 5832-1 standard. On the basis of the obtained results it can be stated that that stainless steel can be applied in funnel chest treatment.

1. INTRODUCTION

Funnel chest (pectus excavatum) is backwards deformation of a corpus of sternum and forward deformation of an ensiform process – fig 1. Costicartilages are deformed and too long. Occurrence of this defect is about 2% but surgical treatment is necessary for about 25% of patients. This type of deformation is almost 2 times frequent in boys than girls [2÷5]. In 1998 Donald Nuss introduced a new, minimally invasive technique of funnel chest treatment. Short hospitalization time and good temporary cosmetic result are doubtless advantages of this method. Correction of deformation is realized by the growth of ribs along the fixation plate. The most popular metallic biomaterial used for this type of implants is austenitic stainless steel [7, 15, 16, 18, and 19]. Plates which stabilize chest used in the Nuss' method are short-term implants. Their implantation time is up to two years. In order to improve the corrosion resistance and to avoid bone overgrowth, the implant is fitted. The plates are produced in two series of types: narrow plates of 11 mm and 14 mm width and length from 120 to 200 mm, and wide plates of 16 mm width and length form 180 to 480 mm – Fig. 2. Division into the series of types allows for a custom design of the plates [20].

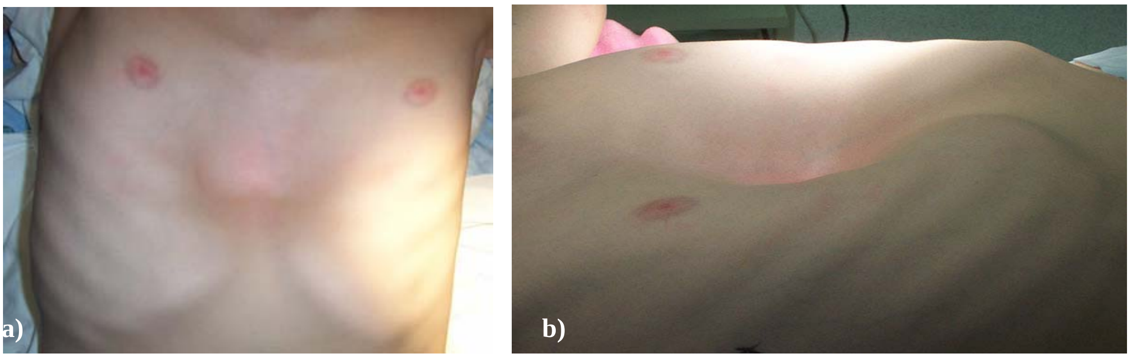

Fig. 1. Pectus excavatum: a) front view, b) side view [21]

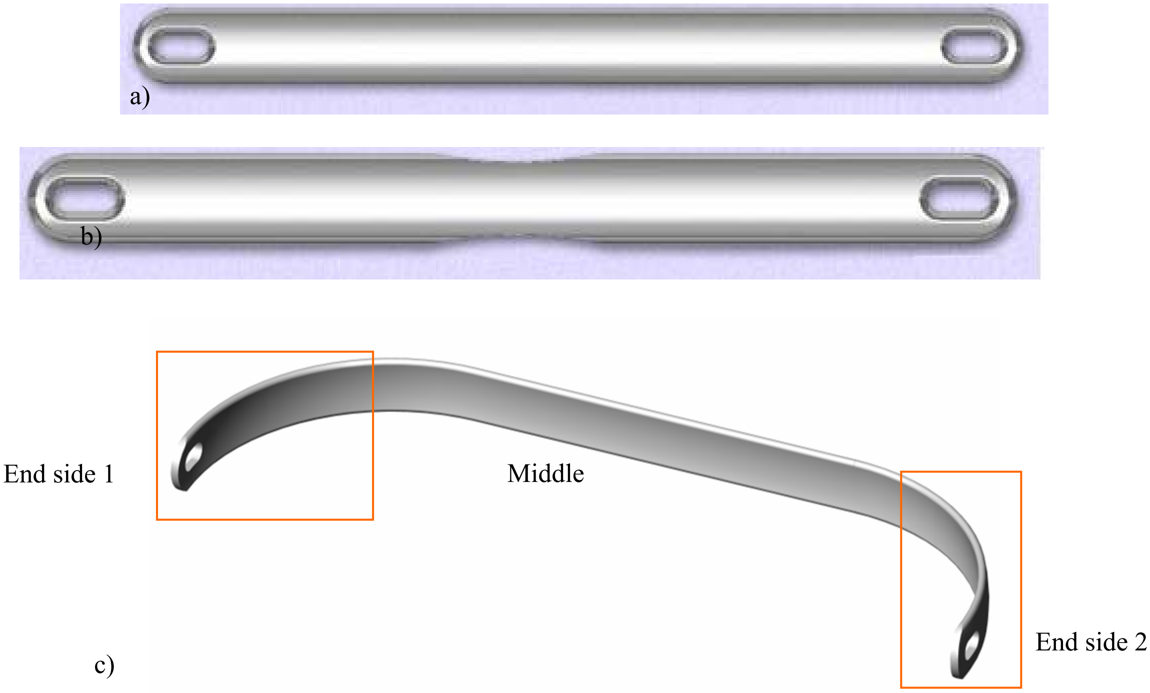

Fig. 2. Fixation plates: in initial state - a) narrow, b) wide [20], - c) after bending

Implantation technique is presented in figure 3. The technique consists of the following operations [1÷6, 21, 22]:

- general anaesthesia with endotracheal intubations and epidural anaesthesia,
- administration of an antibiotic while anaesthesia with 48 hours continuation after operation,
- placement of patient with hand abducted on the shoulder line,
- selection of the proper length of the fixation plate and appropriate bent,
- determination of auxiliary points on chest,
- incision of skin – Fig. 4,
- insertion of thoracoscope,
- insertion of clamp,
- insertion of bent plate,
- reversion of the plate (180˚) and correction of deformation.

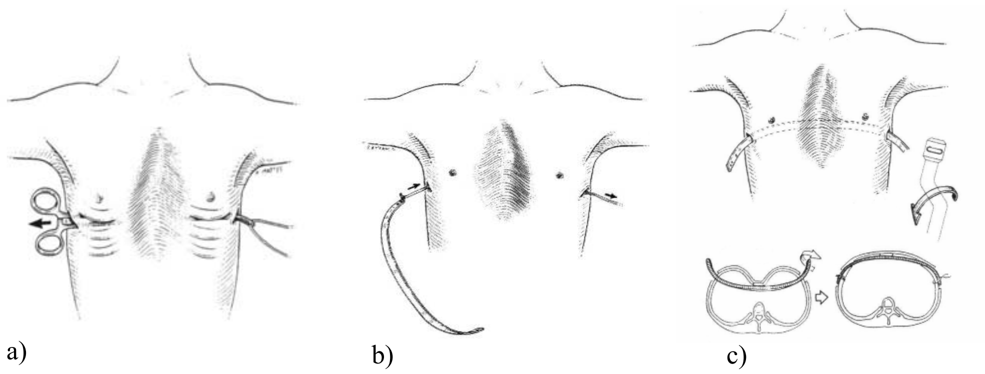

Fig. 3. Implantation technique of fixation plate – Nuss method: a) drilling the holes, b) insertation of clamb, c) insertation of bent plate andreversion of the plate (180°) and correction of deformation [1[1], 4]

Fig. 4. Incision in the Nuss' method [23]

2. MATERIALS AND METHODS

The first stage of research 50 plates after implantation was selected. All the plates were made of the AISI 316 LVM stainless steel. The chemical composition meets the PN ISO 5832-1 standard [17]. In order to check the amount of non-metallic inclusions and grain size, additional metallographic and microscopic tests were carried out with the use of the MEFCA (LEICA) light microscope – Fig. 5.

The last stage of the work was the microscopic evaluation of surface damages of the plates after different times of implantation: 24, 25 and 26 month. That allowed establishing the type and the amount of damages caused by bending of the plate to the anatomical curvature of chest. Reactivity of implants in body environment is generally determined by corrosion resistance of metallic biomaterial. Corrosion resistance is correlated with a biocompatibility. Good biocompatibility is observed for metals and alloys with high anodic potentials [7]. Therefore, for the selected plates, pitting corrosion tests were carried out.

Fig. 5. The MEFCA (LEICA) light microscope

The corrosion resistance tests of the samples were performed with the use of the potentiodynamic tests (VoltaLab, type PGP 201).

Anodic polarization curves were registered with the use of measuring set consisting of:

- potentiostat with generator,
- reference electrode – saturated calomel electrode (SCE),
- auxiliary electrode – platinum electrode,
- working electrode – speciment tested,
- PC computer with special software.

The test consisted in the recording of the anodic polarization curves. Before the tests the samples were cleaned with the ethyl alcohol in the ultrasound washer. The tests were performed in the Tyrode's physiological solution – tab. 1, at the temperature of 37±1ºC and pH = 6,8 ÷ 7,4. Measurements started after the corrosive potential had been established, which took place after about 60 minutes. The change of the potential rate was equal to 1 mV/s.

Table 2. Tyrode's physiological solution [10]

Solution components	NaCl	$CaCl_2$	KCl	$NaHCO_3$	NaH_2PO_4	$MgCl_2$ $6H_2O$
Concentration, g/l distilled water	8,00	0,20	0,20	1,00	0,05	0,10

3. RESULTS

3.1. RESULTS OF STRUCTURES ANALYSIS

Non-metallic inclusions didn't exceed the pattern number equal to 1,5 which according to the ISO 4967-1997 (E) standard [13] is the limit value – Fig. 6.

Structure of the tested stainless steel consisted of deformed austenite with numerous slip bands – Fig. 7. The grain size met the PN – ISO 5832-1 standard and was equal to the pattern number G=11.

No damage of structure (microcracks) and no stress corrosion were observed in the bent area of the plates – Fig. 8. Deformation of austenit grains was caused by clinical prebending of the plate.

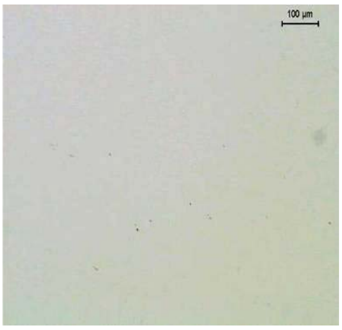

Fig. 6. Non-metallic inclusion stainless steel, longitudinal microsection magn. x100

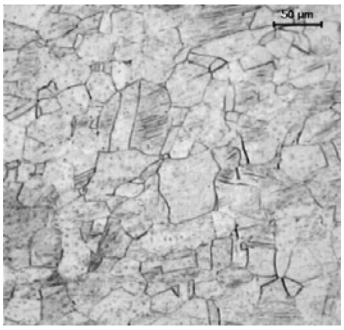

Fig. 7. Structure of the stainless steel, longitudinal microsection, magn. 200x

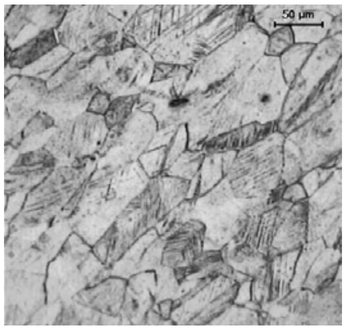

Fig. 8. Structure of the stainless steel in the maximum bent area, longitudinal microsection, magn. 200x

3.2. ANALYSES OF SURFACE DAMAGE

Microscopic observations of implant surfaces showed mechanical damage. Numerous, deep scratches appeared as the result of fitting of the plates to the anatomical curvature of chest with the use of the surgical tool. The most damaged surface was observed in the middle part of the plates (outer side) as well as at the ends (holes) – Fig. 9, 10, 11. The damage was similar for all the plates. These regions are the most subjected to interference of surgical tools damaging the passive layer that cause the decrease of the corrosion resistance of implants. On the basis of these observations the characteristic sections of the plates were selected for potentiodynamic tests.

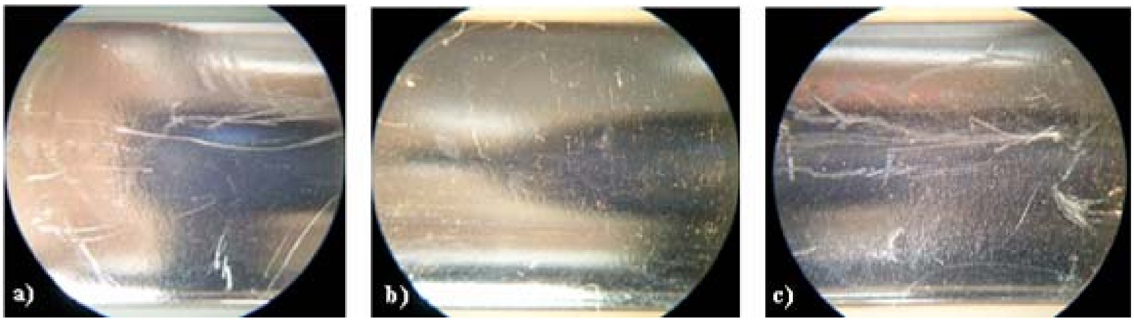

Fig. 9. Plate with the surface damage (24 month): a) end side 1, b) middle, c) end side 2

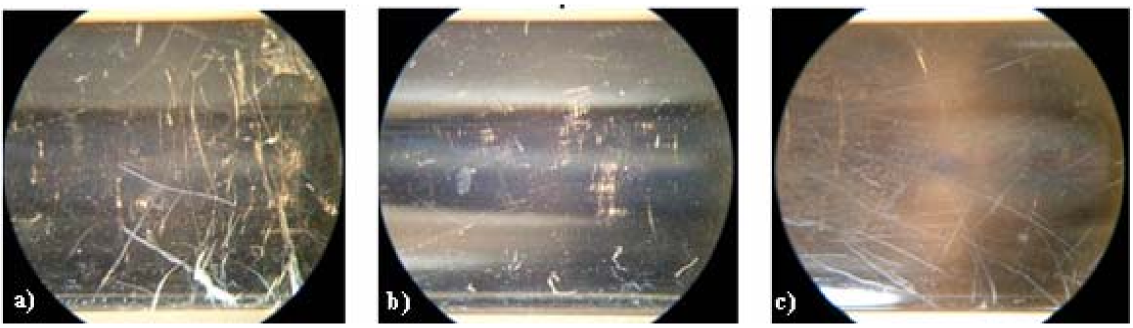

Fig. 10. Plate with the surface damage (25month): a) end side 1, b) middle, c) end side 2

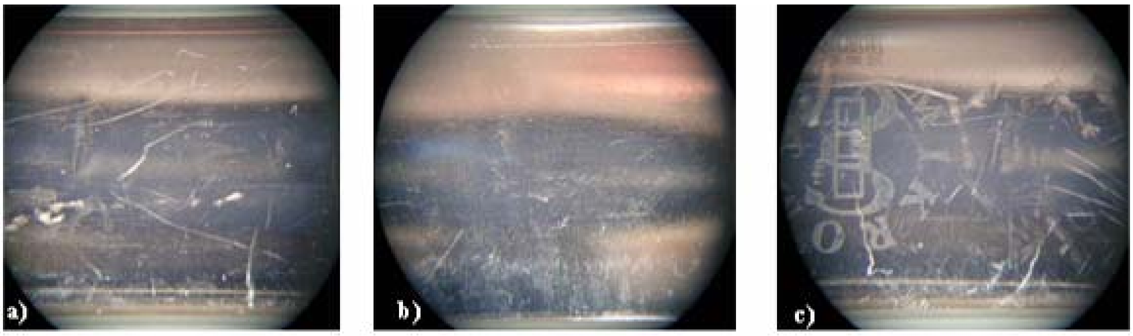

Fig. 11. Plate with the surface damage (26 month): a) end side 1, b) middle, c) end side 2

Corrosion processes of metallic implants are mainly electrochemical. Surface of each metal, even the most clean, is not macroscopically homogeneous. Metals have grain, crystalline microstructure. Grain boundaries, in comparison to inside part of grain, are less ordered. During contact with an electrolyte (body fluid) micro cells are generated that causes a local passage of current. Because grain boundaries energy is higher than energy of grain, therefore the grain boundary is an anode and the grain is a cathode. As the result of electrochemical processes in the micro cells, the corrosion process on the surface proceeds.

3.3. RESULTS OF PITTING CORROSION RESISTANCE

The corrosion tests revealed that in the undeformed areas of the plates, the passive layer formed during technological process assures the corrosion resistance, breakdown potentials E_B are in the range +1180 do + 1220 mV – tab. 2. In the deformed areas of the plates, the passive layer was damaged what initiated pitting corrosion – Fig. 13, 14, 15. The range of breakdown potentials E_B depends on surface damage and decreased from +400 to +668 mV – Fig. 13-15, and tab. 2. These areas are vulnerable to pitting corrosion and metalosis in consequence. The smallest values of breakdown potentials were observed at ends of the plates which showed the greatest mechanical damage. The decrease of the breakdown potentials is significantly showed in relation to the electro polished and fitted sivated steel in the initial state.

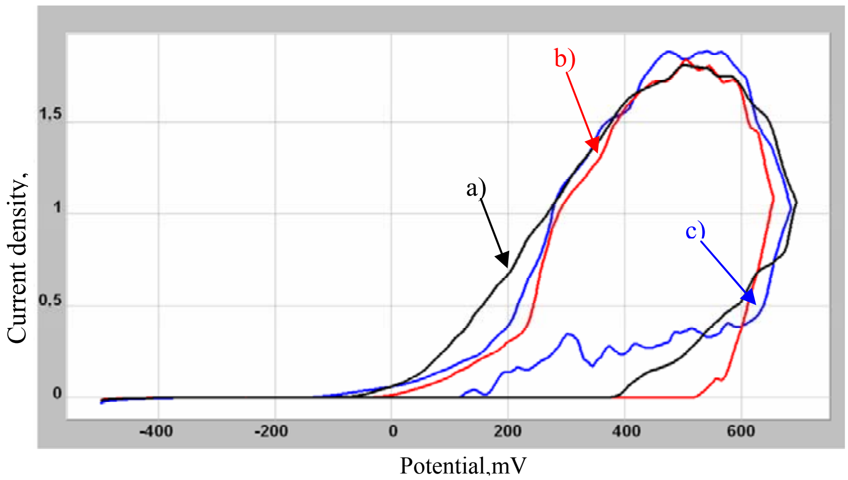

Fig. 13. The anodic polarization curve for plates used for 24 month: a) end side 1, b) middle side, c) end side 2

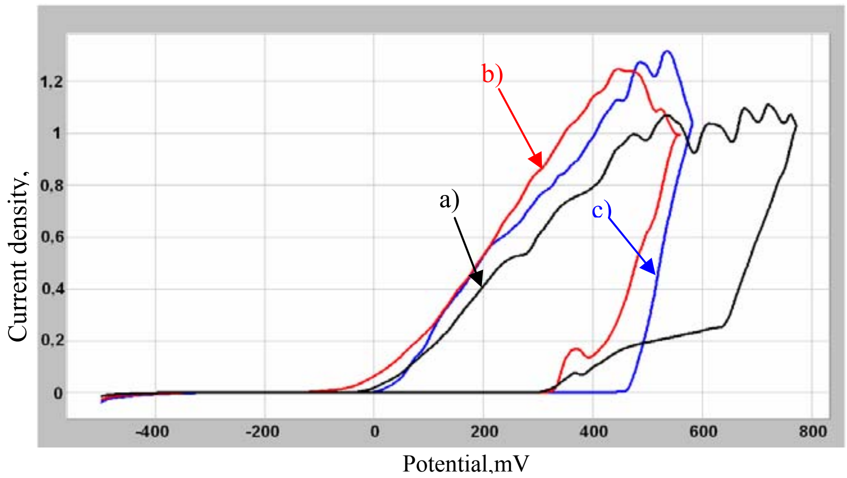

Fig. 14. The anodic polarization curve for plates used for 25 month: a) end side 1, b) middle side, c) end side 2

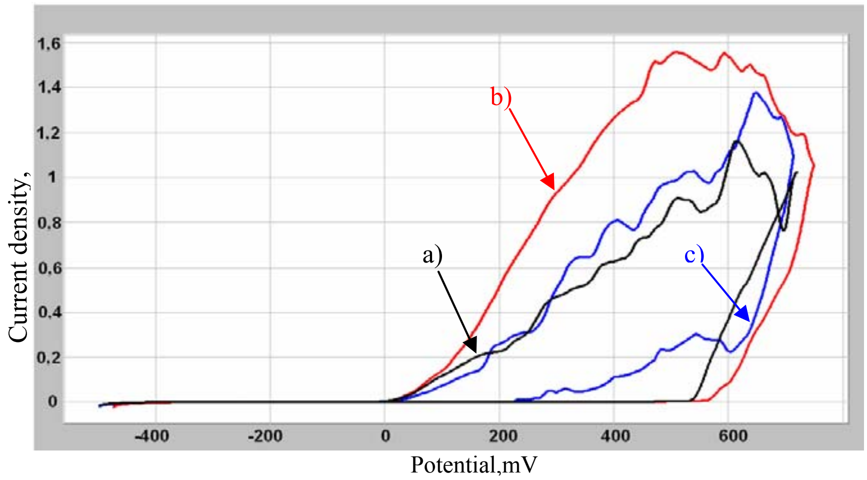

Fig. 15. The anodic polarization curve for plates used for 25 month: a) end side 1, b) middle side, c) end side 2

Table 2. Results of research on the pitting corrosion resistance [24]

Material	Sample	Corrosion potential E_{corr}, mV		Breakdown potential E_{B}, mV	Repassivation potential E_{cp},mV
316 LVM	electropolished and passivated	-85 ÷ +21		+1180 ÷ +1220	0 ÷ +75
	24 month	end 1	+46	+606	-35
		middle	+45	+623	-95
		end 2	+3	+551	-41
	25 month	end 1	+52	+456	0
		middle	+20	+591	-30
		end 2	+32	+400	-115
	26 month	end 1	+34	+510	-5
		middle	+34	+542	-10
		end 2	+24	+668	+5

4. CONCLUSION

The tests showed that the structure of the steel the plates were made of, met the PN-ISO 5832-1 standard. In the maximum deformation areas, no stress corrosion cracks were observed. This proves that mechanical properties of the steel were correctly selected. The surface damage is mostly mechanical. The damage is induced in the given deformation regions and is a potential reason of corrosion. Corrosion products can cause immuno- and allergic reactions. The mechanical damage causes the decrease of the corrosion potentials of the metallic biomaterial that causes the increase of the metalosis risk of. However, the clinical tests showed that the mechanical damage of the surface didn’t influence the correct stabilization of the funnel chest. No complications and inflammatory reactions were observed during the treatment.

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