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In order to manufacture guide wires for cardiovascular treatment, it is necessary to predict the corrosion characteristics of steel wires.

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ABSTRACT

Electrochemical corrosion resistance of stainless steel wires used to make guide wires for invasive cardiology is evaluated, along with the impact of strain during the drawing process and surface modification. Static tensile testing of X10CrNi 18-8 steel wire allowed us to map out its flow curve and mathematically model its flow stress function. Electrochemical corrosion resistance was determined using potentiodynamic analysis of recorded anodic polarization curves. Both electrolytically polished and chemically passivated samples were tested in a solution designed to mimic human blood. Anodic polarization curves as examples were provided. Corrosion resistance was shown to deteriorate with increasing tension. Chemical passivation was discovered to enhance the anti-corrosion properties of wires. Corrosion qualities (polarization resistance Rp) were shown to be statistically dependent on strain imposed during the drawing process.

Introduction

In minimally invasive procedures, guide wires play a crucial role. While first designed for use in the vascular system, guide wires have now found widespread use in many other medical specialties. In procedures such as angioplasty, electrocardiology (the insertion of electrodes into the heart), endoscopic gastrostomy, and endourology [1-3], they are used to get percutaneous access within blood arteries. In the second case, they serve a dual function: (1) facilitating access to targeted regions of the urinary system, and (2) facilitating the insertion of catheters and stents. The need for so many various kinds of guide wires led to their mass manufacture. Their mechanical properties, such as their stiffness or resistance to breaking, as well as their structure and proportions, set them apart from one another [1]. Different manufacturers have their own unique catalog series of guide wires. The majority of them are stiff or semi-rigid overall, but have a bendable, flexible tip. Tissue injury and perforation may be avoided thanks to the elastic tip. Guide wires are often long, thin wires that are either straight or have a "J"-shaped tip. There are also uses for more intricately built guide wires. Guide wires for ureterorenoscopy and endourological percutaneous nephrolithotripsy, for instance, are made up of tiny round wires and flat wires wound together to form a spring [4-8]. Intravascular guide wires are used to safely and accurately place implants like stents used in angioplasty into blood arteries during invasive cardiology procedures. No incisions into blood vessels are required during therapy. There are two applications for guide wires in electrotherapy. The first involves gaining entry to the vein so that an electrode may be implanted. The electrode may be made stiffer in the second method, making it easier to enter it into the heart at the correct location.There are a lot of criteria that guide wires need to fulfil. The safety of the patient is of paramount importance while using them. They need to be very resistant to electrochemical corrosion in the tissue and salt water environment. They are completely nonreactive when exposed to blood. Mechanical qualities necessary for the intended use should also be present in guide wires. The chemical make-up of the material, its metallurgical purity, and the technical parameters of the wire manufacturing process all have an impact on the wire's functional qualities. Guide wire surface physical and chemical characteristics determination is also an important issue. The conditions of human tissue should be taken into account. In the case of plastic working, the right qualities of technical plasticity of the material play a role in choosing the optimal parameters of the wire drawing process. In order to have a product with the desired functional properties, you need a structure that is amenable to the drawing process. The rise in flow stress p, known as work hardening, is a corollary of plastic strain. Wire's strength increases and its plasticity decreases as it hardens. Analysing the trend of the function p = f(), where indicates strain written as a logarithm, is essential for determining the correct parameters of plastic working and achieving the desired final qualities of goods. The so-called flow curves, which show how the stress changes as a function of strain, allow us to predict how the material will behave during plastic working [9]. Guide wires are made from wire that has had substantial strain applied during the drawing process [10, 11].

2. Materials and Methods

The first testing material was 5.65 mm diameter annealed X10CrNi 18-8 steel wire rod. A 1.5 mm diameter wire rod was drawn. As a whole, the sketching procedure caused a logarithmic strain of = 2.65. The cold working process strengthened the wire work. Mechanical and corrosion testing required samples that were clipped off throughout the strain process. On the basis of the tension stress-strain curve, the flow stress p of pulled materials is calculated as r-, where r is the actual stress and is the logarithm of the strain. Determine the true stress by computing the cross section of the sample S under the applied load of force F. The existing elastic and plastic elongation make it necessary to determine the true diameter of the sample, d, in order to calculate the true cross-section of the sample. The value of actual stress r0.2 was determined by applying the formula (1) (9) to the proof stress load.

$$\sigma_{r0.2} = \frac{R_{p0.2}}{\left[\sqrt{1/1.002} - \nu \cdot R_{p0.2}/E\right]^2}, \qquad (1)$$

where [Poisson's ratio, Rp0.2, proof stress, and Young's modulus, E, are all constants. The proof stress and other strength parameters were determined using an Instron 1116 static uniaxial tension testing equipment. The derivative of the function f(p) was then calculated. The exteriors of the wires were then altered. For the purpose of this study, we chose to test wires that had both their surfaces electropolished and chemically pas seated using 40% nitric acid. The pas salvation period lasted for 20-60 minutes at a temperature of 65 C. Abrasive paper ranging in granularity from 80 to 1200 was used to prepare the wires for polishing and passivation. We were able to use it to clean the surface of any remaining grease or sub-grease following the sketching process. Images of drawn 1.5 mm diameter wire and wire rod are shown in Figure 1. A sub grease layer (represented by the rod) and a grease layer (represented by the wires) are clearly discernible on the surface. Grease residues would prevent the electrochemical polishing and passivation processes from being carried out effectively. The wires' resistance to corrosion would likewise degrade. The wire's surface after plastic processing was photographed using a field emission scanning electron microscope (FE SEM) S-4200 from Hitachi.

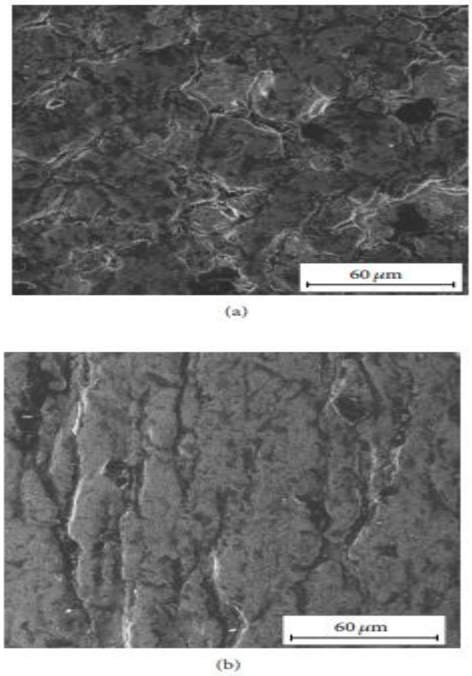

Figure 1: Surface of wire rod (a) and wire with diameter of 1.5 mm (b).

Table 1: Chemical composition of artificial blood plasma solution.

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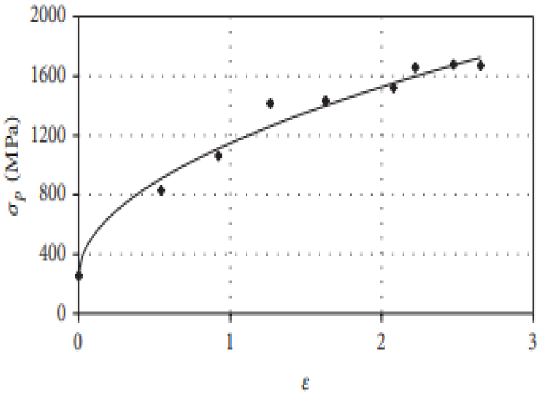
Chemical compound	Amount of distilled water, g/L
NaCl	6.8
$CaCl_2$	0.2
KCl	0.4
$MgSO_4$	0.1
$NaHCO_3$	2.2
Na_2HPO_4	0.126
NaH_2PO_4	0.026

3 Results

The tensile test results for various diameter wires are listed in Table 2. Using the proof stress and the real stress values r0.2 found in tensile testing, a flow curve of the tested wires was constructed, and the mathematical form of the flow stress function was derived. The stress value at the beginning of the drawing process (i.e., for annealed wire) was taken into account while approximating the curve using the function p = p0 + Cn. The tested steel has the following mathematical form for the flow stress function:

$$\sigma_p = 253.1 + 894.6\varepsilon^{0.51}. \qquad (2)$$

The strain in the drawing process is shown as a logarithm in Figure 2, which shows the flow curve of X10CrNi 18-8 steel wires. We were able to evaluate the relationship between the strain imposed during the drawing process and the method of wire surface preparation by conducting potentiodynamic experiments in fake blood plasma. After 60 minutes, the OCP potential of all samples examined had reached a steady state. The results of the corrosion tests are shown in Table 3. Some examples of anodic polarization curves are shown in Figures 3 and 4. The next step was to check whether corrosion characteristics are significantly correlated with strain during drawing.



Process flow diagram for X10CrNi 18-8 steel wire (Figure 2).

Using data from a subset of corrosion experiments, the figure 5 curves demonstrate how the polarization resistance Rp varies with the strain applied during the drawing process. The functions with the transformation Rp = f() was chosen. The items in question resemble the following:

(i) electrochemically polished wires

$$R_p = -118.4\varepsilon + 592.5, \quad R^2 = 0.886, \qquad (3)$$

(ii) wires that were polished and chemically passivated

$$R_p = -444\varepsilon + 2057.5, \quad R^2 = 0.842. \qquad (4)$$

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Static analysis proved that significance level $P < 0.05$.

4. Discussion

One of three standard tests—tensile, compression, or torsion—is used to determine the flow stress of a material experimentally. Although static tensile testing involves a strain that is too tiny to be taken into account by engineers designing plastic forming processes, it remains the sole viable option for doing tests on thin wires. We were able to pick the flow stress function of X10CrNi 18-8 steel drawn wires and calculate their flow curves thanks to the mechanical characteristics tests we ran.

Table 2: Strength properties of wire.

Wire diameter d, mm	Logarithmic strain in the drawing process, ε	Tensile strength R_m, MPa	Proof stress $R_{p0.2}$, MPa
5.65	–	604	252
3.0	1.27	1607	1403
2.0	2.22	1827	1507
1.5	2.65	2178	1653

Table 3: Test results of pitting corrosion resistance.

Wire diameter d, mm	Strain in drawing process ε	Breakdown potential E_b, mV	Polarisation resistance R_p, kΩcm^2	Corrosion current density i_{corr}, μA/cm^2
Electrochemically polished wires				
5.6	0	+612	567	0.04
3.0	1.27	+510	459	0.10
1.5	2.65	+380	229	0.11
Electrochemically polished and chemically passivated wires				
5.6	0	+858	2220	0.012
3.0	1.27	+778	1230	0.021
1.5	2.65	+695	1070	0.024

By conducting potentiodynamic measurements, we were able to determine how the strain introduced during the drawing process affected the resistance of the wire to the fake blood plasma solution used to simulate electrochemical corrosion. Corrosion resistance was shown to deteriorate with increasing tension. The anodic current density rises as the perforation potential and polarization resistance fall. That propensity holds true for wires that have been electrolytically polished as well as those that have been polished and subsequently chemically passivated. The presented findings make it clear that chemical passivation significantly increased wire resistance to electrochemical corrosion in simulated blood plasma. Passivated wires have better resistance to corrosion than electrolytically polished wires. The results of a static study revealed a strong correlation between the strain used in the drawing process and the material's corrosion qualities (polarization resistance). We draw conclusions about the polarization resistance of wire after subjecting its surface to various treatments based on the presented curves and functional relations. Polarization resistance reveals that chemical passivation of wires used in manufacturing X10CrNi 18-8 steel cardiologic guides was warranted. The presented curves are accurate depictions of the experimental findings. Differences in polarization resistance are most apparent for wires of varying starting diameters. It is important to note that the functions described in the article only apply to one heat. The experiments need to be redone with a larger number of temperatures in order to be transformed into universal relations for X10CrNi 18-8 stainless steel.

5. Summary and Conclusions

The study proves that increase of strain in drawing process of wires made of stainless steel X10CrNi 18-8 causes decrease of their resistance to electrochemical corrosion in artificial blood plasma. Moreover, it was observed that chemical passivation improves wire corrosion characteristics. Potentiodynamic test results also enabled us to obtain functional relations showing the influence of strain in drawing process on the change of polarisation resistance. It mustbe mentioned that presented functional relations are not of universal character and refer only to wires made of X10CrNi 18-8 steel tested in artificial blood plasma. If they are to be applied either to wires or other materials (e.g., other grades of steel, titanium alloys, cobalt alloys, alloys with elastic memory effect, and many other) or goods for other purposes, it is necessary to perform similar test for wires made of the respective

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material in another environment simulating human body saline (artificial urine solution, artificial saliva, and Tyrode or Ringer solution). Problematic aspects presented in the study are crucial for process engineers who deal with designing wire drawing processes for medicine, as the issue of correct description of material plasticity is tightly connected with the selection of optimum parameters of wire production technological process. That issue is equally important to guide wire manufacturers, because if the respective curves or functions are to be applied, it is possible to forecast in advance corrosion characteristics of wire with the required strength drawn with the applied strain.

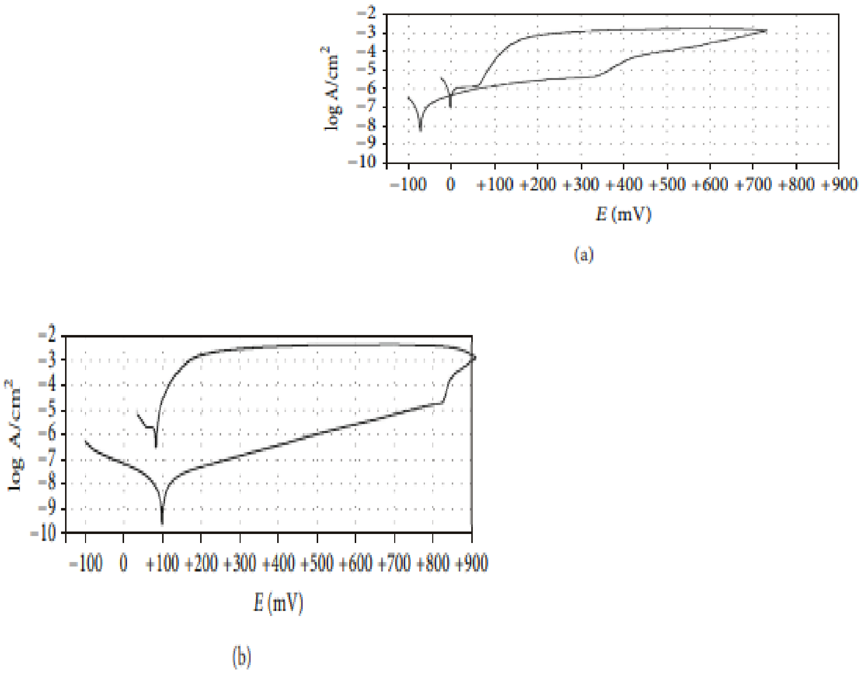

Figure 3 shows an anodic polarization curve for electropolished (a) and passivated (b) wire rod with a diameter of 5.65 mm.

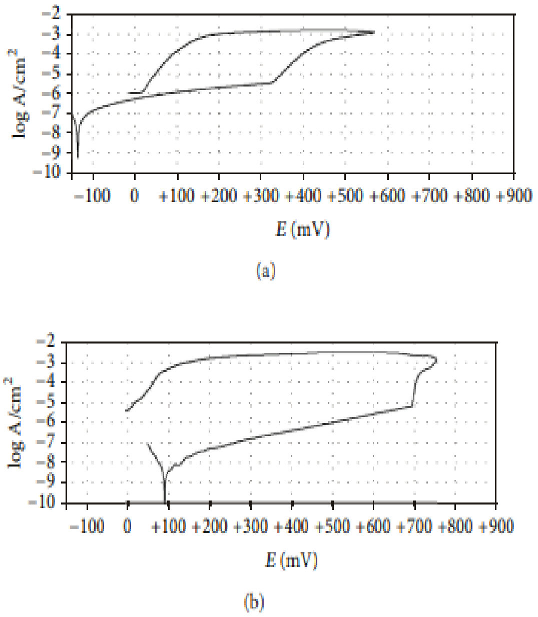

Figure 4 shows the anodic polarization curve for electropolished (a) and passivated (b) wire with a diameter of 1.5 mm.

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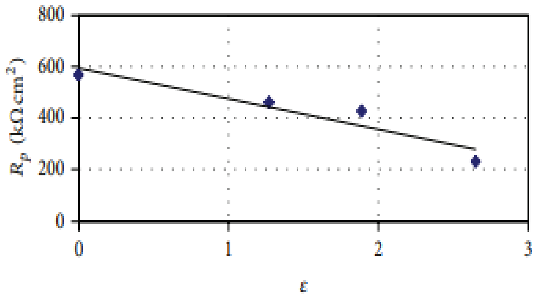
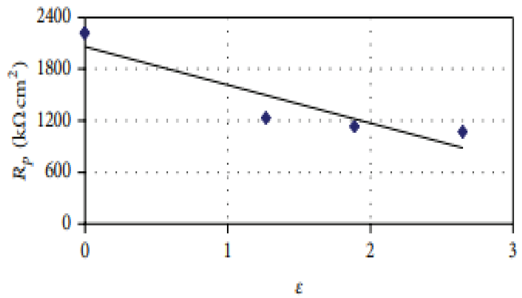


(a)



(b)

Figure 5 shows the relationship between polarization resistance and strain during the drawing process for two types of electrochemically polished and passivated wire (a) and (b).

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