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INFLUENCE OF SURFACE FINISH PARAMETERS ON CORROSION OF ZINC

By

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ABSTRACT

The effect of surface parameters on corrosion behaviour of pure zinc in sodium sulphate solution was investigated. Surface parameters were determined using a Talysurf surface analyzer, and corrosion testing was performed using the Tafel plot technique. It was found that the corrosion rate decreases linearly with increasing the grit size while the polarization resistance increases. Also, it was found that the increase in surface roughness has two conflecting effects. The first leads to a decrease in corrosion potential due to a decrease in the cathodic surface area while the second leads to an increase in corrosion potential due to a decrease in the peak to valley distances of surface irregularities.

INTRODUCTION

Surface parameters has been shown to exert a great influence on corrosion behaviour of steel and in particular the amplitude parameters have the most significant effects (Kandeil and Mourad, 1988). Similarly, a significant increase in pitting resistance of carburized steel was obtained by improving the surface roughness of the material (Sheehan and Howes, 1973). A variety of methods are utilized for preparing specimens for corrosion tests in the laboratory (Uhlig, 1948; Fontana and Green, 1978). The most common and widely used surface finish is produced by simply grinding with grit 120 abrasive paper or its approximate equivalent.

The objective of the present investigation is to examine the effect of surface texture on the corrosion behaviour of zinc in Na_2SO_4 solution using the Tafel plot technique.

EXPERIMENTAL STUDIES

The corrosion specimens were machined from zinc bars 99.99% purity to cylindrical discs 12 mm diameter and 5 mm in height. They were submitted to mechanical polishing using silicon carbide abrasive papers with the following grain sizes: 120, 240, 320 and 400 grit. The surface texture of the polished specimens was measured using a Talysurf-5 surface analyzer (Hobson).

For performing the polarization measurements the specimens were degreased by washing with acetone, then fitted into a flat specimen holder (model K105 EG, G Princeton Applied Research - U.S.A) which contains a sealing washer made of Karlez and exposing 0.24 cm^2 of the specimen surface to the test solution. A corrosion cell (model K47), which contains two counter electrodes made of high density graphite was used with a Corrosion Measurement System (model 350A EG, G Princeton Applied Research - U.S.A). The potential was measured with respect to a saturated calomel electrode (model K77). The experimental measurements were conducted in 0.1 M sodium sulphate solution at 25°C. All solutions were prepared using bidistilled naturally aerated water.

The scanning of the Tafel plots started after an initial delay interval of one hour with a scan rate of 1 mV. sec^{-1}. The anodic and cathodic regions were scanned in a single run by an initial potential of -150 mV, and a final potential of +150 mV, both E_{corr} related, to determine the instantaneous corrosion rate of zinc i_{corr}.

RESULTS AND DISCUSSION

The data of Table 1 show the effect of the grit size of the abrasive papers on the corrosion parameters of zinc specimens in 0.1 M Na_2SO_4 solution at 25°C. Figure 1 shows a typical Tafel plot of zinc specimen polished with 120 - grit. Optical micrographs of the various surface finishs examined are shown in Figure 2.

Table 1

Effect of grit size on corrosion parameters of zinc in 0.1 M Na_2SO_4 at 25°C

Corrosion Parameters \ Grit size	120	240	320	400
E_{corr}, volt	-1.053	-1.051	-1.062	-1.077
$i_{corr} \times 10^4$, nA/cm²	118.70	81.92	48.31	18.42
$i_{cath} \times 10^4$, nA/cm²	62.39	30.44	20.67	17.86
PR, Ω. cm²	37.51	63.24	97.54	143.2
b_a, volt/decade	0.161	0.158	0.153	0.79
b_c, volt/decade	0.262	0.487	0.373	0.263

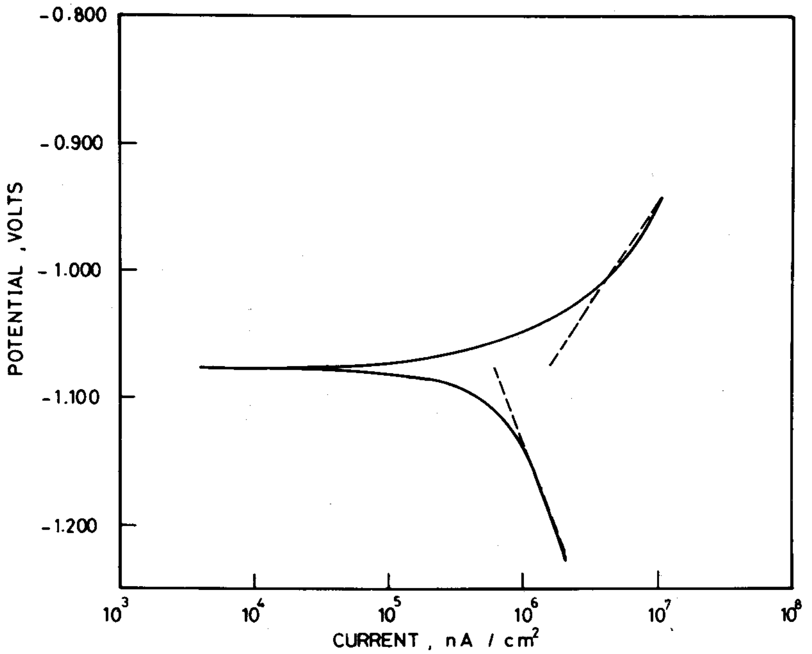

Fig. 1: Tafel plot for Zn-specimen in 0.1 M Na_2SO_4 at 25°C (120 Grit).

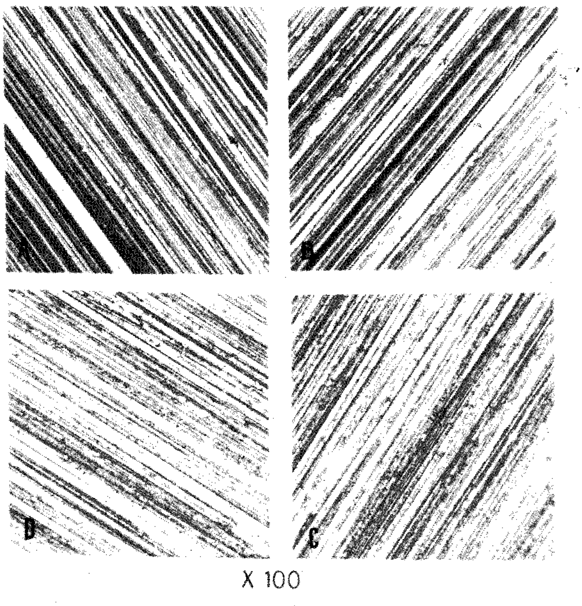

Fig. 2: Optical Micrographs of test specimens with various surface finishs (Grit: A=120, B=240, C=320, D=400).

It can be seen from Table 1 that the corrosion potential shifts to a more negative value with increasing the grit size of the abrasive paper. It was found that the corrosion rate decreases linearly with increasing the grit size (G) according to the equation

$$i_{corr} = 162.5 - 0.36\,G \qquad (1)$$

As seen from Figure 1 the Tafel plots extend over a wide potential range to engender changes in the surface characteristics of the specimens. As a result, the extrapolation of the anodic and cathodic linear Tafel regions do not intersect at E_{corr} which indicates an error in the measurements, since the rate of oxidation must equal the rate of reduction at E_{corr}. Thus it is advisable to measure cathodic corrosion rate i_{cath} at the point where the cathodic Tafel extrapolation intersects E_{corr}.

The results given in Table 1 also indicate that the cathodic corrosion rate i_{cath} decreases with increasing the gift size as shown in Figure 3. Similarly the increase in the grit size leads to an increase in the polarization resistance PR according to the following relationship.

$$\text{Log PR} = 1.392 + 1.86 \times 10^{-3}\,G \qquad (2)$$

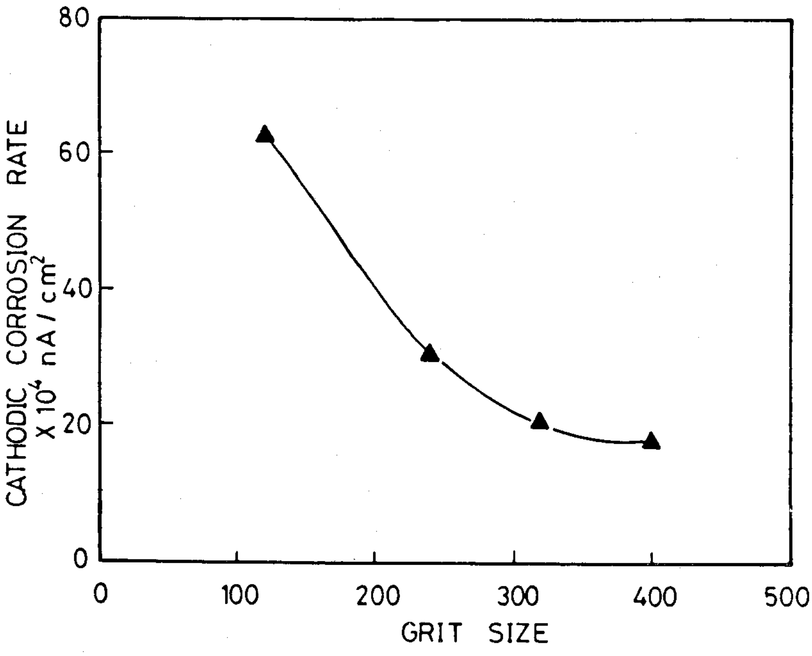

Fig. 3: Effect of grit size on cathodic corrosion rate of Zn in 0.1 M Na_2SO_4 at 25°C.

Surface texture is very complex and can be quantified by many parameters which are related to certain characteristics of the texture. These parameters can greatly affect the corrosion process and clear understanding of the surface morphology, as quantified by these parameters, will help better understanding of the corrosion behaviour. Surface parameters can be classified into three groups, according to the type characteristic that they measure. These are amplitude, spacing and hybrid parameters. Some of these parameters are dealt with in the present study and a brief description is given below. The reader is referred to a specialized reference for more information on surface texture measurements (Dagnall, 1980).

a. Amplitude parameters are measures of the vertical displacements of the surface profile, e.g. Ra, Rq and Rp. Ra is the universally recognised, and most used parameter of roughness. It is the arithmetic mean of the departures of the profile from the mean line. It is normally determined as the mean result over several sampling lengths L (Fig. 4). Rq is the root mean square parameter corresponding to Ra, while Rp is the maximum height of the profile above the mean line within the assessment length (Fig. 5).

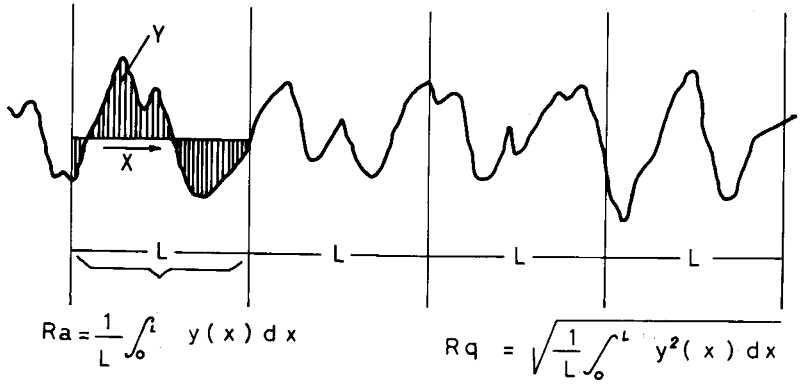

Fig. 4: Determination of the roughness parameters Ra and Rq.

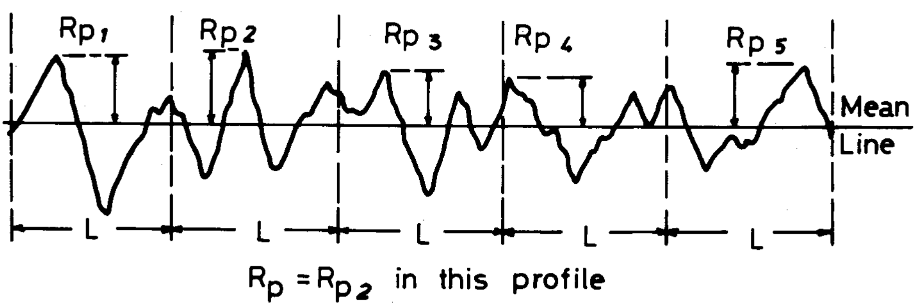

Fig. 5: Determination of the parameter Rp.

b. Spacing parameters are measures of the irregularity spacings along the surface, irrespective of the amplitude of these irregularities.

c. Hybrid parameters relate to both the amplitude and spacing of the surface irregularities, e.g. parameters Δq and λq. The parameter Δq is the root mean square slope of the profile throughout the assessment length, displayed as a ratio and λq is the corresponding root mean square wave length parameter.

$$\text{Numerically } \lambda q = 2\pi \cdot \frac{Rq}{\Delta q}$$

Table 2 shows the effects of the grit size on the surface parameters Ra, Rp, Δq and λq.

Table 2

Effect of grit size on surface parameters of zinc

Surface parameters (um) \ Grit size	120	240	320	400
Ra	1.258	0.711	0.370	0.053
Rp	3.540	1.782	1.672	0.200
Δq	0.051	0.031	0.022	0.006
λq	183.51	173.3	153.7	77.28

Examination of the relationships between the surface parameters and the grit size G shows that a linear relationship between the parameter Ra and G is obtained as shown in Figure 6. This relationship is expressed by the equation:

$$Ra = 1.76 - 4.34 \times 10^{-3}\, G \tag{3}$$

Similar relationships has been found between the parameters Rp, Δq and G, as follows:

$$Rp = 4.79 - 1.109 \times 10^{-2}\, G \tag{4}$$

$$\Delta q = 6.977 \times 10^{-2} - 1.57 \times 10^{-4}\, G \tag{5}$$

The results also indicate that an increase in the grit size leads to a decrease in the surface parameter λq, as shown in Figure 7.

Since the roughness parameter Ra is the most universally recognized measure of surface texture, its effects on corrosion behaviour will be examined in detail in the following section. The effects of other surface parameters are under investigation.

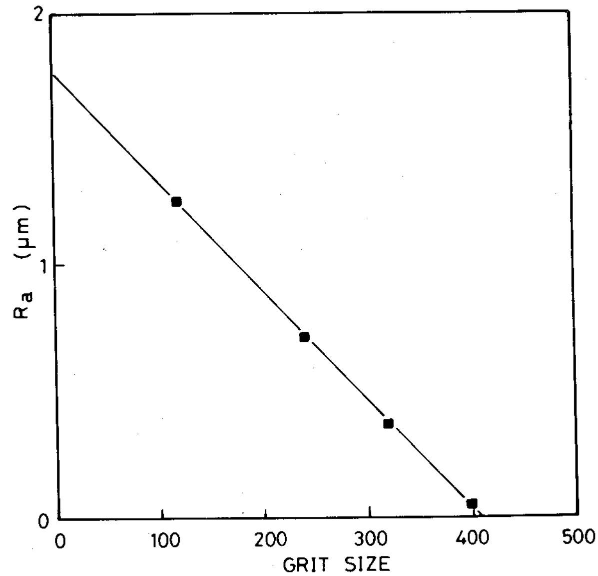

Fig. 6: Relationship between the grit size and the roughness parameter Ra.

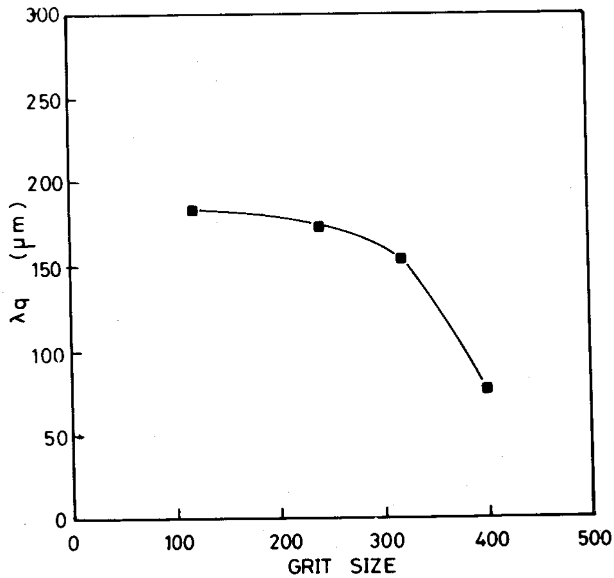

Fig. 7: The dependence of the parameter λ q on the grit size.

Effect of Ra

The experimental data given in Tables 1 and 2 indicate that the decrease of the roughness parameter Ra drifts the corrosion potential towards more negative values. It is further observed that an increase in Ra is accompanied by an enhancement of the corrosion. A linear relationship between the instantaneous corrosion current density i_{corr} and Ra, can be expressed by equation (6) and is shown in Figure 8.

$$i_{corr} = 16.81 + 83.54\,Ra \qquad (6)$$

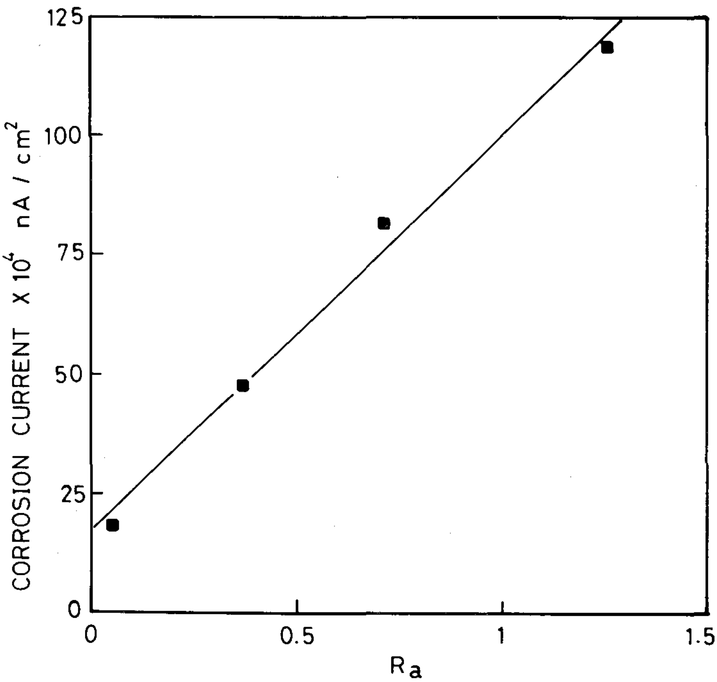

Fig. 8: Effect of the roughness parameter Ra on the corrosion current.

These findings favour the postulation that the increase of the surface parameter Ra causes depolarization of the cathodic process. A schematic representation of the corrosion process can be seen from Evan's diagram constructed in Figure 9. As can be seen from the diagram, an increase in Ra leads to an increase in the corrosion current from I_{c1} to I_{c2} and further to I_{c3} and the free corrosion potential shifts to more positive values from E_c to E_c, and E''_c, respectively. Thus it may be concluded that the corrosion process is mainly cathodically controlled, which is supported by the trend of the Tafel constants given in Table 1.

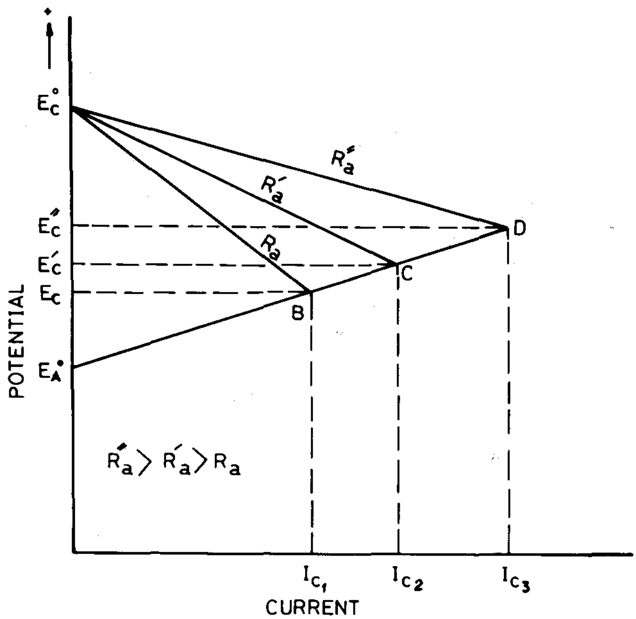

Fig. 9: Polarization diagram showing the effect of Ra on polarization resistance of Zn in 0.1 M Na_2SO_4.

The results shown in Figure 10, indicate that a linear relationship holds between the logarithm of polarization resistance PR and the roughness parameter Ra, as given by equation (Stern and Geary, 1957):

$$PR = 147.9\ Ra^{-0.5} \tag{7}$$

Thus, it can be concluded that an increase in Ra leads to a decrease in the polarization resistance. It is further observed that the corrosion current is inversely proportional to the polarization resistance in accordance with Stern-Geary equation (Stern and Geary, 1957; Stern, 1958) (Fig. 11).

Metal loss and build-up of corrosion products occur at the anodic area of the corrosion cell. The chemical reaction that occurs at the anode (corroding area) is believed to be as follows:

$$Zn + SO^{-2}_4 = ZnSO_4 + 2e \tag{8}$$

The cathodic reaction consists of the reduction of dissolved oxygen due to the emergence of electrons that are generated at the anode (Equation 8) and travel through the zinc to the cathode as follows:

$$\tfrac{1}{2}\ O_2 + H_2O + 2e = 2\ OH^- \tag{9}$$

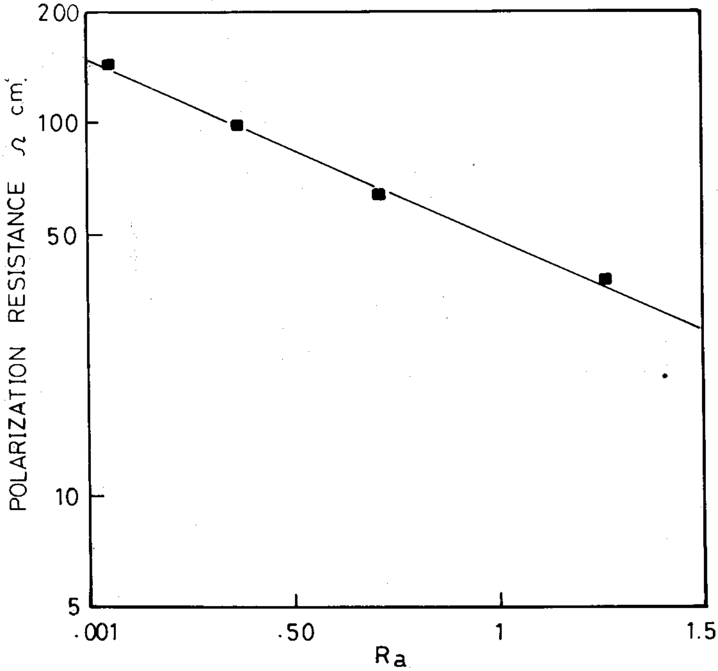

Fig. 10: Effect of the roughness parameter Ra on polarization resistance.

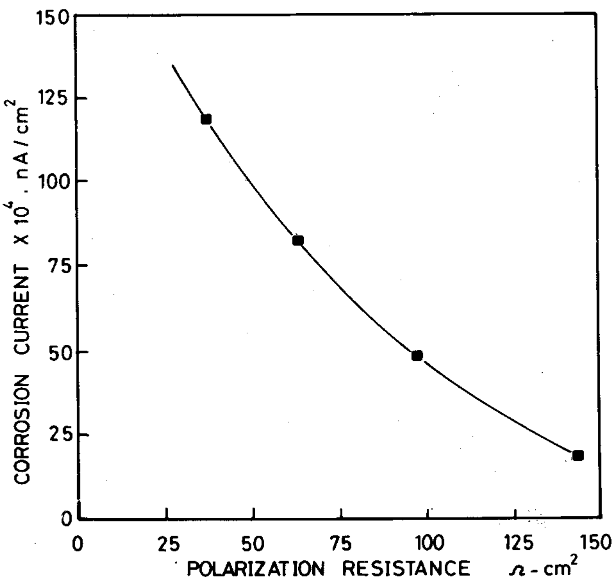

Fig. 11: Relationship between polarization resistance and corrosion current.

The decrease of the corrosion current with increasing the grit size, i.e. decreasing the surface roughness, may be attributed to a decrease in the true surface area of the corroding surface and probably due to a decrease in the concentration gradient of the dissolved oxygen within the valley areas of the surface profile. Another important factor to consider is the area effect, or the ratio of the cathodic to anodic areas (peak to valley areas). As this area ratio increases the current density at the anode will increase and this is the case with the rough surfaces produced with the small grit size. On the other hand, the distances between the peaks and valleys decrease with decreasing the surface roughness, as illustrated in Figure 12. This decrease in the peak-valley distances tends to increase the corrosion current.

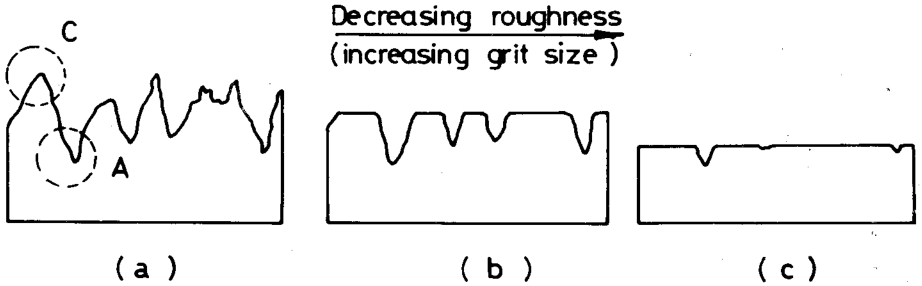

Fig. 12: Schematic illustrating the change of the surface profile with increasing the grit size (C: cathodic area A: anodic area).

In other words, the increase in surface roughness has two conflecting effects. The first leads to a decrease in corrosion potential due to a decrease in the cathodic surface area. The second effect leads to an increase in corrosion due to a decrease in the peak to valley distances of surface irregularities.

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تأثير تشطيب السطح على تآكل الزنك

ممدوح يوسف مراد و عبد الرازق يوسف قنديل

تم دراسة تأثير طريقة إعداد سطح العينة على تآكل الزنك النقي في محلول سلفات الصوديوم ، وقد تم قياس معاملات خشونة السطح بواسطة جهاز قياس خشونة الأسطح (تيليسيرف) وتم إجراء إختبارات التآكل باستخدام طريقة (التافل) . وقد وجد أن معدلات التآكل تتناسب تناسباً عكسياً مع زيادة حجم حبيبات التلميع للسطح بينما تقل مقاومة الإستقطاب . وقد أُستنتج أن زيادة خشونة السطح لها تأثيران متضادان ، أحدهما يؤدي إلى نقص في معدلات التآكل نتيجة نقص في المساحة الكاثودية بينما يؤدي الآخر إلى زيادة جهد التآكل نتيجة لنقص المسافات بين المرتفعات والمنخفضات على سطح العينات المتآكلة وقد تم التوصل إلى علاقات عددية تربط خشونة السطح مع معدلات التآكل للزنك .