Alex. Eng.J., Alex. Univ., Volume 28 No. 4, pp 311 - 329 (1989)

TOWARDS A BETTER EVALUATION ELECTROPOLISHED SURFACES

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Abstract

The use of the standard surface roughness parameters and introducing of advanced parameter towards a better evaluation of the electropolishing process for vertical Brass cylinders was represented. Expermintal analysis was performed to evaluate the process and the variables affecting it. The effect of the electropolishing process on the surface quallity and on some of the mechanical properties of the tested specimens was also investigated.

The surface quality and the mechanical properties of the electropolished products were found to be function of the electropolishing variables such as $H_3 PO_4$ concentraction, time of electropolishing and the temprature of $H_3 PO_4$ during the process. The use of some advanced parameters for surface evaluation in electropolishing namely, the average wave length and the average slope, was found to hav e a good guide in determining the recommended working conditions for electropolishing process.

The tensile strength, ductility and the fatigue life of brass are affected by the electropolishing process and its variables.

1. INTRODUCTION

Electropolishing is the smoothing of a metal surface anodically in a concentrated acid. Metals are electropolished for one or more of the following purposes:

1- Improve appearance and reflectivity.

2- Remove edge burrs produced by mechanical cutting tools

3- Remove the stressed and disturbed layers of surface metal caused by cutting processes.

Electropolishing is a very effective process in removing micro-roughness of metal. The evaluation of the quality of electropolishing-process depends on many parameters, the most important among these parameters is the quality of the surface texture of the produced surface, i.e. the degrees of smoothness and brightness of the surface.

The surface texture can be analysised to three main features, the micro-irregularities (roughness), the macro-irregularities (waveness), and the form errors (Fig. 1). However, the roughness of the electropolished surfaces can be considered as the dominant feature of the surface texture which affects its quality.

There are many parameters can be used for roughness assessment. These parameters fall into three groups, depending on the characteristics of the roughness profile that they quantify. These groups are:

1. Amplitude parameters:

Which are determined solely by peaks or valley height, or both.

2. Spacing parameters

which are determined by the spacing of irregularities along the surface

3. Hybrid parameters

Which are determined by amplitude and spacing in combination

The most feasible roughness parameters which reflect smoothness and the degree of brightness characteristics of the surfaces are; the roughness average value (Ra)(amplitude parameter), the average wave length (λ_a) (spacing parameter), and the average slope (Δa) (hybrid parameter), (Fig. 2). These roughness parameters are chosen to be involved in the evaluation of the surface quality of the polished surfaces.

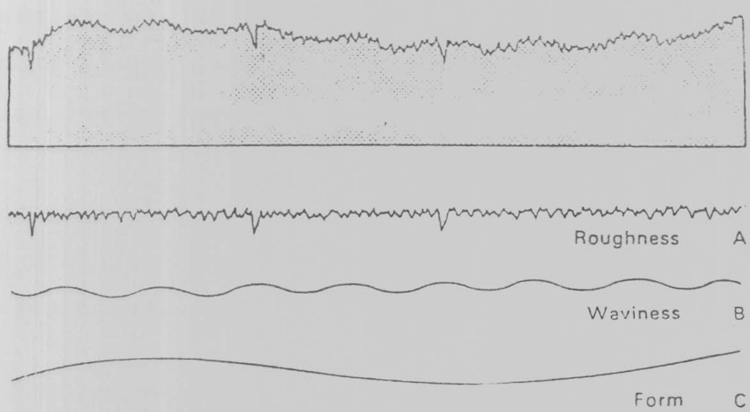
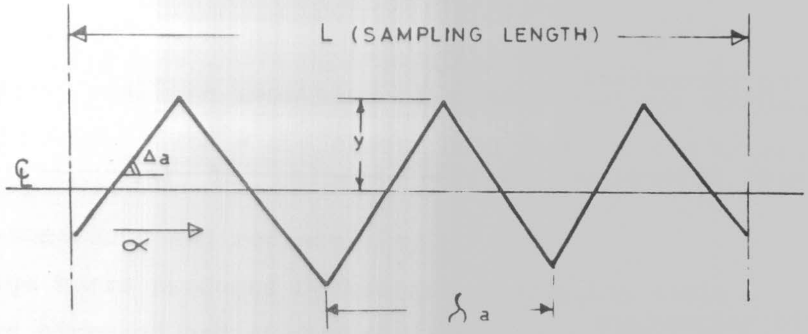


Fig. 1 A surface profile represents the combined effect of roughness, waviness and form



$$R_a = \frac{1}{L}\int_0^l /y_x/\, d_x$$

$$\lambda_a = 2\pi \frac{R_a}{\Delta a}$$

Fig.2 Surfaces roughness parameters

2.EXPERIMENTAL TECHNIQUES

Frequently in the process industries, it is desirable to change process variables to elaborate their effect on the process quality . One of the most frequent questions is : What effect will this change have on the electropolishing process?

In the following section, some of the most common variables are considered, to investigate their effect on the surface quality of the electropolished surfaces as well as the mechanical properties of electropolished specimens.

Experiments were carried out for vertical Brass cylinder(70% Cu,30%Zn) of 20 mm diameter and 20 mm height in phospheric-acid(H_3PO_4).

fig.(3). shows the cell and the electrical circuit used. The following variables were investigated:-

- H_3PO_4 concentration (8,10 & 12 M/1).
- Electropolishing time (20,30,40, & 50 min.)
- Temperature of phosphoric-acid(30,40,50 & 60 °C).

The surfaces profiles for all tested specimens were measured using Talysurf 4 instrument,before and after electropolishing. The surface roughness parameters(R_a,λ_a &Δ_a)were calculated directly from the instrument and were obtained as printouts.

For tensile tests, specimens were precimens were prepaired for use on the (Instron) testing machine, which gives direct printouts for the results of tension tests(Load-extension curves) ,to calculate the variations in the stress and strain for each test.

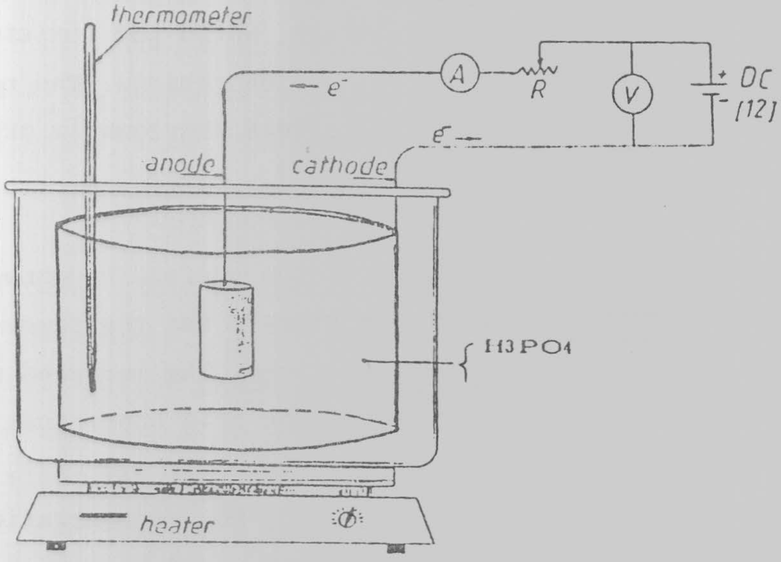


Fig.3. Electropolishing cell and electrical circuit.

Bending loading fatigue tests were performed using rotating bending fatigue machine with the recommended shapes from Brass specimens to calculate the fatigue life for the electropolished Brass specimens under differents working conditions.

3. RESULTS AND DISCUSSIONS

3.1 EFFECT OF PHOSPHORIC ACID(H_3PO_4) CONCENTRATION

Electropolishing is a process which take place at the limiting current,which is the maximum possible current at which a given electrochemical process can be conducted. For three different H_3PO_4 concentralions (8,10 &12 M/1) using the electropolishing cell(see Fig.(3).) the limiting currents were determined.Moreover surface roughness parameters were measured as well as the rate of metal removal after the electropolishing process.

The relationships between current density and potential for the three concentrations are shown in Fig.(4),in which the limiting current decreases with the increase of H_3PO_4 concentrations. The results are in agreement with other workers (2). This decrease is explained on the basis of mass transfer equation(2,3).

Fig.(4) illustrates the variations of the surface roughness average Ra, average wave length λ_a, the average slope Δa,and the removed metal Δw against the phosphoric-acid concentrations. The measured parameters R_a, λa & Δa decrease with the increase of the acid concentration till they show minimum values at concentration of 10 M/1, then they increase again with the increase of the H_3PO_4 concentration. As Faust(5) mentioned, an electropolished surface in essentially equipotentialized. Thus, only a minimum number of local corrosion cells can be set up, because local galvanic difference due to stress in the metal surface have been eliminated. But as Fontana (5) reported that when the acid concentration is increased, the corrosion rate likewise increased. This is primairly due to the fact that the amount of hydrogen ions which are the active specis are increased as acid concentration increased.However, as acid concentration is increased further, corrosion rate reaches maximum and then decreases, this could be a reseonable explaination for the appearance of minimum in the values of the measured surface roughness parameters R_a,λa&Δa. at 10 M/1 as shown in Fig.(5), which insure the improvements in the surface quality.

3.2.EFFECT OF ELECTROPOLISHING TIME

The effect of electropolishing time on the different measured parameters is shown in Fig.(6), the removed metalΔw increases with the increase of the electropolishing time. The surface roughness parameters R_a,λa &Δa show decreasing trends with the increase of the electropolishing time,till they reach minimum values at a range of electropolishing time between 30-40 min.,then they tend to increase.

The trend ofΔw could be the explanation for the trend of the surface roughness parameters. After certain machining time the rate of metal removal will be the cause of surface disturbance, which leads to the increase in the values of the surface parameters.

Therefore, for vertical Brass cylinders it is recommended to perform the electropolishing process in phosphoric-acid of 10 M/1 concentration for a duration between 30 and 40 min. to get the best

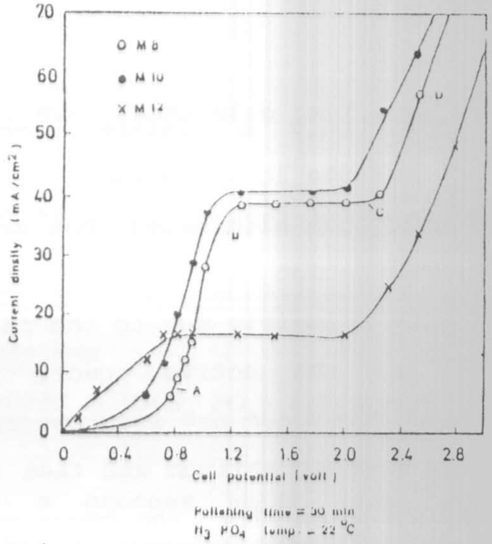
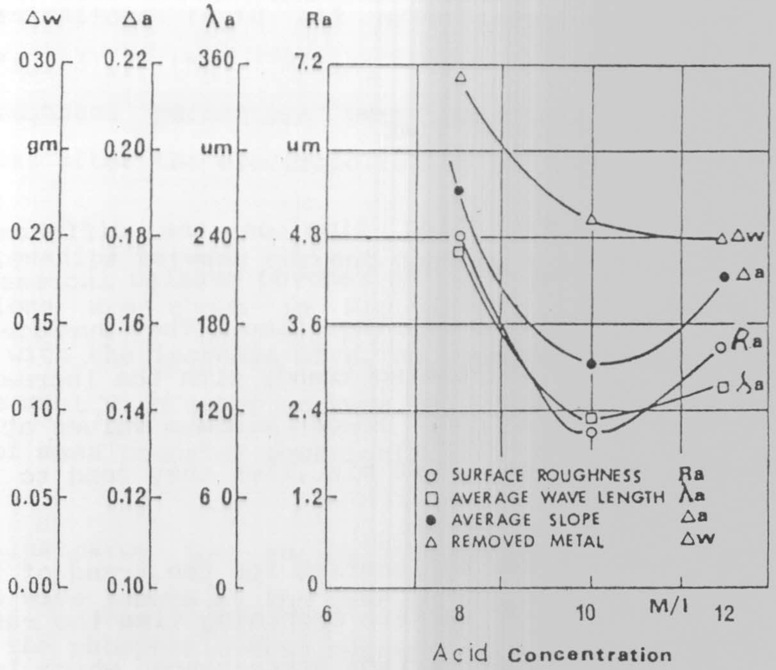


Fig. (4) Effect of H_3PO_4 concentration on limiting current



Work

Applied voltage V= 6 V

Used current I= 3 A

Process duration = 30 min.

Working temp. = 25 C

Specimen:- "Brass 70% Cu, 30%Zn "

Diameter = 20 mm

Height = 20 mm

Fig.5. Effect of acid concentration on the surface quality of electropolished surfaces.

surface quality.

3.3. EFFECT OF TEMPERATURE

In this part from the experimental work it was important to put some spot lights on the effect of the temperature of the acid on the process variables and on the measured parameters.

The limiting current,which is the maximum possible current at which electropolishing process can be conducted, is mainly affected with the phosphoric-acid temperature. This effect was investigated in the range of temperature from 25 °C to 60 °C as shown in Fig.(7), in which the relation between current density against acid temperature is plotted to determine the limiting current of the process for each working temperature. The results are summarized in Fig.(8). The current density shows a minimum value at a working temperature of 30 °C, then it increases with the increase in the acid working temperature. The results are in agreement with the conclusion from Fontana (5),temperature increases the rate of almost all chemical reactions. Representative photographs were taken for electropolished brass specimens at different working temperatures to illustrate the effect of the temperature on the electropolished surfaces. The increase of working temperature increase the possibilities of the appearance for the dezincification phenomina(selective leaching), in which the selective removal of zinc in brass alloys takes place (5). This phenomina leads to imperfection of the surface roughness of electropolished surfaces as indicated from the shown photographs in Fig.(8).

Fig.(9) shows the increase in the surface roughness average R_a

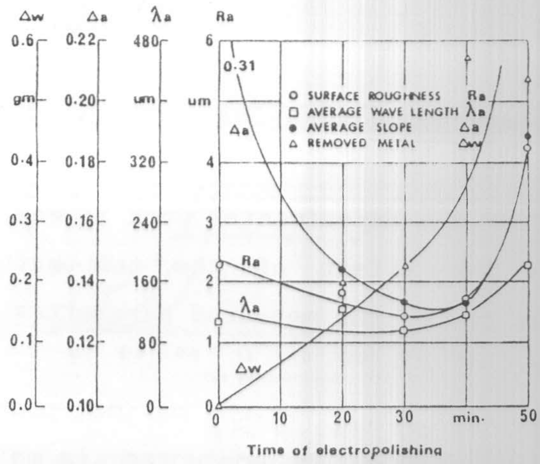


Fig.6. The effect of electropolishing time on the surface quality of electropolished surfaces.

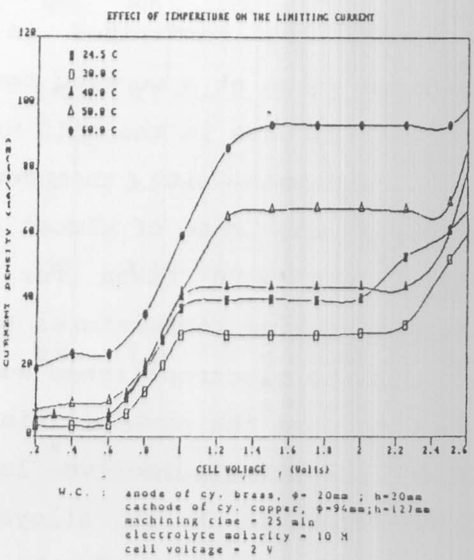


Fig.7 Effect of acid temperature on the limiting current.

against the increase in the acid working temperature. The removed metal Δw increases with the increase in the working temperature till it reachs a maximum at 40 °C, then almost constant rate prevails as the working temperature increases. The relations of the average wave length λ_a and the average slope Δ_a against the working temperature in Fig.(9) show a minimum at 40 °C, then increase with the increase in the working temperature. From the above results concerning the working temperature, it is recommended to perform the electropolishing process for vertical brass cylinders at working temperature not more than 40 °C The increase in the working temperature more than 40C will disturbe the process stability (lilmiting current) and will lead to the appearance of the undesired dezincification phenomina.

Electropolishing is primarily intended to remove the surface layer of a metal by anodic treatment in an acid bath.Electropolishing is effective in removing microroughness, remove edge burrs produced by mechanical cutting tools and also it remove the stressed and disturbed layer of surface metal caused by cutting process, and tearing action of mechanical stock removal or of abrasive finishing.

A representative photographs taken under the microscope(SEM),for turned brass discs (facing process) with rough and fine machining conditions (see Fig.(8) &Fig.(11)) before and after electropolishing. It is obvious from both figures that the disturbed layers,burrs, microroughness and the machining marks in Fig.(10 a,c) and Fig.(11.a) are totaly disappeared after electropolishing as shown in Fig.(10 b,d) for fine facing process and improved to a great extend for rough facing process as shown in Fig.(11 b). The photographs shown also the results of hemogenous, uniform and reproducible surfaces due to the electropolishing process. These photographs give a close view on the electropolished surfaces to have a clear idea about what could

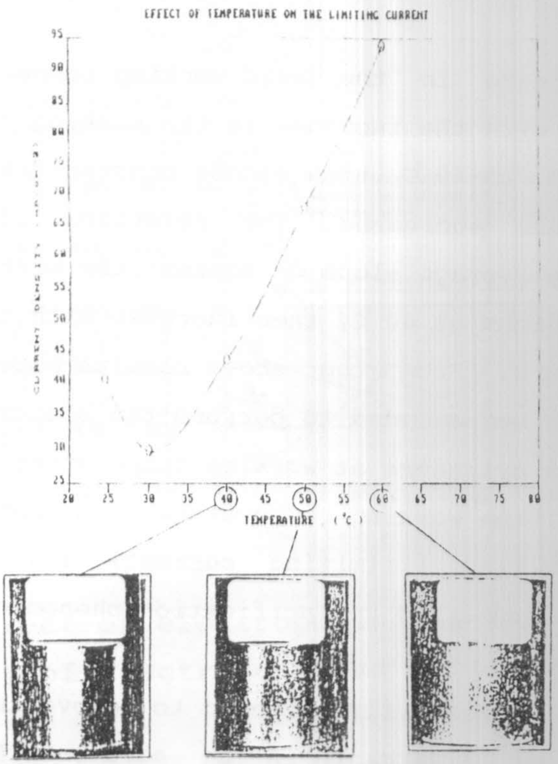


Fig.8. Effect of working temperature on the limiting current.

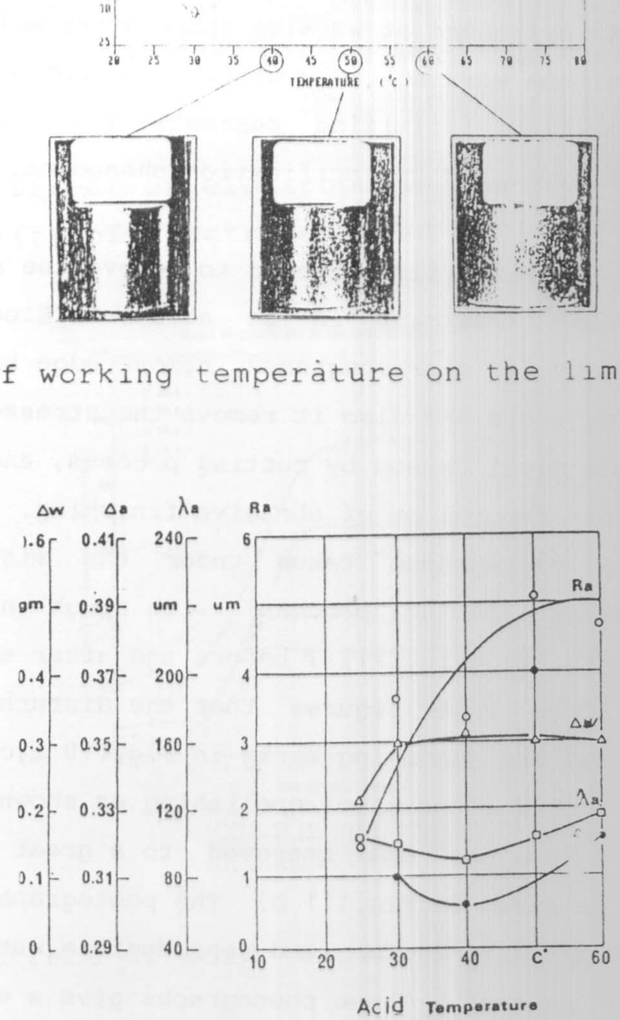


Fig.9. Effect of working temperature on the surface quality of electropolished surfaces.

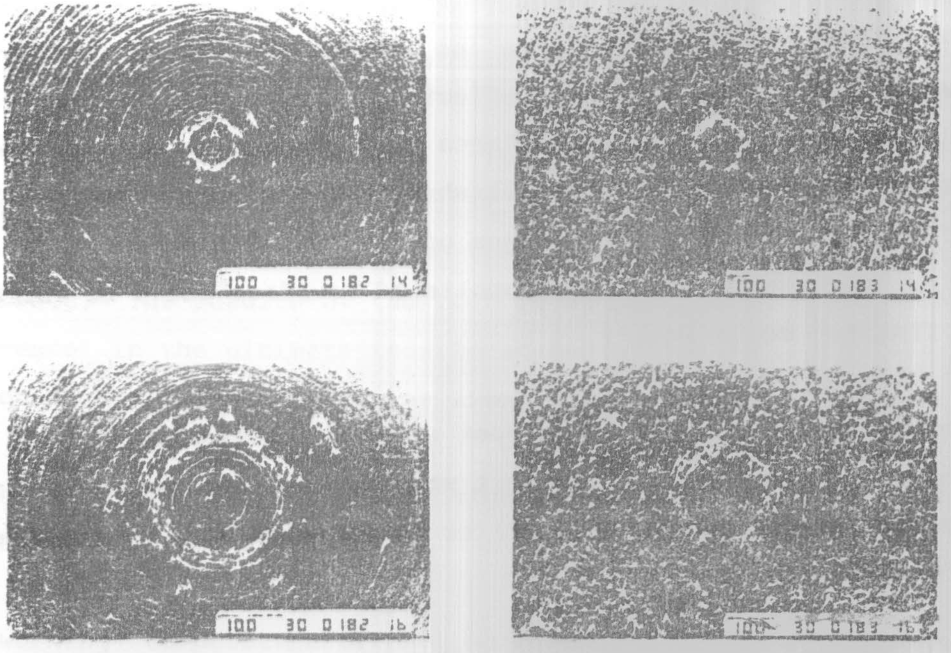


Fig.10.Effect of electropolishing process on the microroughness of machined surfaces (fine facing)

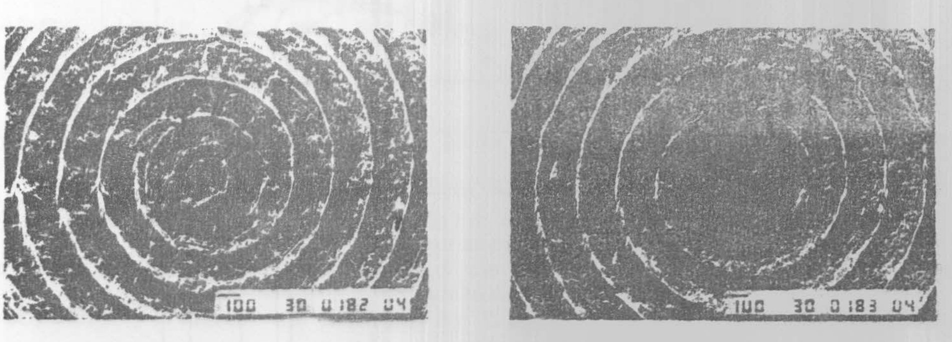


Fig.11. Effect of electropolishing process on the machining marks for rough faced surfaces

electropolishing do in the metal surfaces.

3.4. EFFECT OF ELECTROPOLISHING PROCESS ON THE MECHANICAL PROPERTIES

Since electropolishing empolys no mechanical action, it providesthe means of studying the /true effect" of mechanical treatments of the metal surface. The microroughness of a surface is a major factor in friction and abrasion, electropolishing affects mainly the coefficient of friction and wear performance of any two matting surfaces (4).For bearing services, the electropolished surface could be superior to that finished mechanically.

In order to investigate the effect of electropolishing process on the mechanical properties of brass, it was necessary to prepair main shaps of brass specimens(see Fig.(12) to be suitable for the tension tests and fatigue life tests.

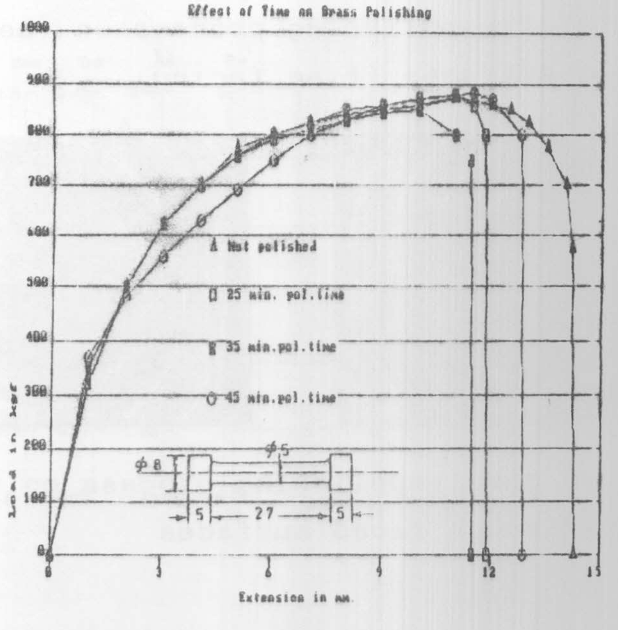


Fig.12. Effect of electropolishing time on the tension tests of electropolished brass specimens.

The effect of electropolishing time as well as the effect of acid working temperature on the tensile strength and ductility of cylindrical brass specimens were investigated and the necesary tests were performed. The results of the tension tests are shown in Fig.(12) and Fig.(13).

Fig.(12) shows the effect of electropolishing time on the tensile strength and ductility of brass . It is clear from the load- extension curve that the electropolishing time affects mainly the ductility of the brass. The results of the test is summarized in Table(1).A small difference in the ultimate tensile strength from 434.78 to 424.78 MPa was found, but the strain varies from 52.9% to 42.9 % .
these difference appears at 35 min. working time. With the increase in the working time the load- extension curve will be close to the curve of the not-polished specimen.

The working temperature of phosphoric-acid affects the ductility and the tensile strength of the brass as shown from the results of the tension tests in Fig.(11) and Table (2). The increament in the working tempeature leads to an increase in the ultimate tensile strength of the brass and leads to a clear decrease in the ductility of brass specially at 35 C working temperature.

These variations in the ductility and in the tensile strength of the electropolished specimens could be refered to the phnomina "Hydrogen Embrittlment", which is caused by penetration of atomic hydrogen into the metal structure during the electropolishing process which results in loss of ductility and tensile strength (5). It is also necessary to notice that dissolved hydrogen reacts to from brittle hydride compounds which could lead to different resu ts (5).

Time min.	Temp. C	UTS MPa	Strain %
— — —	5-6	434.78	52.69
25	25	434.78	44.10
25	35	469.76	44.40
25	40	444.77	52.60
25	50	444.77	48.15

Table 1. Effect of electropolishing time on the stress and strain of brass

Time min	Temp, C	UTS MPa	Strain %
— — —	— — —	434.78	52.96
25	25	434.78	44.10
35	25	424.78	42.96
45	25	434.78	47.78

Table 2 Effect of working temperature on the stress and strain of electropolished brass specimens.

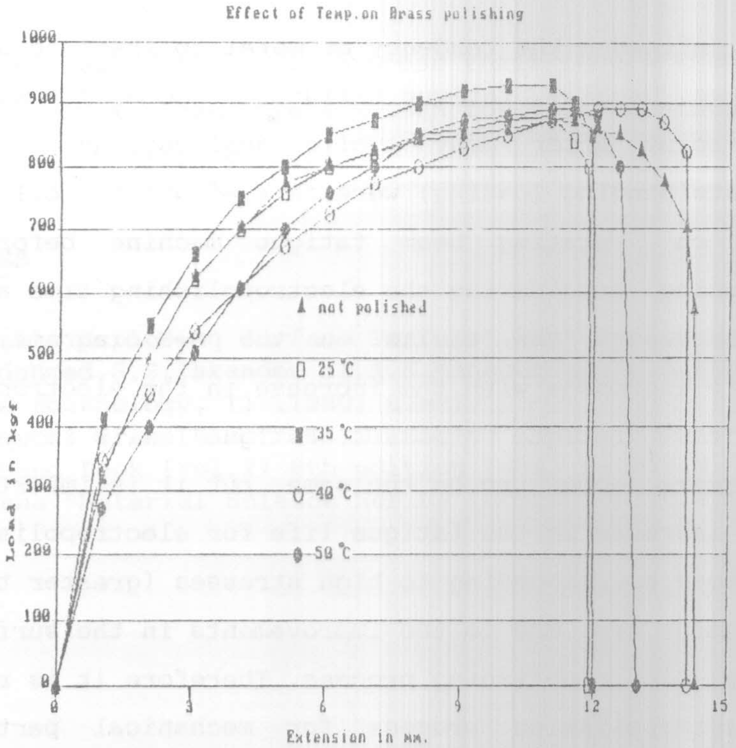


Fig.11. Effect of working temperature on the tension tests of electropolished brass specimens.

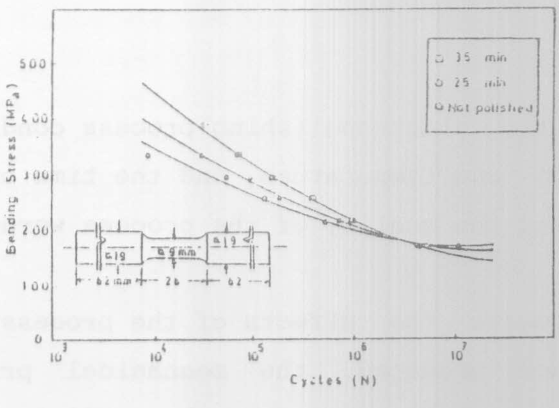


Fig.12. The effect of electropolishing time on the Fatigue strength of brass specimens.

Fatigue is defined a the tendency of metal to fracture under repeated cyclic stress. Usually, fatigue failure occure at stress levels below the yield point after many cyclic applications of this stress. Factigue tests(bending loading) were carried out for cylindrical brass specimens on rotating beam fatigue machine before and after electropolishing considering the electropolishing time as a variable. Fig.(13) represents the results on the S-N diagrams, showing that fatigue life increases with the increase in the electropolishing time under the same fatigue stresses. Fatigue limits for all the tested conditions were about to be the same. but it is important to notice the great increase in the fatigue life for electropolished specimens specially those corresponding to high stresses (greater than 250 MPa). This increament is due to the improvements in the surface roughness due to the electropolishing process. Therefore it is recommended to perform electropolishing process for mechanical parts which are subjected to high fatigue stresses.

4. Conclusion

The effects of the electropolishing process conditions; phospheric acid concentration and temperature, and the time of electropolishing on the behaviour and the quality of the process were investigated.

The results elaborate the effects of the process conditions on the quality of surface produced, the mechanical properties and micro structure of the polished workpieces. The conditions which results in better surface quality were concluded. The electropolished workpieces behave better fatigue behaviour specially at high fatigue stresses.

5. ACKNOWLEDGEMENT

The authers would like to express their incere thank for Engineer A.M.Shamsan and Engineer Liala Hassan for their assistance during the experimental work of this research.

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