

ELECTROCHEMICAL POLISHING OF Al-6.75% Si ALLOYS

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ABSTRACT

Electrolytic polishing of flat surfaces of Al-Si (6.75 %) using of 63 ml perchloric acid (70%), 700 ml ethanol, 100 ml 2-butocyl ethanol and 137 ml distilled water is experimented under conditions of variable cell voltage, distance between electrodes and time. It has been shown that the best conditions with respect to polished surfaces is at 56 volt, 20 seconds and 10 mm separation between the two electrodes. The results agree with the assumptions made by Wagner's in the theory of electropolishing.

Key words: Polishing, Surface roughness, Current density, Separation distance.

INTRODUCTION

Electrochemical behavior of aluminum silicon alloys is a subject of tremendous technological importance due to the increased industrial applications and demands of these materials. Electrolytic polishing (EP) or electrochemical polishing of such materials has been studied extensively [1-3]. The EP is a finishing process used to produce a mirror like surface of a metallic workpiece when it is made anodic in an electrolytic cell under certain conditions. The use of Al-Si alloys for automobile cylinder blocks, cylinder heads and pistons has obvious advantages in terms of weight saved as compared with the usual iron castings. Automobile manufacturers have been using these alloys, in engine pistons, because of their hardness. Now there is a need for alloys containing higher silicon content to meet the demand for compact engines with greater horse power. Other advantages include high thermal conductivity that assists heat transfer in the water cooling and lubrication systems; and enhanced corrosion resistance, low cost and high scrap value [4-5]. Thus one can say that the improvements in efficiency of internal combustion engines have resulted in the increased usage of aluminum silicon alloys. The requirements of high surface quality play a major role in their functional characteristics. Al-Si alloys are difficult to cut due to the presence of large quantities of silicon rich phase (mainly β) specially in the hypereutectic alloys. The β phase is present as nodules of hard phase

distributed at random over a matrix of Al (soft phase) and this makes it difficult to produce very smooth surfaces by the conventional machining techniques. Therefore, electrolytic polishing is widely used to finish parts of engines, airplanes and other mechanical parts [3,6]. Among the numerous theories that describe electrolytic polishing comes Wagner's theory that found important implication in the theory and practice of EP [7,8]. Surface roughness change reflects the index of the polishing process. Surface smoothing depends on the crystal and phase structure as well as by the preceding mechanical treatment to which the material has been subjected. The electrochemical polishing is believed to occur mainly due to preferential reaction of active ions in the electrolyte with active ions at position of higher energy at the specimen surface. The preferential attack of ions will consequently be affected by crystallographic structure of the material i.e. planes directions, grain size and number and distribution of phases present in the grains. Also a strain hardened material would be expected to suffer higher rates of surface deterioration than an annealed one since surface homogeneity is not maintained.

Since EP is expected over a wide range of cell potential, the proper cell voltage is an important factor. In this work, the effect of cell voltage, polishing time and separation distance, between electrodes, on the effectiveness of the polishing of the Al- 6.75 Si alloy is experimented and the results

are reported to determine optimum electrochemical polishing conditions.

EXPERIMENTAL CONDITIONS

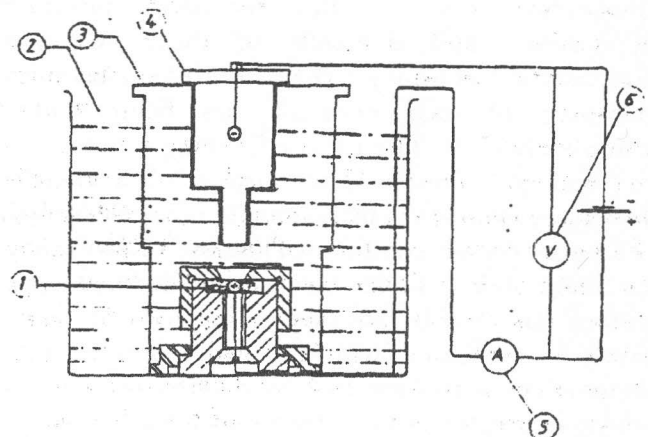
The apparatus used in the present work is shown in Figure (1). Flat workpieces of 16x16x5 mm were cut from car pistons. The chemical composition of workpiece material is shown in Table (1). The initial workpiece surface was generated by conventional grinding, followed by fine mechanical polishing using a series of standard emery paper leaving the initial roughness between 0.6 to 0.9 μm Ra. The cathode material was pure commercial aluminum (99.9 %) with an active area facing the anodic workpiece of 0.785 cm^2 . The electrical circuit consisted of 60 volt dc power supply besides a multirange ammeter of maximum reading 3 A and a sensitivity of 0.0001 A. The anodic workpiece was connected to the positive terminal while the cathodic end (tool) was connected to the negative terminal. A voltmeter was also used to measure the cell voltage. The distance between electrodes was varied between 5 and 20 mm. The change in current density, with time, for the different voltages was monitored. Each electrochemical polishing test was carried out using fresh electrolyte of 63 ml perchloric acid (70%), 700 ml ethanol, 100 ml 2-butocy ethanol, 137 ml distilled water with a non-electrochemically polished workpiece.

Table 1. Chemical composition of tested alloy (wt%).

Al	Fe	Zn	Si	Ni
92.53	.065	.006	6.75	0.01
Mn	Pb	Cu	Mg	Ti
.226	.007	.01	.36	.004

In a preliminary group of tests electrolyte temperature was measured and found to remain almost constant. This constant temperature was attributed mainly to the large electrolyte volume with respect to the small polishing current and short time during the process. The workpiece clamping device in Figure (1) ensures proper insulation to the workpiece area since it leaves only the area of 0.785

cm^2 facing the cathodic tool. In addition, care was taken to ensure that the active part of the anode surface faces the cathodic area which was achieved by insulating the sides of the cathode using a rubber insulation. Under such conditions the stray machining effect was completely stopped. After each test, specimens were washed in water, dipped in petroleum ether, air dried and the surface profiles were then measured using a roughness meter. Three surface roughness traverses were made for the arithmetic average roughness, Ra, and the maximum peak-to-valley, Rt at 120° angles through the center of the circular electrochemically polished area. Using the original surface roughness values, the changes in surface roughness, ΔRa and ΔRt , were determined and considered as indices for the polishing process. Polishing and surface improvement occur whenever ΔRa and ΔRt are positive. Tests were conducted at cell voltage up to 60 volt, time spans 10 - 600 seconds and separation distance, between electrodes 5-20 mm.



- 1-Workpiece (anode).
- 2-Electrolyte
- 3-Fixture.
- 4-Cathode.
- 5-Ammeter
- 6-Voltmeter.

Figure 1. Experimental setup.

RESULTS AND DISCUSSIONS:

In a previous investigation [3], results showed that polishing of Al-Si (2%) alloy occurs at low voltage of 3.5 volt and long machining time of 15 minutes. Therefore, in the present study, preliminary tests

were conducted at low voltage range of 1-10 volt and polishing times of 30, 60, 300 and 600 seconds. Figures (2 and 3) show the changes of surface roughness as indicated by ΔRa and ΔRt . Since the roughness change is negative, surface pitting and deterioration is evident because the final roughness exceeds the original one. Clearly the level of surface deterioration decreases as the time of exposure is decreased. Further tests at a polishing time of 30 seconds and a separation length of 10 mm were also conducted with a wider range of voltages up to 60 volt. Figure (4) gives the change in both Rt and Ra with the applied cell voltage. Clearly surface pitting occurs at low as well as high voltage ranges. Polishing and, hence, surface improvement is obvious for the positive change in Ra and Rt during the voltage span 40 and 50 volt.

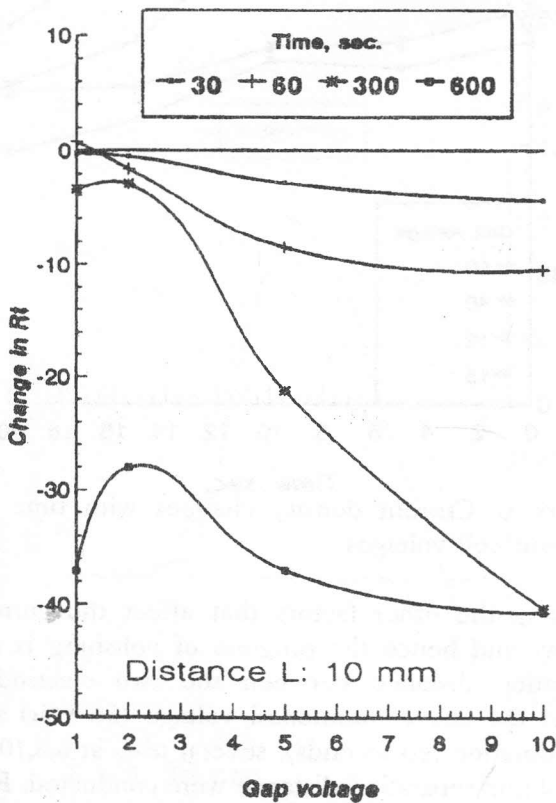


Figure 2. Effect of cell voltage and polishing time on the change in roughness Rt .

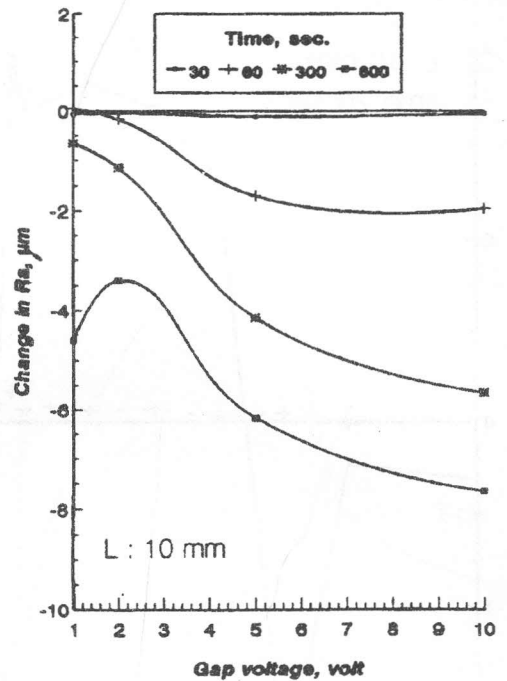


Figure 3. Effect of cell and polishing time on the change in roughness Ra .

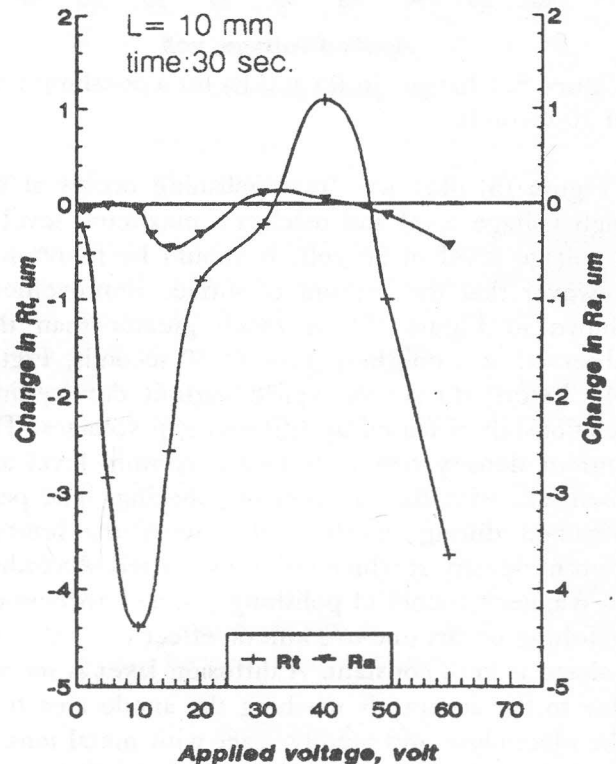


Figure 4. Changes in roughness Ra and Rt for larger voltage range and time of 30 seconds.

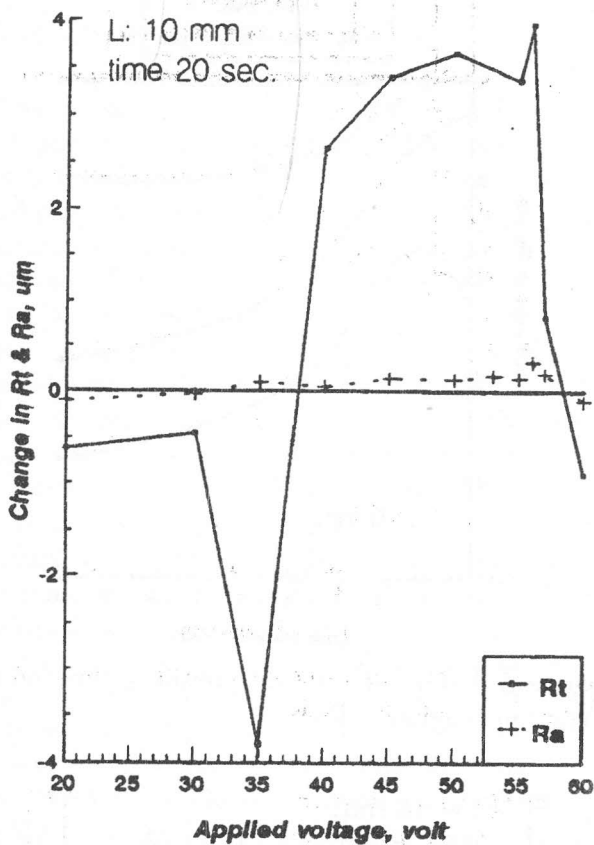


Figure 5. Changes in Ra and Rt for a polishing time of 20 seconds.

Figure (5) illustrates that polishing occurs at the high voltage level and reaches a maximum level at a voltage level of 56 volt. It should be mentioned however that the amount of surface improvement, shown in Figure (5), is much greater than that observed at a polishing time of 30 seconds, Figure (4). Figure (6) shows typical current density-time relationship obtained at different gap voltages. The current density first rises to a maximum level and then falls with the progress of polishing. The peak obtained during polishing represents the limiting current density at which polishing started. According to Wagner's theory of polishing [8], electrochemical polishing occurs due to a kinetic effect when the cell voltage is kept constant. A diffusion layer is formed due to the acceptor's reaching the anode area from the electrolyte and readily react with metal ions. It is obvious that the rate of smoothing will be very high in the beginning and then it decreases with

time since the effective area, to be polished, decreases with time. In contrast, anodic oxidation of specimen surfaces occurring at the small voltages (12, 15 volt) is reflected on the current density versus time plots as it decreases onward with the progress of the polishing effect, Figure (6). Figure (7) shows the surface profiles obtained by electrolytic polishing of the given alloy.

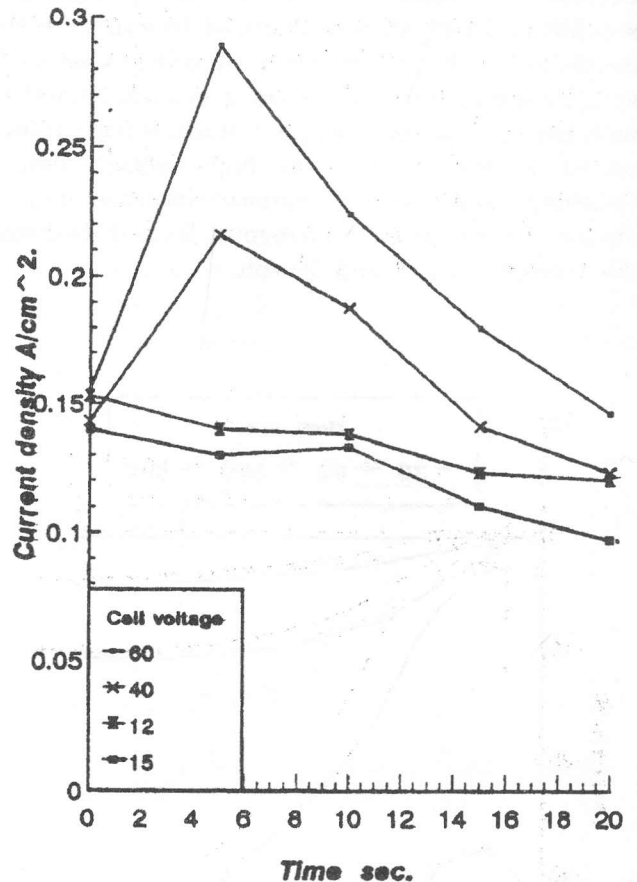


Figure 6. Current density changes with time for different cell voltages.

Among the other factors that affect the current density and hence the progress of polishing is the separation distance between the two electrodes. Under the above mentioned voltage (56 volt) and time duration (20 seconds), several tests at 6,8,10,12 and 14 mm separation distance were conducted. Fig. (8) concludes an optimum separation distance of 10 mm. Surface pitting and deterioration occur at smaller distance as well as greater ones.

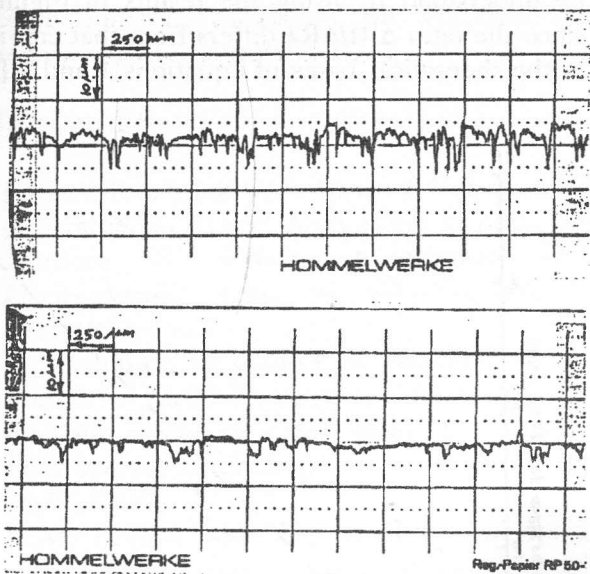


Figure 7. Surface roughness profiles before and after polishing at 56 volts, 20 sec. and distance of 10 mm.

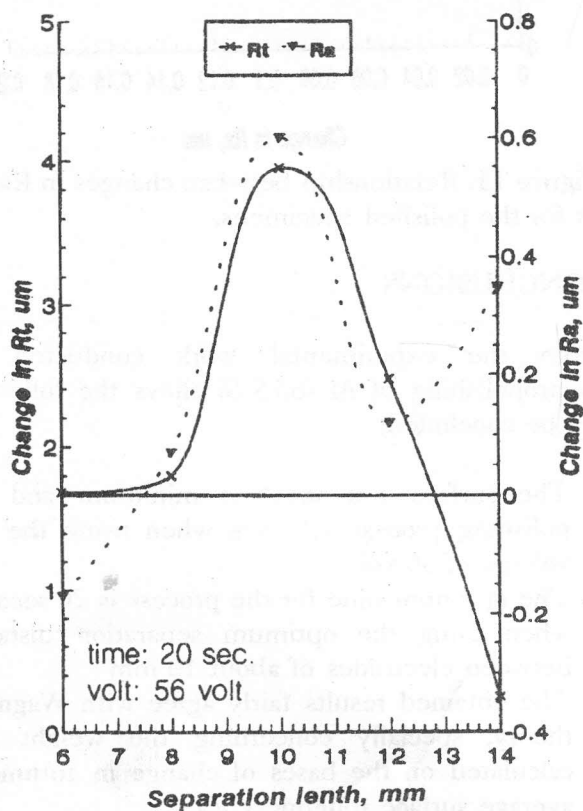


Figure 8. Effect of separation length on the polishing process.

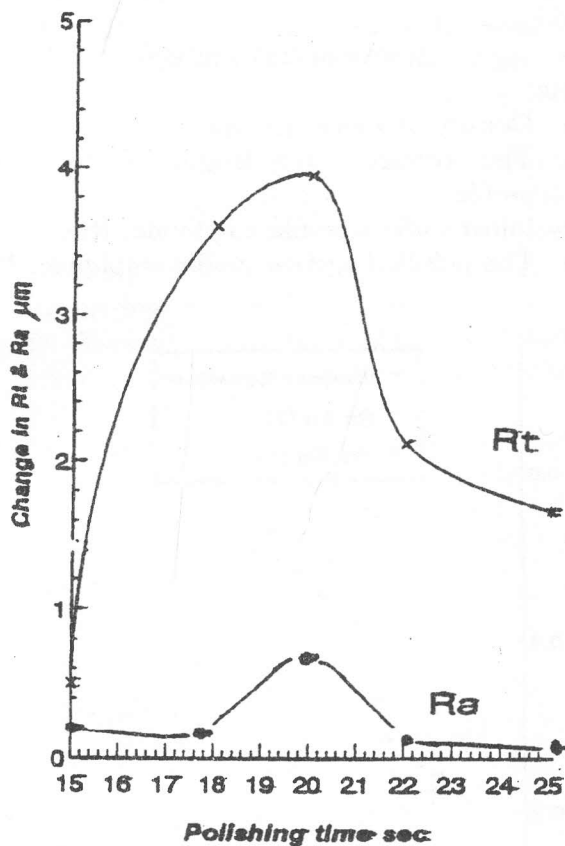


Figure 9. Changes in Ra and Rt with time at 56 volts and 10 mm separation length.

One can then notice that a voltage of 56 volt, 20 seconds and 10 mm distance can be considered as being the most efficient polishing variables for the given alloy using the given solution. To shed more light on the polishing time, several experiments were carried out at 56 volt, separation distance of 10 mm and polishing time of 15, 18, 20, 22 and 25 seconds. As can be shown in Figure (9), polishing occurs over the entire range of time experimented, it has the largest effect when the polishing time is 20 seconds. Reference [3] showed that the change in mass Δm per unit area A during polishing can be described as follows:

$$\Delta m/A = \rho \Delta Rt/2 \quad (1)$$

$$\Delta m/A = \pi \rho \Delta Ra/2 \quad (2)$$

Comparing these equations with Wagner's formula [8] for the loss of metal per unit area of anode surface,

$$\Delta m/A = (\alpha\rho/2\pi) \ln(b_0/b) \quad (3)$$

where;

ρ = Density of anode material.

α = The average wave length of the surface profile.

b_0 = Initial surface profile amplitude, R_{t0} .

b = The polished surface profile amplitude, R_t .

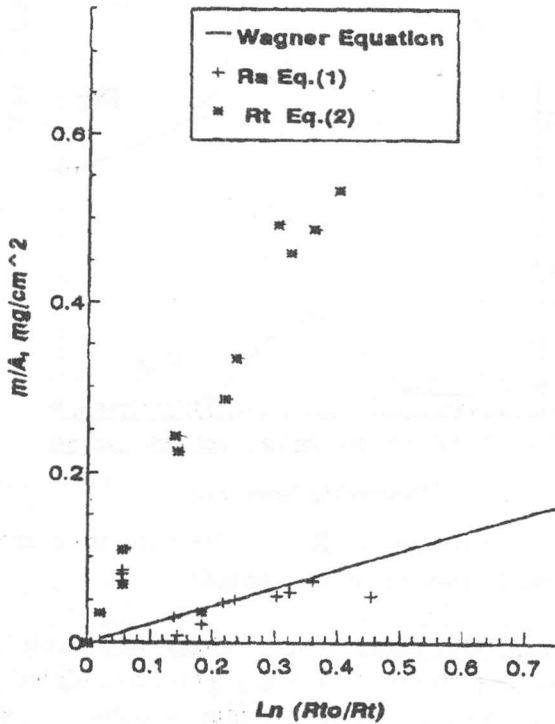


Figure 10. Comparison between derived equations and Wagner's theory.

For an average wave length of 0.0005 cm, $\Delta m/A V_s$ $\ln(R_{t0}/R_t)$ was plotted for equations 1, 2 and that for Wagner's 3. It can be concluded from Figure (10) that equation 2 fairly represents Wagner's assumptions in the theory of electropolishing. A model of electropolishing by an acceptor mechanism as proposed originally by Wagner has been developed by Matlosz et al [9]. The results here are in good agreement with the acceptor mechanism of EP. In addition, equation 1 that represents the peak-to-valley roughness deviates from that of Wagner's. The reason behind such a deviation can

be understood by using the results of Figure (11) since the ratio $\Delta R_t/\Delta R_a$ differs from that considered in the theoretical bases of equations 1 and 2 [3].

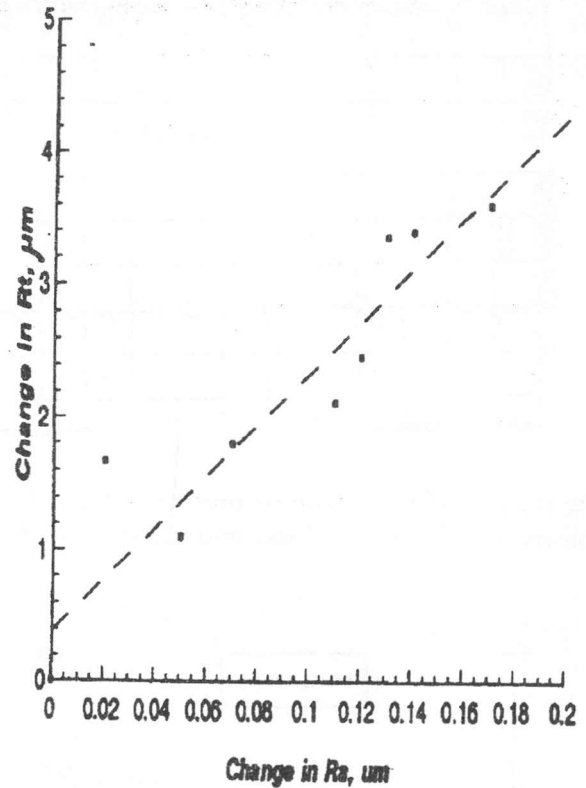


Figure 11. Relationship between changes in Ra and Rt for the polished specimens.

CONCLUSIONS

From the experimental work conducted for electropolishing of Al -6.75 Si alloys the following can be concluded;

- 1- The surface roughness is minimum and the polishing process achieves when using the cell voltage of 56 volt.
- 2- The optimum time for the process is 20 seconds when using the optimum separation distance between electrodes of about 10 mm
- 3- The obtained results fairly agree with Wagner's theory, specially concerning the weight loss calculated on the bases of change in arithmetic average surface roughness Ra.
- 4- Effects of other variables such as heat treatment and silicon content of the alloy and electrolyte

temperature and agitation on the polishing process must be investigated

REFERENCES

- [1] F.M. Al-Karafi and W.A. Badawy, Corrosion and passivation of Al and Al-Si alloys in nitric acid solutions II- Effect of chloride ions., *Electrochimica Acta*, vol, 40 No. 12, pp. 1811-1817, 1995.
- [2] H. Yoshiki, V. Alexandrnk, K. Hashimoto and A. Fujishima, Electroless copper plating using ZnO thin film coated on a glass substrate, *Journal of Electrochemical Society*, vol, 141 No.5, pp. 56-58, 1994.
- [3] M.M. El-Aiat and H.A. El-Hofy, Elecrolytic polishing of aluminum silicon alloys{ *Alexandria Engg. Journal (AEJ)* vol, 31, No. 4, pp. 511-516, Oct., 1992.
- [4] Shivanath, Ret al , Wear of Aluminum silicon alloys, *American Society of Metals (ASM)*, pp. 186-192, 1978.
- [5] I. Fukumoto and T. Ayab, Improvements of ground surface roughness in Al-Si Alloys, *Wear*, vol, 137, pp. 199-209, 1990.
- [6] H.M. Hajka, M. Zamin and M.K. Murthy, On the validity of Wagner's theory of electropolishing, *J. of Electrochem. Soc.* vol, 126 No. 5, pp. 795-797, 1979.
- [7] M.A. Kamal, M.Z. El-Abd, A.M. Hamouda and G.H. Sedahmad, Study of the factors affecting the rate of electrolytic polishing of cylindrical surfaces, *PEDAC3 Conference Proceedings*, Alexandria, pp. 309-318, 1983.
- [8] C. Wagner, Contribution to the theory of electropolishing, *Journal of Electrochemical Society*, vol, 101, 255, 1954.
- [9] M. Matlosz, S. Mgino and D. Landolt, Impedance analysis of a model mechanism for acceptor limited electropolishing, *J. of Electrochemical Society*, vol, 141, No. 2, pp. 410-418, 1994.