

# Effect of polishing time on the surface property of Maraging Steel on Electropolishing

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## Abstract

Polishing of surfaces improves the functionality of the metal workpiece. Mechanical polishing is very time consuming as well as damages the surface property. To overcome this, Electropolishing (EP), a non-conventional process is used to polish a metal surface where change in surface property is negligible. The surface of metal is polished by the anodic dissolution of the ions from the workpiece surface. In the present study, maraging steel is electropolished with Ortho-phosphoric acid (88%), Sulphuric acid (97%) and Hydrochloric acid (35%) mixed in the volume of 64 ml, 34 ml and 2 ml respectively. Linear sweep voltammetry is performed to find the passive region for EP. To analyse the surface elemental composition before and after EP, Energy Dispersive X-Ray Spectroscopy is performed. Surface roughness (Ra) and surface reflectance with increasing polishing time has also been performed to see the effect of time on EP. An improvement of 61.23% in surface roughness and 70% surface reflectance is observed.

**Keywords:** Electropolishing, maraging steel, surface roughness, surface reflectance

## 1. Introduction

Maraging steel is heavily use in Aerospace industry mainly to manufacture landing gear, rocket motor, slat tracks etc. It is an alloy which has high corrosion resistance, high temperature strength, high strength and toughness without losing its ductility. It exhibits such property because of presence of nanoscale evenly dispersed precipitated phase and high content of Ni, Al, Co and Mo. Maraging steel 300 does not contain chromium. However, they are strengthened by precipitation hardening and have microstructures somewhat similar to precipitation-hardened stainless steels [1].

Electropolishing (EP) is surface finishing process which streamlines the metal surface through electrochemical process. In electropolishing method, metal is removed in the form of ions by ions from the surface [2]. It is a non-conventional process and the fundamental principal behind electropolishing is electrochemical machining which works on the Faraday's law of electrolysis [3]. The metal which needs to be electropolished is submerged into the electrolyte and direct current is passed through it. Electrolyte is generally strong acid such as phosphoric acid ,sulphuric and their mixture [4]. Metal which is to be is electropolished is made anode and appropriate metal is selected to work as cathode. Chemical lead is generally used to form cathode due to non-reactive nature which makes it reusable. During EP, a viscous film layer of vary thickness is formed at the anode surface due to dissolution and limits mass transport due to resistance property. The viscous layer formed has maximum thickness over the micro-depression and minimum thickness over the micro-projection. As thickness of viscous layer is minimum over micro-projection hence its provide minimum electrical resistance which result greater metal removal rate compare to micro-depression area hence surface obtained after electropolishing is more uniform [5]. The polarised surface is formed during electropolishing due to evaluation of gas which form passive oxide film on the surface result in increase in corrosion resistance and biocompatibility [6].

In this study, the electrochemical performance of maraging steel 300 is obtained by measuring the linear sweep voltammetry (LSV) by using polarization curve. Gamry electrochemical cell is used for measurement which is three electrodes system to determine the polishing zone. It will help is to determine the voltage suitable for EP. To analyse the surface composition before and after EP, EDS (Energy Dispersive X-Ray Spectroscopy) has been performed. Surface roughness as well as surface reflectance before and after EP with increasing polishing time has also been analyzed.

## 2. Experimental approach for Electropolishing

### 2.1 Setup for Electropolishing

Electropolishing process setup is an extended version of electrochemical machining setup. It also requires an electrolyte setup with cathode and anode electrodes.

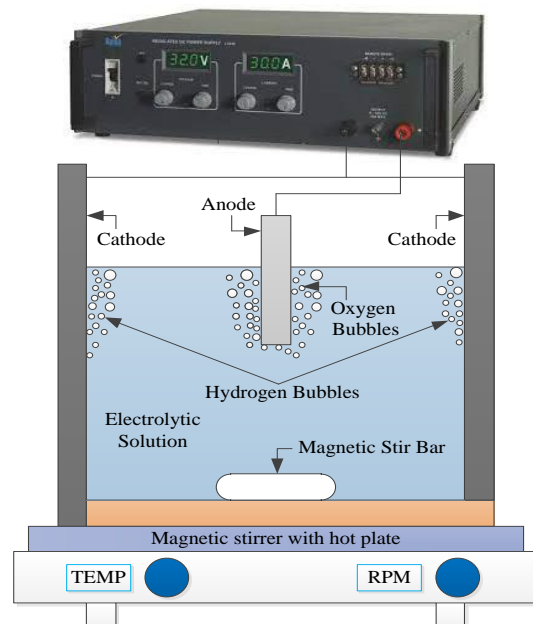


Fig. 1. Schematic of Electropolishing setup

The schematic set for the electropolishing for maraging steel as shown in Fig. 1. A glass container of 100 ml is used as the container for electropolishing. Chemical lead rod is used as cathode, which connects to the negative terminal of the power supply. The Cathode surface should be greater than anode [7]. A rectangular maraging steel 300 of dimension 10 mm×15 mm is used as the anode, which connects to the positive terminal of the power supply. The complete setup is kept over a hot plate with the magnetic stirrer. Hot plate is used to provide a required amount of heating to increase the temperature of the electrolyte. Magnetic stir bar which rotates with the help of magnetic stirrer, agitates the solution during electropolishing such that the anodic dissolve particles can be easily clean off from the surface [8]. An Aplab make constant DC power supply of rating 60 V and 20 A is used to provide the potential difference between anode and the cathode.

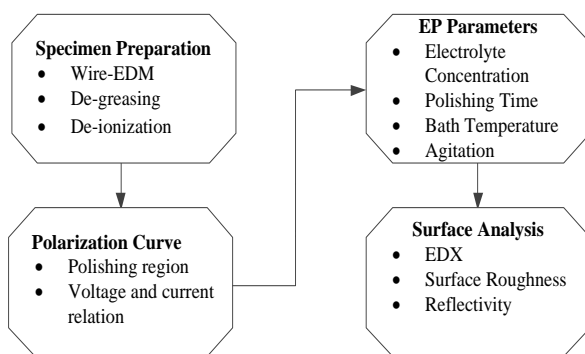
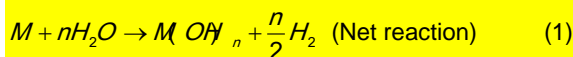


Fig. 2. Flow chart of Electrochemical Polishing (EP) process

The flow chart of electropolishing process step by step process is shown in Fig. 2. The first step is the preparation of sample. The specimen size was cut into 10 mm (width) by 15 mm (length) by 2 mm (thickness) with the help of wire-EDM. The test specimens were first ground by #200, #400 and #600 sand papers to remove the scratches and the deformed layer from previous process. The surface is cleaned using acetone manually. Further, it is cleaned with de-ionized water in an ultrasonic cleaner for 15 minutes. The initial average surface roughness measured using optical profilometer for the unpolished specimen is about 0.272  $\mu\text{m Ra}$ .



Reaction 1 shows the overall reaction happening in the electrolytic cell. Hydrogen gas is evolved at cathode and metal hydroxide acts as precipitates.

## 2.2 Electrochemical analysis for electrochemical polishing

To find the correlation between voltage and current for the electrochemical polishing, polarization curve has been drawn with the help of linear sweep voltammetry (LSV). The electrolyte consists of Ortho-phosphoric acid (64%) and Sulphuric acid (34%) and Hydrochloric acid (2%). LSV gives three zones namely active region, passive region and transpassive region. An electrochemical workstation having (Gamry) three electrodes system is designed namely the working electrode, the reference

electrode and the counter electrode. The maraging steel sample, Ag/AgCl electrode and the platinum electrode are the respective three electrodes. The voltage has been swept from 4.5 V to 0 V with a scan rate of 10 mV/s [9]. The potential must be swept from positive values in the cathodic direction in order to obtain reproducible measurements and to avoid pitting of the electrode surface [10].

## 3. RESULTS AND DISCUSSIONS

Electrochemical polishing (EP) has been performed on the maraging steel 300 sheet. The electrolyte consists of Ortho-phosphoric acid (88%), Sulphuric acid (97%) and Hydrochloric acid (35%) mixed in the volume of 64 ml, 34 ml and 2 ml respectively. The setup has been made indigenously for the EP which consists of electrolyte with electrodes. Surface composition and polarization curves are obtained. The effect of polishing time on surface roughness and surface reflectance are investigated and the results are discussed in the following sections.

### 3.1. Anodic polarization behaviour of maraging steel

Linear sweep voltammetry (LSV) has been performed for the anodic polarization behaviour of maraging steel as shown in Fig. 3. Three electrodes system has been used to determine the region of EP. The polarization curve is done at room temperature by varying the potential from 4.5 V to 0 V with a scan rate of 10 mV/s. The polarization curve is obtained for the electrolyte which consists of Ortho-phosphoric acid (88%), Sulphuric acid (97%) and Hydrochloric acid (35%). It consists of three regions. The region from 0 to 0.38 V is the active region (I) in which current increases with increase in potential. The region from 0.38 to 2.05 V is the passive region (II), in which current is stable with respect to increase in voltage. After this, the current increases rapidly in the transpassive region (III). As per literatures, EP occurs only in passive region [9].

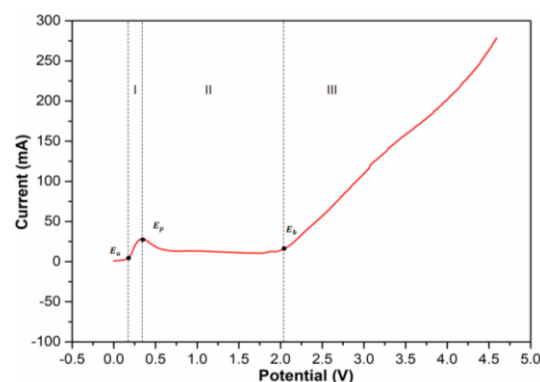


Fig. 3. Anodic polarization behaviour of maraging steel

Based on the curve Fig 3, the activation potential ( $E_a$ ) was 0.2 V, the passivation potential ( $E_p$ ) was 0.38 V and the breakdown potential ( $E_b$ ) was 2.05 V. The region (I) between potential  $E_a$  to  $E_p$  represent active region. In this region the sample will be etched and the surface could not be smoothed. When potential is between  $E_p$  and  $E_b$ , it is termed as passive region (II) and a viscous layer is formed on the sample surface which is made up metal ions. For

electropolishing, 2 V is preferred. The region beyond  $E_b$  is called transpassive layer. A serrated current curve is observed in this region which results in non-uniform dissolution of the sample surface.

### 3.2. Effect of EP on surface elemental composition

Energy-Dispersive X-Ray Spectroscopy (EDS) analysis has been performed to investigate the elemental composition on the surface of maraging steel 300 before and after EP. The initial surface is cleaned with acetone followed by ultrasonic cleaner. EDS analysis of maraging steel before and after EP is shown in Fig. 4 (a & b). It is observed that there is negligible change in element composition before and after electropolishing. This shows that EP does not alter the surface composition. Thus, surface property after EP does not deteriorate, it may improve.

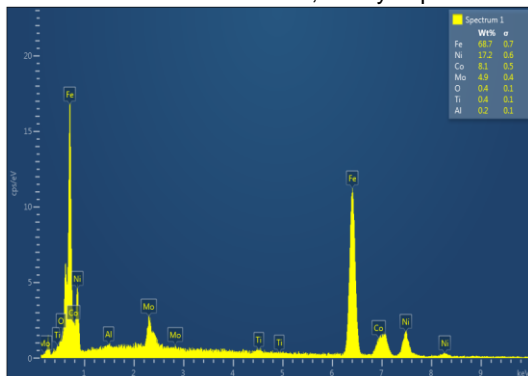


Fig 4 (a) EDS analysis of maraging steel before EP

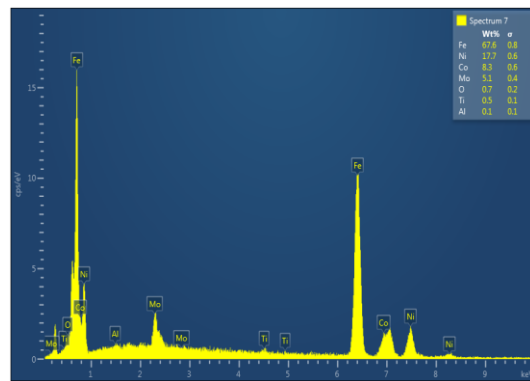


Fig 4 (b) EDS analysis of maraging steel after EP

### 3.3. Effect of Electropolishing on surface roughness

The Optical profilometer is used to study the surface roughness of electropolished sample. EP is done at 2 V and magnetic stirrer rotates at 400 rpm, however, the polishing time is varied from 2 min to 8 min. The comparison of surface roughness profile of sample before and after EP is obtained for time period of 2 min, 4 min, 6 min and 8 min as shown in Fig.5 (a-d).

Table 1 shows the initial and final value of surface roughness for 2 to 8 minutes before and after EP. It can be seen that maximum % improvement in surface roughness of 61.23% is observed, when EP is done for 6 min. As polishing time increases, the surface irregularities decreases and difference between peak and valley reduces. However, if EP is performed for 8 minutes, % improvement of surface roughness starts to decrease as small pits are formed on the surface, which increases the surface roughness.

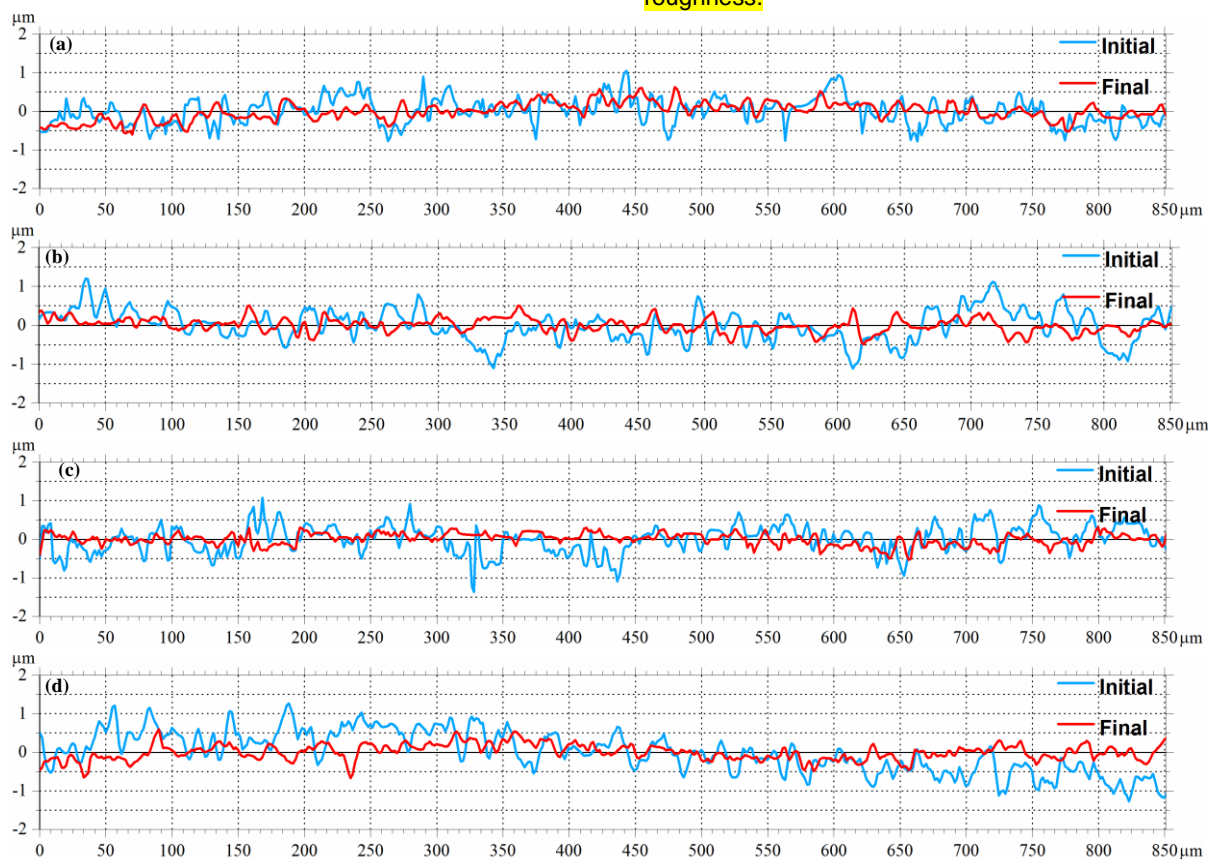


Fig.5 Surface roughness before and after electropolishing at (a) 2 min (b) 4 min (c) 6 min (d) 8 min

Table1. % Improvement in Ra

Sl. No.	Initial Ra ( $\mu\text{m}$ )	Final Ra ( $\mu\text{m}$ )	% Improvement in Ra
(a)	0.272	0.162	40.44
(b)	0.266	0.137	48.49
(c)	0.276	0.107	61.23
(d)	0.268	0.133	50.37

Figure 6 shows the error calculation in Ra before and after EP. Three readings of Ra have been taken and the average is considered.

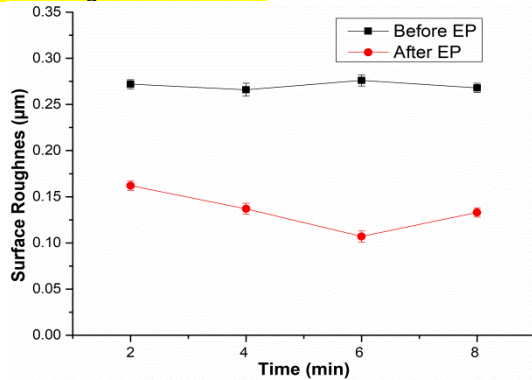


Fig.6. Error calculation in Ra before and after EP

### 3.4. Effect of Electropolishing on surface reflectance

Spectroscopic reflectance is performed to determine the reflectance of EP metal. The UV visible spectrophotometer is used to measure the reflectance of EP surface. In Fig.7, a comparison is made between unpolished and polished samples. The effect of time on surface reflectance for EP has also been shown in Fig.7. The unpolished sample has a maximum reflectance of 20% compared with polished silver (100% reflectance). EP is performed at 2V and magnetic stirrer rotates at 400 rpm by varying the time from 2 to 8 minutes.

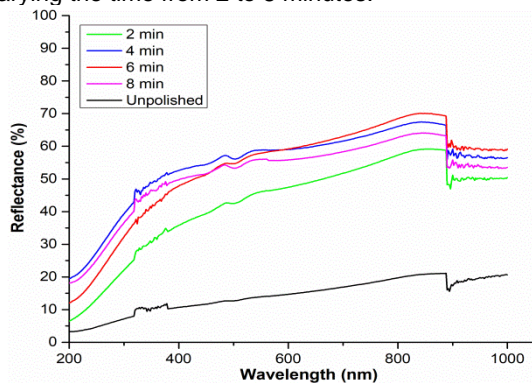


Fig.7. Surface reflectance before and after EP

Surface reflectance has a direct relation with the surface finish. Higher the surface finish, higher will be surface reflectance [11]. Figure 7 shows as time increases, reflectance increases. However, maximum reflectance (70%) is observed after 6 minutes of polishing. After 8 minutes of EP, small amount of pits formed on the surface, which reduces the surface reflectance. Higher polishing time deteriorates the surface reflectance. Higher reflectance surface can be of higher importance where radiation sensitive is of critical requirement. Figure 8 shows the surface

reflectance of maraging steel before and after EP.

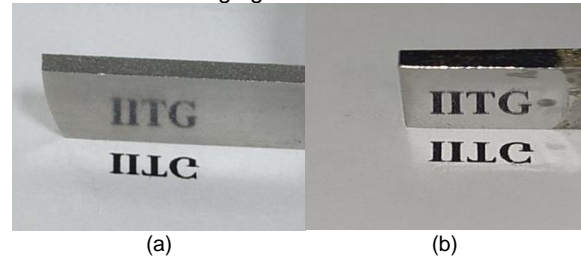


Fig.8. Surface reflectance (a) before and (b) after EP

### 4. Conclusions

With the help of present study, it can be conclude that EP can reduce Ra value up to 60% without changing major surface composition. EP also enhances the surface reflectance for the polishing time of 6 minutes. Upto 8 minutes of EP, pits formed on the surface which deteriorates the surface roughness as well as surface reflectance. EP sample can also be used where radiation sensitive is of critical requirement.

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