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# Experimental study on the porosity of electrochemical nickel deposits

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## Abstract

Porous metal parts offer unique advantages over traditional parts as they have excellent specific mechanical properties at a lesser weight. In this paper, the effect of the electrical parameters of deposition such as voltage and pulse duty cycle during pulsed electrodeposition on the current density and porosity of the manufactured parts was studied. Porosity at the micron scale, with a pore size between 1 – 10 µm was identified while using a 250 µm anode (tool). It is demonstrated that the porosity during these depositions occurs due to the kinetics of the electrochemical deposition, nucleation and crystal growth mechanisms. Through the study, it was found that the pulse duty cycle and voltage influence the porosity of the part. Higher duty cycle and higher voltage result in lower porosity in deposits, except in the case of 50% duty cycle when the double layer capacitance confines the deposit.

*Keywords:* Electrochemical Deposition; Porosity; Current Density

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## 1. Introduction

Porous metal parts are increasingly being used in many fields including the energy, environment, metallurgy, chemical, and biomedical industries [1-4]. The porous part not only inherits the intrinsic metal characteristics such as weldability, plasticity, thermal conductivity, and electric conductivity, but also displays many new properties such as small specific weight, controlled permeability, large specific surface area, and high energy absorption [3].

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Some of the methods used in the manufacturing of porous metal parts include injection molding, e-beam melting, and powder sintering [2, 4, 5]. The recent advances in additive manufacturing have made engineering-controlled porosity in the part possible. Some of the metal additive manufacturing processes involved in manufacturing porous parts are selective laser melting (SLM), electron beam melting (EBM), laser engineered net shaping (LENS), and inkjet 3D printing [6-8]. These methods suffer from lower part quality because of thermal stress or are limited by the powder size, which determines the minimum feature size [9, 10]. The minimum pore size of the parts using these processes can be engineered only to about 20 µm. Controllability of the porosity of parts is an issue in Selective Laser Sintering (SLS) [11]. One parameter that porosity depends on in SLS is the alignment of the powder particles. SLS is dependent on the motions of the powder, which are both unpredictable and hard to control [12]. In powder metallurgy, porosity is dependent on the pressure of the gas and the metal's tension and thus has no replicability, causing each part produced to be slightly different than others [13]. For the sintering and dissolution process, there is randomness associated with the template placement, causing the porosity to be unpredictable [13].

A recently developed process combining the principles of AM and Localized Electrochemical Deposition (LECD), Electrochemical Additive Manufacturing (ECAM) is a novel process capable of producing parts from any conducting material, such as metals, metal alloys, semiconductors, and conducting polymers [14]. Since it is a non-thermal process, ECAM is capable of producing parts with low residual stresses and is able to overcome some challenges of traditional AM processes, such as the need for support structures [14, 15]. Material addition in ECAM is performed by LECD. In this paper, the porosity of the deposits made by LECD under varying process parameters was studied. As the LECD process adds material atom by atom through an electrochemical reaction, the porosity study also gives insights into the electrochemical deposition mechanisms. This increases the controllability of the porosity achievable in this process.

## 2. Literature Review

The feasibility of the LECD technique was reported in [16]. Most of the following studies focused on investigating the effects of various process parameters on the characteristic of the deposited structures and the deposition rate [17]. While there is a minimum voltage required for deposition to occur, very high voltages cause porous or irregular deposition structures due to the depletion of ions at high currents and bubble formation [18]. The same study reported that there was no significant effect of the electrolyte concentration on the deposition rate, but lower concentrations affected the quality of the deposit (porous) [18]. This phenomenon is again explained due to the reduction of ions from the formation of the depletion layer at lower electrolyte concentrations. The choice of electrolyte for the electrodeposition process has been derived mostly from the electrolyte used for the electroplating of the same metal. Organic additives to the electrolyte produce smooth and fine-grained microcrystalline deposits [18, 19]. This is due to the altering of the reduction (deposition) mechanism with the addition of additives. Insulation of the micro tool electrode (anode) results in improved localization of the deposition [16]. However, insulation layer damage due to the formation of bubbles is an issue as it limits the life of the tool. The accumulation of bubbles, which hinders the deposition by blocking the interelectrode gap region, is another reason for the reduction in quality of the deposits. Repeatability of localized electrochemical deposition has been a challenge due to vigorous bubble formation disturbing the interelectrode dynamics as well as a lack of a proper feedback gap control to maintain a stable interelectrode gap [20]. In one study, the deposition rate increased toward the center of the cathode, which caused a more conical shape. The parts produced tend to be more porous toward the bottom of the pillar than the top [21].

Several studies focusing on the quality of the deposit during electrochemical deposition has been reported in the literature [17-19, 22]. Studies have shown that several mechanisms and process parameters such as current density, gas bubbles, feeding mechanism, electrolyte flow, and pulse parameters influence the quality of the electrodeposited part, but these parameters are all related to the current density associated during the deposition. In one electroforming study considering three different kinds of wave pulse, it was concluded that a triangular waveform produced the best surface finish as compared to a sine and a square wave pulse at a higher current density. The range of current densities studied was 5 to 19.2 A/dm$^2$, and the deposits had a smooth surface finish and a smaller grain size. A high nucleation rate is promoted by the high pulse current density of the triangular waveform, leading to a