# Varying the Infill Parameters of an Electroplated 3D Print to Improve Electrical Performance

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## Background

- 3D printing is a **multibillion dollar international industry**
  - Applications are present in fields such as automotives, robotics, aerospace, and locomotives
- Conventional, commercially available 3D printing filaments and technologies are responsible for creating parts with **high electrical resistance** and thus limited electrical applications
  - Conductive alternatives such as pure metals or alloys lack the **cost-effectiveness** and **light weight** of 3D prints
    - **Large degree of configurability** unique to 3D printing is sacrificed when using alternatives
- Electroplating and variance of infill parameters for 3D prints has been tested in the past to **improve electrical performance**, but never in conjunction with one another
- This study aims to determine if **electroplating**, the process by which metals can be used to coat a given substrate, in conjunction with a variance of printing parameters, can **improve** the electrical properties of **3D printed parts**.

## Variables, Constants, and Controls

**Independent Variable**(s): Electroplating (yes/no) and infill density (20, 30, or 40 percent)
**Dependent Variable**(s): Electrical resistance (Ohms)
**Constants**: Electroplating conditions, testing equipment and configurations, CAD model, slicing software (PrusaSlicer)
**Controls**: Non-electroplated parts' electrical properties

## Hypothesis

Prints with **small gaps in their infill** will yield **greater increases** in electrical performance post-electroplating when compared to prints with more dense infill due to the **better coverage of the metal on the substrate**.

## Experimental Design

**1. Printing**

1. The printing phase involves printing 30 3D prints (10 of each of the following infill densities: 20%, 30%, and 40%) with the linear infill pattern.

Image of 3D printing model in slicing software where infill can be seen

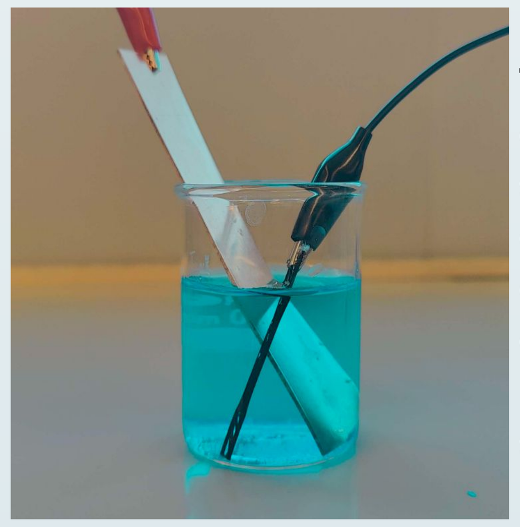
**2. Paint Application**

2. The paint application phase involves painting all 30 of the fabricated 3D prints with one coat of nickel-conductive paint in order to prepare them for electroplating; drying occurred for 24 hours at ~21 $^{0}$C.

Visual comparison of 3D print post-painting (left) and pre-painting (right)

**3. Plating**

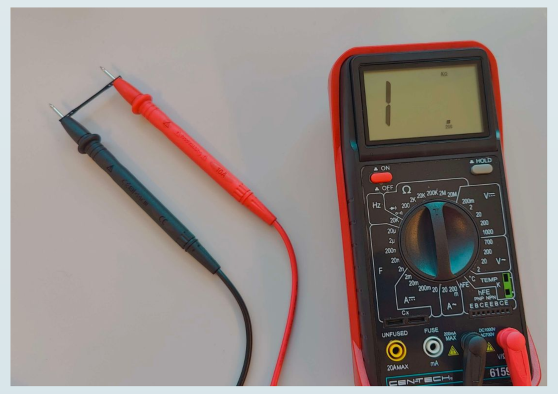
3. The plating phase involves electroplating 15 of the 30 total prints using a copper anode and 9g $CuSO_4$, 30mL $H_2SO_4$, and 90mL $H_2O$ at ~4V for 40s; parts were dried for 2 hours at 20 $^{0}$C.



Typical electroplating setup for the coating of copper metal onto the 3D printed substrate

**4. Electrical Test**

4. The testing phase involves employing all 30 of the 3D prints in a multimeter and recording their resistance in Ohms. Pieces are tested from end-to-end by placing the probes in the gaps of the parts' infills.



Example setup for the resistance testing of a 3D printed test piece using a multimeter

## References


Angel, K., Tsang, H. H., Bedair, S. S., Smith, G. L., & Lazarus, N. (2018). Selective electroplating of 3D printed parts. *Additive Manufacturing, 20*, 164–172. https://doi.org/10.1016/j.addma.2018.01.006

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## Data and Results

**Average Resistance of Electroplated and Non-Electroplated 3D Prints at Differing Infill Densities**

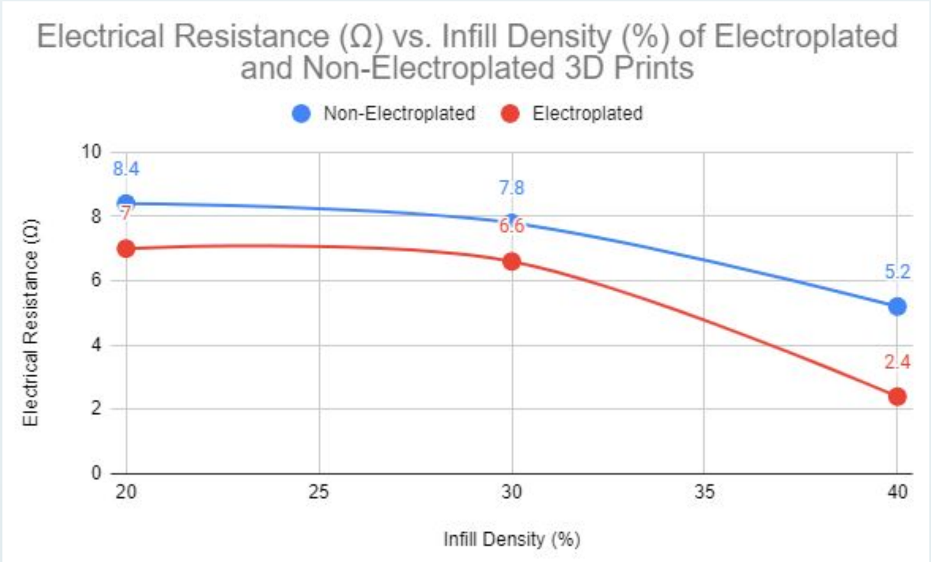
| Electroplated (Y/N) | Infill (%) | Average (Ω) |
|---|---|---|
| N | 20 | 8.4 |
| N | 30 | 7.8 |
| N | 40 | 5.2 |
| Y | 20 | 7.0 |
| Y | 30 | 6.6 |
| Y | 40 | 2.4 |

Each average value is computed by taking the arithmetic mean of 5 data points for electrical resistance per electroplating/infill combination

**Results of Dunn's Test Comparing Resistances of 3D Prints with Differing Infill Densities Post-Electroplating**

| Comparison | p-Value |
|---|---|
| 20% vs. 30% | >0.05 (0.832) |
| 20% vs. 40% | <0.05 (0.001) |
| 30% vs. 40% | <0.05 (0.006) |

Kruskal-Wallis Test Statistics:
p-Value=0.009
KW-Statistic=9.42




## Discussion

The data collected reflects that resistance did change with electroplating and in response to the variance of infill parameters: the Dunn's test (conducted after a Kruskal-Wallis test) reveals that there is not a statistically significant difference between the resistances of the prints with 20 and 30 percent infill densities while there was a significant difference between the prints of 20 and 40 percent infill densities as well as the prints with 30 and 40 percent infill densities. This could reflect that infill densities may not vary proportionally with the effect of electroplating on a given part.

Further research in this area could involve determining how the combination of electroplating and the variance of printing parameters, including settings like print speed and print bed temperature, affect other industrially-relevant properties, such as mechanical strength as measured by tensile strength or Young's modulus or corrosion resistance.