Complete Electroplating Process Guide for 3D Printed Parts

Project Overview

This guide details the process for copper electroplating 3D printed parts to enhance their mechanical properties. The process is designed for parts with varying geometric complexity, with no part exceeding 2×2×2 inches³ in volume (ensuring plating time ≤ 30 minutes).

Safety Notice

⚠️ **CRITICAL: Steps 3, 4, and 5 MUST be performed in the University Teaching Lab (UTL) with full PPE and supervision.**

Step 1: 3D Print and Surface Preparation

Required Materials:

- 3D printed part (PLA, ABS, or PETG recommended)
- Sandpaper set (400, 800, 1200, 1600, 2000 grit)
- Steel wool (#0000 grade)
- Isopropyl alcohol (IPA) 99%
- Clean, lint-free cloths
- Compressed air (optional)

Detailed Process:

1a. Print Model

- **Print Settings:**
  - Layer height: 0.1-0.2mm for smoother finish
  - Infill: minimum 30% for structural integrity
  - Support material: remove completely before proceeding
- **Post-print checks:**
  - Ensure no warping or layer separation
  - Verify dimensions are within 2×2×2 inches³
  - Allow part to fully cool and stabilize

1b. Progressive Sanding (Total time: 30-45 minutes)

1. **400 Grit (10 minutes)**
    - Purpose: Remove visible layer lines
    - Technique: Circular motions with moderate pressure
    - Focus on: High points and rough areas
    - Check progress frequently under bright light
2. **800 Grit (10 minutes)**
    - Purpose: Smooth scratches from 400 grit
    - Technique: Figure-8 pattern
    - Pressure: Medium-light
    - Surface should start feeling smooth
3. **1200 Grit (10 minutes)**
    - Purpose: Further refinement
    - Technique: Random orbital pattern
    - Pressure: Light
    - Surface should be uniformly smooth
4. **1600 Grit (5-10 minutes)**
    - Purpose: Pre-polish preparation
    - Technique: Very light circular motions
    - Check for any remaining imperfections
5. **2000 Grit (5-10 minutes)**
    - Purpose: Final smoothing
    - Technique: Gentle polishing motions
    - Result: Satin-smooth finish

1c. Polish (Optional but recommended)

- Use #0000 steel wool
- Apply in one direction for uniform finish
- Duration: 5-10 minutes
- Remove all steel wool particles with compressed air

1d. Clean

1. **Initial cleaning:**

- Blow off all dust with compressed air
- Pay attention to crevices and complex geometries

2. **IPA cleaning:**
   - Soak lint-free cloth with 99% IPA
   - Wipe entire surface thoroughly
   - Use fresh cloth sections for final wipe
3. **Drying:**
   - Air dry for 15-20 minutes
   - Ensure no IPA residue remains
   - Part must be completely dry before next step

Step 2: Apply Conductive Layer

Required Materials:

- Conductive copper spray paint
- Masking tape (if selective plating desired)
- Spray booth or well-ventilated area
- Digital multimeter
- Wire or holder for suspending part
- Disposable gloves

Detailed Process:

2a. Apply Copper Spray Paint

Preparation:

1. Set up in well-ventilated area or spray booth
2. Temperature should be 65-75°F (18-24°C)
3. Humidity below 50% for best results
4. Shake spray can vigorously for 2 full minutes
5. Test spray on scrap material

Application Technique:

1. **First Coat:**

- Distance: 8-10 inches from part
- Motion: Smooth, sweeping passes
- Overlap: 50% between passes
- Coverage goal: 60-70% opacity
- Dry time: 10 minutes

2. **Second Coat:**
   - Apply perpendicular to first coat
   - Same distance and technique
   - Coverage goal: 90-95% opacity
   - Dry time: 15 minutes
3. **Third Coat (if needed):**
   - Light application only
   - Target any thin areas
   - Final coverage: 100% opacity
   - Dry time: 20 minutes

2b. Allow to Dry

- Total drying time: 30-45 minutes minimum
- Test dryness: Light touch with gloved finger
- Surface should be completely tack-free
- Avoid handling during this period

2c. Test Conductivity

1. **Multimeter setup:**
   - Set to resistance mode (Ω)
   - Use lowest range (200Ω)
2. **Testing procedure:**
   - Place probes 1 inch apart
   - Test at least 5 different locations
   - Record readings
3. **Acceptable values:**
   - <50Ω between any two points: Excellent

- 50-100Ω: Acceptable
- 100Ω: Apply additional coat

Step 3: Chemical Cleaning Process (UTL REQUIRED - Full PPE)

Required Safety Equipment:

- Chemical-resistant goggles (not safety glasses)
- Nitrile gloves (double layer recommended)
- Lab coat or chemical apron
- Closed-toe shoes
- Fume hood access

Required Materials:

- Sodium hydroxide (NaOH) - 50g
- Sodium carbonate (Na_2CO_3) - 50g
- Hydrochloric acid (HCl) 35% - 100ml
- Distilled water - 3 liters
- Glass beakers (1L) - 3
- Glass stirring rods - 3
- Plastic tongs (acid-resistant)
- Timer
- pH test strips

Solution Preparation:

Prepare in Fume Hood:

5% NaOH Solution (Degreasing)

1. Measure 800ml distilled water in 1L beaker
2. Slowly add 50g NaOH pellets while stirring
3. **CAUTION:** Solution will heat to ~60°C
4. Stir until completely dissolved
5. Add distilled water to reach 1L mark
6. Cool to room temperature before use

7. Label: "5% NaOH - CAUSTIC"

5% Na_2CO_3 Solution (Neutralizing)

1. Measure 800ml distilled water in 1L beaker
2. Add 50g Na_2CO_3 while stirring
3. Continue stirring until dissolved
4. Add distilled water to reach 1L mark
5. Label: "5% Na_2CO_3 - Neutralizer"

10% HCl Solution (Activation)

1. **CRITICAL:** Always add acid to water
2. Measure 700ml distilled water in 1L beaker
3. SLOWLY add 100ml concentrated HCl
4. Stir gently with glass rod
5. Add distilled water to reach 1L mark
6. Label: "10% HCl - ACID"

Cleaning Process:

3a. Soak in 5% NaOH Solution

1. Using tongs, fully submerge part
2. Duration: 5 minutes
3. Agitate gently every minute
4. Purpose: Removes organic contaminants and oils

3b. Rinse in 5% Na_2CO_3 Solution

1. Remove from NaOH with tongs
2. Rinse in running distilled water for 30 seconds
3. Transfer to Na_2CO_3 solution
4. Soak for 2 minutes
5. Purpose: Neutralizes residual base

3c. Dip in 10% HCl Solution (Brief)

1. Remove from Na_2CO_3 with clean tongs

2. Quick rinse in distilled water
3. **Dip in HCl for exactly 10 seconds**
4. Purpose: Activates copper surface
5. Immediately rinse in distilled water

3d. Dry Between Steps

- Use compressed air (preferred) or lint-free cloth
- Ensure complete drying between solutions
- Work quickly after HCl dip to prevent oxidation
- Part should proceed to plating within 5 minutes

Step 4: Setup Electroplating Bath (UTL REQUIRED - Full PPE)

Required Equipment:

- PEAK Tech 30A DC Power Supply
- Glass or plastic container (2L capacity)
- Copper anodes (4 oz total)
- Anode bags
- Copper wire (16 AWG)
- Alligator clips (6)
- Hot plate with magnetic stirrer
- Digital thermometer
- Glass stirring rod

Required Chemicals:

- Copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) - 250g
- Sulfuric acid (H_2SO_4) battery acid - 50ml
- Distilled water - 1L

Bath Setup Process:

4a. Prepare Container

1. Clean container with distilled water
2. Ensure no contamination

3. Place on magnetic stirrer/hot plate
4. Insert clean stir bar

4b. Prepare Electrolyte Solution

Copper Sulfate Bath Recipe:

1. **Heat water:**
   - Add 800ml distilled water to container
   - Heat to 50-60°C with stirring
2. **Dissolve copper sulfate:**
   - Slowly add 250g $CuSO_4 \cdot 5H_2O$ while stirring
   - Maintain temperature at 50-60°C
   - Stir until completely dissolved (10-15 minutes)
   - Solution will be bright blue
3. **Cool and add acid:**
   - Cool solution to 40°C
   - In fume hood, slowly add 50ml H_2SO_4
   - **NEVER add water to acid**
   - Stir gently for 5 minutes
4. **Final adjustment:**
   - Add distilled water to reach 1L total
   - Mix thoroughly
   - Cool to room temperature (20-25°C)

Final Bath Parameters:

- Copper sulfate: 200-250 g/L
- Sulfuric acid: 50-75 g/L
- pH: 0.5-1.0 (verify with pH strips)
- Temperature: 20-25°C for operation

4c. Place Anodes

1. **Anode preparation:**
   - Use 2-4 copper anodes (depending on part size)

- Place each anode in an anode bag
- Bags prevent copper particles from contaminating bath

2. **Positioning:**
   - Space anodes evenly around container
   - Anodes should be 3-4 inches from center
   - Submerge anodes 80% into solution
   - Leave top portion dry for connections

4d. Suspend 3D Part

1. **Create hanging system:**
   - Attach copper wire to conductive paint area
   - Use minimal contact point
   - Create hook or cradle to suspend part
2. **Positioning requirements:**
   - Center part in bath
   - Minimum 2 inches from nearest anode
   - Part fully submerged except wire connection
   - No contact with container bottom or sides

4e. Ensure Electrical Connections

1. **Anode connections (Positive):**
   - Connect all anodes together with copper wire
   - Use alligator clips for secure connection
   - Connect to positive (+) red terminal of PSU
2. **Cathode connection (Negative):**
   - Connect part wire to negative (-) black terminal
   - Ensure solid connection at conductive paint
3. **Verification:**
   - Double-check polarity (anodes positive, part negative)
   - Ensure all connections are secure
   - No exposed wire in solution except at connection points

Step 5: Electroplating Process (UTL REQUIRED - Full PPE)

Plating Parameters:

- Current density: 20-30 ASF (Amps per Square Foot)
- Recommended: 25 ASF for optimal results
- Voltage: 1-3V (will auto-adjust on constant current)
- Bath temperature: 20-25°C
- Agitation: Gentle magnetic stirring

Pre-Plating Calculations:

5a. Calculate Required Current

1. **Measure surface area:**
   - Calculate total surface area in square inches
   - For complex shapes, estimate or use CAD data
2. **Convert to square feet:**
   - Area (ft^2) = Area (in^2) ÷ 144
3. **Calculate current:**
   - Current (A) = Area (ft^2) × 25 ASF
   - Example: 6 in^2 = 0.042 ft^2 × 25 = 1.05A

5b. Calculate Plating Time

For desired thickness:

- Use online calculator (link in original procedure)
- Or use formula:

```
Time (min) = (Thickness (inches) × 2.95 × Area (in²)) / Current (A)
```

- For 0.001" (1 mil) on 6 in^2 at 1A ≈ 18 minutes

Plating Process:

5c. Begin Plating

1. **Final checks:**
   - Part is clean and dry
   - All connections secure

- Bath temperature 20-25°C

2. **Start sequence:**
   - Turn on magnetic stirrer (low speed)
   - Set PSU to constant current mode
   - Set current limit to calculated value
   - Turn on PSU with current at zero
3. **Ramp up:**
   - Slowly increase current over 30 seconds
   - Watch voltage (should stabilize at 1-3V)
   - Look for uniform bubble formation

5d. Monitor During Plating

1. **Visual checks (every 5 minutes):**
   - Even bubble distribution
   - No dark or burnt areas
   - Uniform color development
2. **Parameter monitoring:**
   - Current remains stable
   - Voltage within 1-3V range
   - Temperature stays 20-25°C
3. **Adjustments if needed:**
   - Reduce current if burning occurs
   - Rotate part for even coverage
   - Add distilled water if evaporation occurs

5e. Complete Plating

1. **Shutdown sequence:**
   - Reduce current to zero over 30 seconds
   - Turn off PSU
   - Turn off stirrer
2. **Part removal:**
   - Lift part slowly from bath

- Allow excess to drip back
- Immediately rinse in distilled water
- Rinse for minimum 1 minute

Troubleshooting Guide:

Problem	Cause	Solution
Dull/matte finish	Low acid concentration	Add 10ml H_2SO_4 per liter
Dark/burnt areas	Current too high	Reduce by 20%
Poor adhesion	Inadequate surface prep	Restart from Step 1
Rough/nodular	Contaminated bath	Filter bath, clean anodes
Uneven thickness	Poor current distribution	Reposition anodes

Step 6: Part Finishing

Required Materials:

- Sandpaper (400-2000 grit)
- Steel wool (#0000)
- Metal polish (optional)
- Clean cloths
- Clear lacquer (optional)

Finishing Process:

6a. Initial Sanding (if needed)

1. **Identify imperfections:**
   - High spots
   - Rough areas
   - Nodules
2. **Progressive sanding:**
   - Start with 400 grit for major issues
   - Progress through grits as in Step 1
   - Be gentle - copper layer is 0.001-0.002" thick
   - Focus on problem areas only

6b. Polish (Optional)

1. **Steel wool polishing:**
   - Use #0000 steel wool
   - Light pressure, circular motions
   - Work small sections at a time
2. **Metal polish (for mirror finish):**
   - Apply small amount to cloth
   - Work in circular motions
   - Buff with clean cloth
   - Repeat until desired shine achieved

Post-Process Requirements:

Waste Disposal:

1. **Chemical solutions:**
   - NEVER pour down drain
   - Neutralize acids with Na_2CO_3 before disposal
   - Follow institutional hazardous waste procedures
2. **Copper bath:**
   - Can be reused 10-20 times
   - Store covered and labeled
   - Filter before reuse

Documentation:

- Record all parameters used
- Note any issues encountered
- Photo document results
- Calculate actual thickness achieved

Quality Testing:

1. **Adhesion test:**
   - Tape test (ASTM D3359)
   - No copper should remove with tape

2. **Thickness measurement:**
    - Use micrometer if available
    - Compare weight before/after
3. **Conductivity:**
    - Should be <1Ω across surface

Safety Reminders

1. **Chemical safety:**
    - Always add acid to water
    - Use fume hood for all chemical work
    - Know location of safety shower/eyewash
2. **Electrical safety:**
    - Never touch electrodes while power is on
    - Keep electrical connections dry
    - Maximum 30A current for safety
3. **PPE requirements:**
    - Never work without full PPE in chemical steps
    - Replace gloves if contaminated
    - Wash hands thoroughly after work

Additional Resources

- SDS sheets for all chemicals (see materials list)
- Online plating calculator (mentioned in original procedure)
- ASTM standards for plating quality
- University chemical waste disposal guidelines