

Phenolic Resin Laminate Garolite G-10/FR4 Technical Material Specification

1.0 Material Overview & Common Uses

Garolite G-10/FR4 is a high-pressure thermoset phenolic resin laminate reinforced with continuous filament woven fiberglass cloth. It is the industry standard for printed circuit board (PCB) substrates and structural electrical insulation. FR4 denotes a flame-retardant grade meeting UL94 V-0 standards. This material offers excellent mechanical strength, dimensional stability, low moisture absorption, and high dielectric strength, making it suitable for both electrical and mechanical applications in demanding environments.

- Primary applications: PCB substrates, electrical insulation panels, structural components in transformers, switchgear, and high-voltage equipment.
- Mechanical uses: Jigs, fixtures, precision spacers, washers, and wear plates where electrical isolation is required.
- Aerospace and defense: Radomes, antenna components, and structural supports due to low dielectric constant and high strength-to-weight ratio.
- Automotive: Battery pack insulators, motor end laminations, and sensor housings in electric vehicles.

2.0 Core Technical Properties & Sizing

- Density: 1.85 g/cm³ (nominal, per ASTM D792).
- Tensile strength (lengthwise): 310 MPa (45,000 psi) minimum per ASTM D638.
- Flexural strength (lengthwise): 415 MPa (60,000 psi) minimum per ASTM D790.
- Compressive strength (flatwise): 415 MPa (60,000 psi) minimum per ASTM D695.
- Dielectric strength (perpendicular to laminate): 20 kV/mm (500 V/mil) minimum per ASTM D149.
- Water absorption (24-hour immersion): 0.10% maximum per ASTM D570.
- Flammability rating: UL94 V-0 (FR4 grade).
- Continuous service temperature: 130°C (266°F) maximum (UL 746B).
- Standard sheet sizes: 1220 mm x 2440 mm (48" x 96") and 1220 mm x 1220 mm (48" x 48").
- Thickness range: 0.10 mm (0.004") to 50 mm (2.0") with standard tolerance of ±10% for thicknesses up to 1.6 mm, ±8% for 1.6–3.2 mm, and ±5% for thicker sheets.
- Flatness tolerance: 0.5 mm per 300 mm (0.020" per foot) for sheets up to 3.2 mm thick; 0.3 mm per 300 mm (0.012" per foot) for thicker sheets.
- Hardness: Rockwell M 100–115 per ASTM D785.

3.0 Processing, Machinability & Application

Garolite G-10/FR4 is abrasive due to the fiberglass reinforcement, requiring carbide or diamond-tipped tooling for consistent edge quality and tool life. It can be machined using conventional woodworking or metalworking equipment, but dust control is critical due to the respirable silica content in the glass fibers. The material is not thermoplastic; it cannot be melted or reformed. Cutting, drilling, and routing produce a fine, irritating dust that must be managed with local exhaust ventilation.

- **Cutting:** Use carbide-tipped saw blades with 60–80 teeth for clean edges. Feed rate: 3–5 m/min (10–16 ft/min) for sheet thickness up to 3 mm; reduce feed for thicker material to avoid delamination.
- **Drilling:** Use solid carbide drill bits with a 118° point angle. Spindle speed: 10,000–20,000 RPM. Feed: 0.05–0.15 mm/rev (0.002–0.006 in/rev). Peck drilling recommended for holes deeper than 3x diameter to clear chips and reduce heat buildup.
- **Routing:** Use diamond-coated or carbide burr bits. Spindle speed: 15,000–25,000 RPM. Climb milling preferred to minimize edge fraying. Use a vacuum table or double-sided tape for workholding.
- **Waterjet cutting:** Recommended for complex shapes without heat-affected zones. Use 60–80 mesh garnet abrasive at 350–400 MPa (50,000–60,000 psi). Edge quality is excellent with minimal delamination.
- **Laser cutting:** CO2 lasers (10.6 µm) can cut thin sheets (<1.6 mm) but produce a charred edge and release hazardous fumes. Not recommended for thick sections or where edge appearance matters.
- **Bonding:** Use epoxy-based adhesives (e.g., 3M DP420, Loctite EA 9460) after surface roughening with 120-grit sandpaper and solvent cleaning (isopropyl alcohol). Clamp pressure: 0.1–0.3 MPa (15–45 psi). Cure at room temperature for 24 hours or 60°C for 2 hours.
- **Threading:** Use thread-forming taps (roll taps) for holes in thicker sections. Cutting taps may cause delamination. Recommended tap drill size: 75% thread engagement maximum.

4.0 Common Defects & Quality Control

- Reject if visible delamination (separation between fiberglass layers) is observed at edges or on the surface under 5x magnification.
- Reject if surface pits or voids exceed 0.5 mm (0.020") in diameter or depth, as they compromise dielectric strength.
- Reject if warp or twist exceeds 0.5 mm per 300 mm (0.020" per foot) for sheets up to 3.2 mm thick, or 0.3 mm per 300 mm (0.012" per foot) for thicker sheets.
- Reject if thickness is outside the specified tolerance band ($\pm 10\%$ for <1.6 mm, $\pm 8\%$ for 1.6–3.2 mm, $\pm 5\%$ for >3.2 mm).
- Reject if there are cracks, chips, or frayed edges on machined parts that extend more than 0.2 mm (0.008") into the laminate.
- Reject if the material shows signs of moisture absorption (blistering, discoloration) after storage, as it reduces electrical insulation properties.
- Reject if the flame retardant grade (FR4) does not meet UL94 V-0 certification; verify via manufacturer's test report.
- Acceptance criteria: Visual inspection under 5x magnification, dimensional check with calibrated micrometers, and flatness check on a granite surface plate with feeler gauges.

5.0 Storage, Handling & WHMIS Guidelines

- Store in a dry, climate-controlled environment at 15–30°C (59–86°F) and relative humidity below 60% to prevent moisture absorption and dimensional changes.
- Shelf life: Indefinite under proper storage conditions; however, material older than 5 years should be tested for dielectric strength and moisture content before use.
- FIFO protocol: Rotate stock using first-in, first-out to ensure older material is used within 5 years of manufacture date.
- WHMIS classification: Not classified as a hazardous material in solid form. However, dust generated during machining is classified as a hazardous substance under WHMIS 2015.
- WHMIS hazard statements for dust: H315 (Causes skin irritation), H319 (Causes serious eye irritation), H335 (May cause respiratory irritation).
- Mandatory PPE during machining: NIOSH-approved N95 or P100 respirator, safety glasses with side shields, cut-resistant gloves (ANSI A4 or higher), and long sleeves to prevent skin contact with dust.
- Engineering controls: Use local exhaust ventilation (LEV) with HEPA filtration at the point of dust generation. Maintain air velocity of at least 0.5 m/s (100 ft/min) at the source.

- Spill and disposal: Collect dust using a HEPA vacuum; do not sweep. Dispose of waste as non-hazardous industrial solid waste per local regulations. Do not incinerate.
- First aid: For eye contact, flush with water for 15 minutes. For skin contact, wash with soap and water. For inhalation, move to fresh air and seek medical attention if irritation persists.

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