PCB Material Selection Guide

A Failure Analysis (FA) Perspective & Technical Reference

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Date: Mar 2025

1. Introduction: The Material-Failure Nexus

In the context of Printed Circuit Board (PCB) Failure Analysis (FA) and Root Cause Corrective Action (RCCA), the proper selection of base dielectric materials and laminates is paramount. This guide is a specialized technical reference designed to move beyond general material specifications, focusing instead on how specific material properties directly influence susceptibility to common PCB failure modes. Optimal material selection, particularly in post-FA redesigns, is the most effective proactive measure against systemic reliability issues.

2. Critical Material Properties Linked to Failure Modes

Property	Definition	Relevant Failure Modes	Design/FA Considerations
Glass Transition Temperature (Tg)	The temperature at which the PCB substrate transitions from a rigid, glassy state to a soft, rubbery state.	**Delamination, Via Barrel Cracking, Solder Pad Lift.**	Must be significantly higher (typically 20–30 °C higher) than the maximum operating and processing (soldering) temperatures. Low Tg materials soften, increasing Z-axis expansion during reflow.
Decomposition Temperature (Td)	The temperature at which the material loses 5% of its mass via decomposition (pyrolysis).	**Thermal Decomposition, Outgassing, Delamination.**	A robust Td is critical. A Td that is too close to the soldering temperature indicates the material is thermally unstable and susceptible to permanent damage during assembly.
Coefficient of Thermal Expansion (CTE) (Z-axis)	The rate at which the material expands perpendicular to the plane of the board when heated.	**Plated Through Hole (PTH) Crack, Inner Layer Separation, Via Barrel Fracture.**	The primary driver of via failure. Lower Z-axis CTE is highly desirable, especially above Tg. High-reliability applications demand

Property	Definition	Relevant Failure Modes	Design/FA Considerations
	Expressed in parts per million per degree Celsius (ppm/°C).		materials with CTE_z < 40 ppm/°C (below Tg).
Moisture Absorption (%)	The percentage of moisture the material absorbs when subjected to high humidity, often measured after a standardized soak.	**Conductive Anodic Filament (CAF), Delamination, Measling, Popcorning during reflow.**	Moisture acts as an electrolyte for electrochemical failures (CAF) and creates internal vapor pressure, leading to explosive delamination during rapid thermal excursions.
Comparative Tracking Index (CTI) (Volts)	A measure of the electrical resistance to breakdown on the surface of an insulating material.	**Surface Arcing, Tracking, Carbonization.**	Critical for high-voltage applications. Higher CTI reduces the risk of long-term tracking failures under contamination.
Relative Permittivity (Dk) / Dissipation Factor (Df)	**Dk** (Dielectric Constant) relates to signal speed. **Df** (Loss Tangent) relates to signal attenuation (loss).	**Signal Integrity Failures, Intermittent Data Errors, Excessive Heat Generation.**	Low and stable Dk/Df across frequency and temperature are essential for high-speed digital and RF designs to prevent intermittent communication failures, which can be difficult to root-cause.

3. Material Selection Strategies by Failure Mode

A. Delamination & PTH Failures

Thermal or Thermo-mechanical failures.

FA Root Cause:

Low Tg, high Z-axis CTE, or low Td relative to the soldering process.

Key Solution:

High-Tg Laminates (> 170 °C); Low-CTE (Z) Materials (CTE_z < 45 ppm/°C).

B. CAF & Corrosion Mitigation

Electrochemical growth of copper salts.

FA Root Cause:

High moisture absorption, low material purity, or poor resin-to-glass adhesion.

Key Solution:

CAF-Rated Materials (specialty resins/glass treatments); High Td Halogen-Free systems.

C. Solder Joint/Pad Cracking

Fatigue failure from thermal cycling.

D. High-Speed/RF Reliability

Signal loss or intermittency.

FA Root Cause:

Excessive X/Y-axis CTE mismatch (PCB vs. Component/Solder).

Key Solution:

Low In-Plane CTE Materials (BT-Epoxy, Aramid Fiber); Metal Core PCBs (MCPCBs).

FA Root Cause:

High Df, or inconsistent Dk over temperature/frequency.

Key Solution:

Low-Loss Hydrocarbon/PTFE Materials (Df < 0.005); Tightly controlled Resin Consistency.

4. Selection Flowchart: Post-FA Decision Matrix

Observed Failure Signature	Primary Material Property Target	Secondary Property Target	Recommended Material Family
PTH/Via Barrel Crack	Low CTE_z (especially above Tg)	High Tg, High Td	High-Tg Epoxies, Polyimide
Delamination (Internal)	High Td, Low Moisture Absorption	High Tg	Polyimide, Modified Epoxies
CAF/Electrochemical Migration	CAF-Resistant Resin/Adhesion	Low Moisture Absorption	CAF-Rated Systems, Advanced Halogen-Free
Solder Joint/BGA Cracking	Low CTE_x/y	Thermal Conductivity	BT-Epoxy, Aramid-Reinforced, MCPCB
Excessive Signal Loss	Ultra-Low Df (Dissipation Factor)	Stable Dk over temperature	Hydrocarbon/PTFE Composites

5. Material Families Overview

Standard FR-4

Cost-effective, good electrical properties up to 1 GHz. Prone to CAF, high Z-axis CTE above Tg.

FA-Use: Low-complexity, low-power, non-critical boards.

High-Tg FR-4

Improved thermal stability (Tg > 170 °C), offering better resistance to PTH failure during thermal excursions.

FA-Use: Multi-layer boards, high-layer count, Pb-free soldering.

Polyimide

Excellent thermal properties (Tg ≈ 240 °C), extremely low CTE_z after post-cure. Very expensive.

PTFE/Hydrocarbon Blends

Used for microwave/RF applications. Highly stable Dk and ultra-low Df. Poor mechanical stability and

FA-Use: Extreme high-temperature operating environments, downhole/aerospace.

high CTE are potential FA risks if not handled correctly.

FA-Use: High-speed backplanes, RF power amplifiers.

Appendix: Material Data Sheet Review in FA

When reviewing material data sheets post-failure, pay special attention to the **Thermal Stress/Endurance** section (often missing in basic data) and the Z-axis CTE plot. Request a **Thermogravimetric Analysis (TGA)** plot if the failure involves excessive heat, as this visualizes the material's mass loss (decomposition) point, Td, which is a clearer indicator of assembly process compatibility than Tg.