CLEARROOT MATERIALS
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CLEARROOT MATERIALS LLC

Example Investigations

Representative Materials Failure Analysis & Characterization Examples

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Root Cause. Clear Solutions.

ABOUT THESE EXAMPLES

How ClearRoot approaches complex materials challenges.

The following representative investigations demonstrate how ClearRoot Materials LLC approaches complex materials challenges through a structured process of problem definition, evidence collection, analytical characterization, and technical interpretation. These examples are educational demonstrations rather than client engagements, but the investigation strategies and engineering principles reflect real-world approaches commonly used in materials failure analysis, contamination investigations, supplier qualification, and materials characterization.

01	02	03	04
Define	**Investigate**	**Analyze**	**Deliver**
Clarify failure mode, business impact, history, constraints, and the question that needs answering.	Review samples, documentation, field conditions, process inputs, and relevant evidence.	Connect observations to likely mechanisms using materials science and analytical chemistry.	Provide clear findings and practical recommendations that support technical and business decisions.

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EXAMPLE INVESTIGATION CRM-CS-001

Adhesive Bond Failure Investigation: Silicone Contamination in Elastomer-to-Metal Bonds

CLIENT OVERVIEW

A manufacturer of industrial equipment experienced recurring adhesive bond failures in elastomer-to-metal assemblies. These failures were leading to increased warranty claims, production delays, and growing concerns about long-term product reliability.

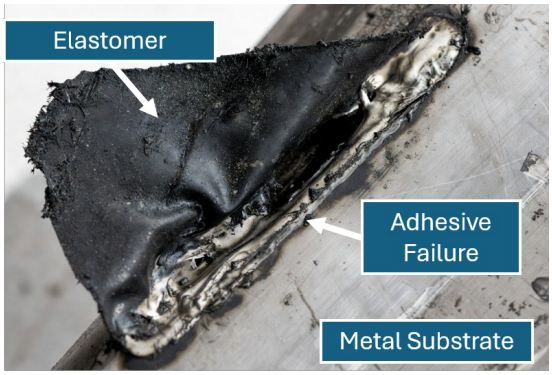


Figure 1: Magnified image generated for educational reasons showing an elastomer debonding from a metal substrate.

THE CHALLENGE

Assemblies that passed initial inspection began exhibiting bond-line delamination after 3–6 months in service (**Figure 1**). Internal investigations could not identify whether the root cause was adhesive selection, surface preparation, environmental exposure, or a manufacturing variation.

ANALYTICAL APPROACH

- **Optical Microscopy** – Documented failure more and initiation sites.
- **SEM with EDS –** Examined fracture surfaces and elemental composition (**Figure 2**).
- **FTIR-ATR Spectroscopy –** Identified surface contamination (**Figure 3**).
- **Goniometer (Water Contact Angle) –** Evaluated surface 'wettability' (Figure 4).
- **Manufacturing Process Review**

KEY OBSERVATIONS

SEM/EDS elemental mapping (**Figure 2**) revealed localized silicon-rich regions (*red*) at the failed bond interface. These red regions were absent in control specimens. FTIR identified the silicone contaminant as polydimethylsiloxane (PDMS; **Figure 3**).

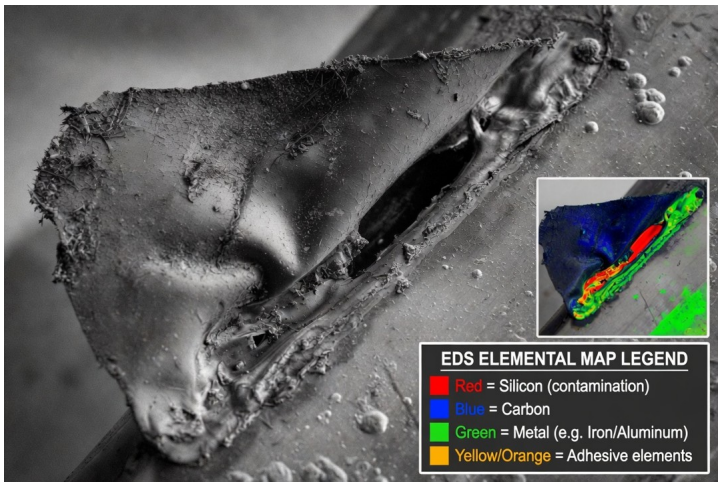


Figure 2: Scanning Electron Microscopy image generated for educational purposes only. Here it demonstrates a failed part with an Elemental Map displayed on the bottom right. Red colored section indicates a silicon-containing material.

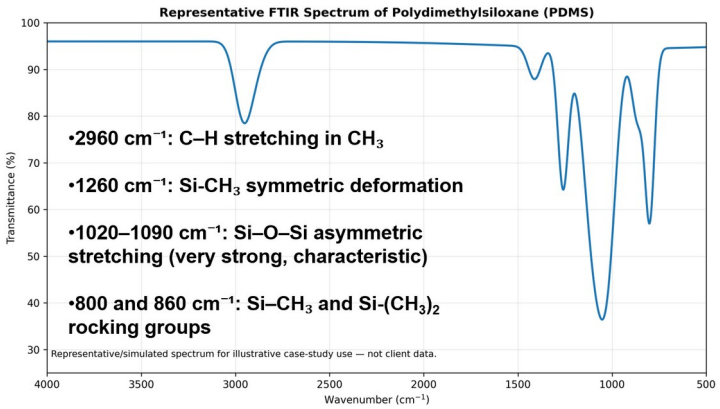
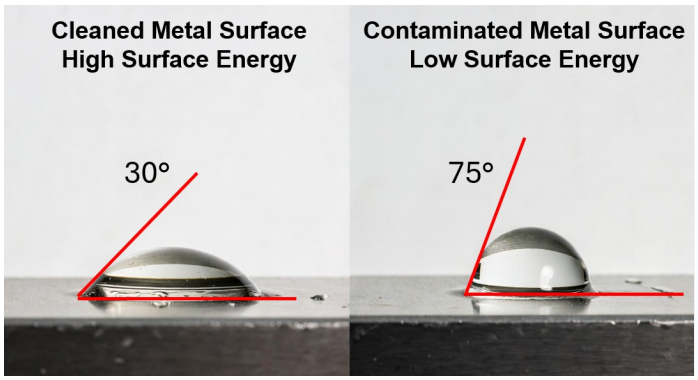


Figure 3: Example FTIR spectrum of polydimethylsiloxane (PDMS). Image generated for illustrative purposes to demonstrate the type of analytical data commonly used during contamination investigations.

LIKELY FAILURE MECHANISM

The primary failure mechanism was adhesion loss caused by silicone-based contamination on the metal substrate. FTIR and elemental analysis confirmed polydimethylsiloxane (PDMS) on the bonding surface. This contamination was introduced during upstream molding operations from mold release agents. Silicone residue significantly reduced the metal surface energy, with failed surfaces exhibiting a 150% increase in WCA, indicating substantially reduced surface energy and poor adhesive 'wettability' (**Figure 4**). This prevented proper adhesive wetting, creating a weak boundary layer that propagated under thermal and humidity cycling.



Surface Condition	Water Contact Angle (°)
Control Surface	30°
Failed Surface	75°

Figure 4: Water droplet placed on the control surface (left) vs. the failed surface (right). Image generated for illustrative purposes to better understand surface energy concepts.

RECOMMENDED CORRECTIVE ACTIONS

- **Isolation:** Eliminated silicone-containing materials from all upstream handling and molding processes
- **Surface Quality Control:** Implemented a rapid, line-side water contact angle testing (< 40° prior to bonding)
- **Process Optimization**: Standardized robust surface cleaning and preparation procedures

POTENTIAL BUSINESS IMPACT

Metric	Outcome
Field Failures	85% Reduction
Annual Warranty Savings	$250k
New QA Procedure	Implemented Globally
Root Cause Investigation Timeline	Completed in 3 Weeks

KEY TECHNICAL INSIGHT

Even trace levels of silicone contamination — often invisible during standard inspection — can cause premature adhesive failure. Routine surface energy verification (via water contact angle) is a critical, yet frequently overlooked, quality control step in elastomer-to-metal bonding applications.

ABOUT CLEARROOT MATERIALS

Specialists in polymer, elastomer, adhesive, and coating failure analysis, interfacial forensics, root cause investigations, unknown material identification, and industrial materials troubleshooting.

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EXAMPLE INVESTIGATION CRM-CS-002

Premature Elastomer Cracking Investigation
Root Cause Traced to Ozone-Induced Degradation and Improper Material Selection

CLIENT OVERVIEW

A manufacturer of outdoor industrial equipment experienced recurring cracking and premature failure of an elastomer sealing component. Failures resulted in water ingress, increased maintenance costs, and reduced product reliability.

THE CHALLENGE

The elastomer seals passed initial qualification tests but developed surface cracks in 6–12 months of outdoor service (**Figure 1**). Internal investigations initially suggested mechanical overload or installation damage, yet the failure pattern did not align with either hypothesis.

Failure Rate: 12%
Service Life: 6–12 months
Environment: Outdoor Exposure
Component: Elastomer Seal

Figure 1: Failed industrial rubber part. Note cracking propagation relative to applied strain. Image generated for illustrative purposes.

ANALYTICAL APPROACH

- Visual and optical microscopy
- Scanning Electron Microscopy (SEM) for crack morphology
- Fourier Transform Infrared (FTIR) spectroscopy for elastomer analysis
- Environmental and service condition assessment
- Comparative analysis with ozone-resistant materials

KEY OBSERVATIONS

Fine surface cracks were observed perpendicular to the applied strain direction (**Figure 2**). The crack morphology is consistent with classical ozone attack. FTIR spectroscopy identified the failed material as natural rubber (cis-1,4-polyisoprene), an unsaturated elastomer known to exhibit poor resistance to long-term ozone exposure (**Figure 3**).

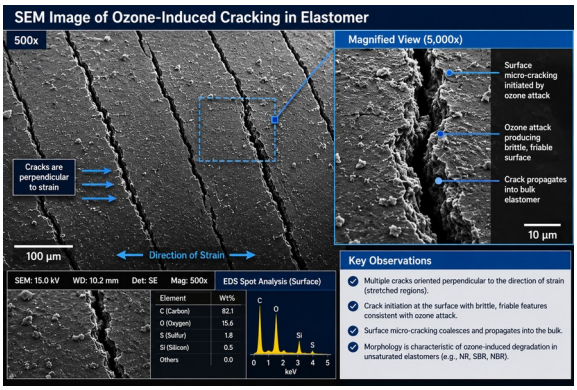
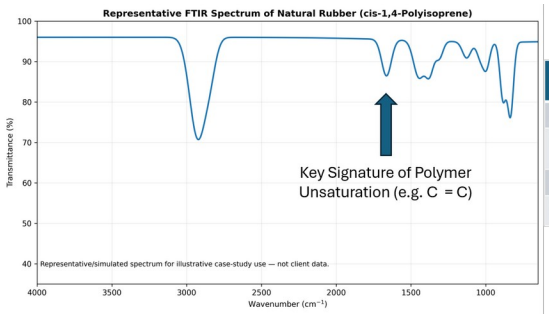


Figure 2: Representative SEM-style image generated for illustrative purposes to demonstrate the type of fracture surface features commonly evaluated during failure analysis investigations. This example is consistent with environmentally induced elastomer degradation.



Functional Group	Natural Rubber (cm^{-1})	EPDM (cm^{-1})	Structural Indication
C-H Stretching	2960, 2850	2920, 2850	Present in both
C=C Stretching	1660-1664	None	Primary fingerprint for unsaturation
C-H Methyl Bend	1445, 1374	1460, 1380	Present in both
C=C-H Wag	830-840	None	Sign of *cis*-1-4, NR

Figure 3. Representative cartoon FTIR spectrum of natural rubber (cis-1,4-polyisoprene). Spectral analysis identified the failed material as an unsaturated elastomer susceptible to ozone-induced degradation under long-term environmental exposure. Image generated for illustrative purposes to demonstrate analytical identification of elastomer materials.

LIKELY FAILURE MECHANISM

The primary failure mechanism was ozone-induced degradation of an unsaturated elastomer that lacked adequate long-term ozone resistance. Atmospheric ozone attacked the carbon-carbon double bonds in the polymer backbone, leading to chain scission and progressive surface cracking (**Figure 4**). Natural rubber was selected for an outdoor service environment where long-term ozone exposure was expected. The material lacked sufficient ozone resistance for the application.

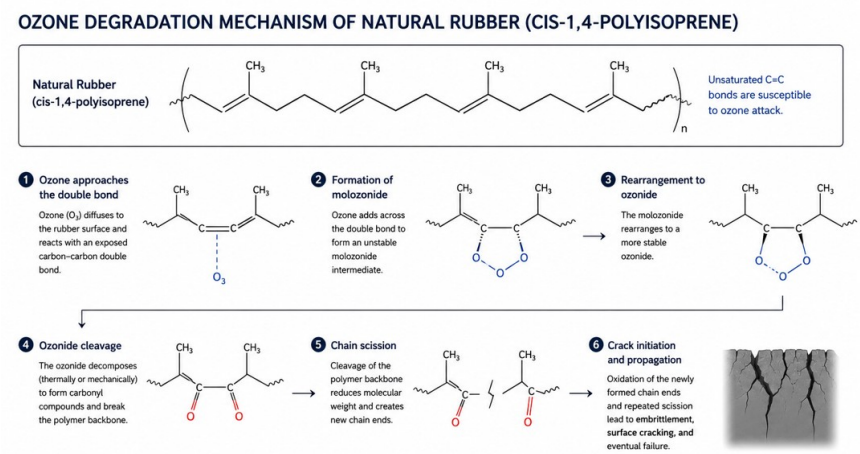


Figure 4: How ozone attacks natural rubber's double bonds, causing chain scission, which ultimately makes the rubber part much harder, stiffer, and prone to cracking.

RECOMMENDED CORRECTIVE ACTIONS

1) Replaced existing natural rubber with ozone-resistant EPDM
2) Updated material specifications with ozone exposure requirements
3) Added accelerated ozone testing to qualification protocols
4) Implemented supplier material verification requirements (**Figure 5**)

Figure 5: Comparison of Failed Natural Rubber Part with EPDM Part.

POTENTIAL BUSINESS IMPACT

Metric	Outcome
Service Life	3x Increase
Field Failures	Eliminated
Warranty Claims	Significant Reduction
Root Cause Investigation	Completed in 3 Weeks

KEY TECHNICAL INSIGHT

Ozone cracking is frequently misdiagnosed as mechanical fatigue. Characteristic crack orientation (perpendicular to strain) and morphology are reliable indicators of ozone attack and should prompt immediate material compatibility review.

ABOUT CLEARROOT MATERIALS

Specialists in polymer and elastomer failure analysis, degradation mechanisms, root cause investigations, adhesive and interfacial forensics, material selection consulting, and industrial troubleshooting.

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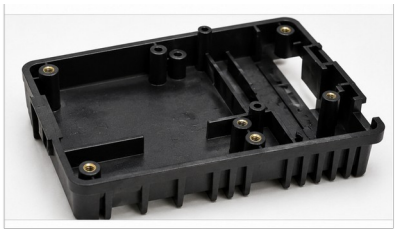
EXAMPLE INVESTIGATION CRM-CS-003

Unknown Injection Molded Plastic Characterization Enables Supplier Qualification and Cost Reduction

CLIENT OVERVIEW

A manufacturer of injection-molded industrial components sought to qualify a second supplier for a critical plastic housing used in a high-volume product line (**Figure 1**). The incumbent supplier considered the material formulation proprietary and provided only limited information on resin selection and additive.

Unknown Molded Plastic Housing Component Submitted for Material Identification



Close-Up of Injection Molded Housing Features

Parameter	Value
Component	Injection Molded Housing
Industry	Industrial Equipment
Annual Volume	50,000+ Units
Objective	**Qualify Second Supplier**

Figure 1: Injection molded industrial housing submitted for material identification and supplier qualification. The component was specified only as a "black engineering thermoplastic," requiring analytical characterization to determine polymer composition and evaluate alternative suppliers. Image generated for illustration purposes.

THE CHALLENGE

The manufacturer needed to determine what polymer was being used, whether replacement materials were equivalent, and whether lower-cost suppliers could be qualified without increasing product risk. Existing documentation specified only 'black engineering thermoplastic,' which was insufficient for supplier qualification.

ANALYTICAL APPROACH

Visual inspection, FTIR spectroscopy, pyrolysis-gas chromatography mass spectrometry, TGA, SEM/EDS, and comparative material analysis were performed to identify the polymer, thermal properties, filler package, and supplier-to-supplier differences.

KEY FINDINGS

FTIR analysis identified the material as a polyamide (PA). Py-GC/MS subsequently confirmed the material to be Nylon 6 and NOT Nylon 11 or Nylon 12 through identification of characteristic ε-caprolactam pyrolysis product (**Figure 2**). While Py-GC/MS confirmed all candidate materials contained a Nylon 6 chemistry, additional characterization was required to determine whether the formulations, including fillers, were truly equivalent.

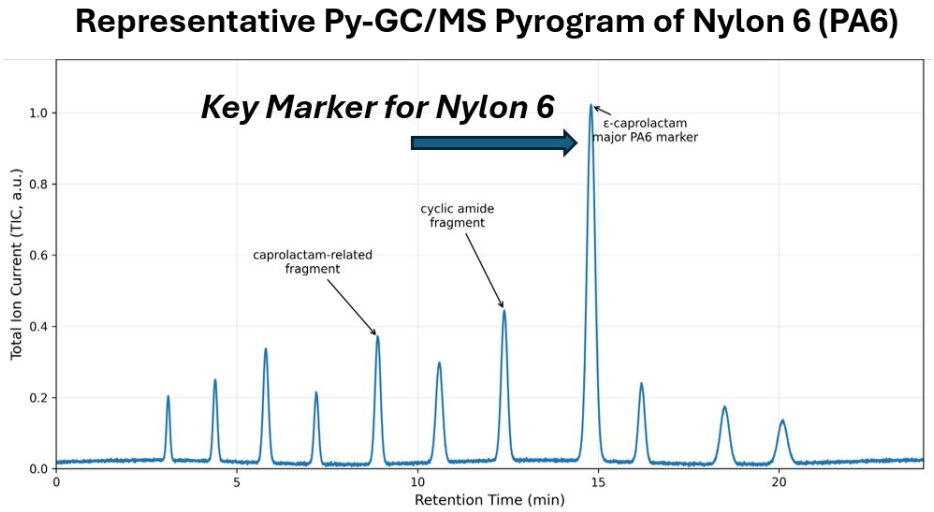
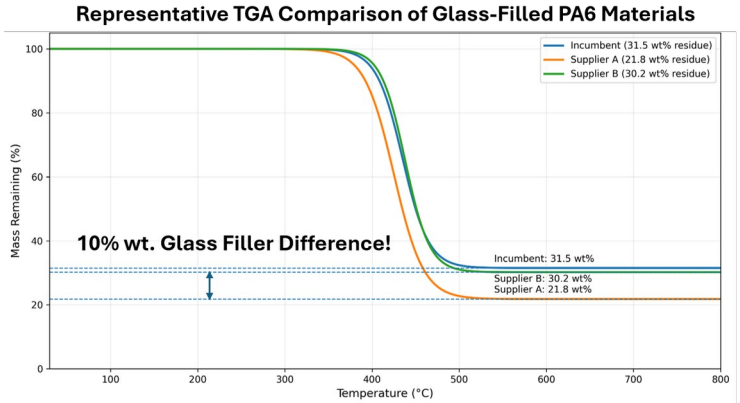


Figure 2: Example pyrogram illustrating characteristic Nylon 6 (PA6) decomposition products. Image generated for illustrative purposes to demonstrate the type of analytical data used during material identification investigations.

SEM/EDS and TGA characterization revealed 31.5% glass fiber reinforcement in the incumbent material compared to 30.2% (Supplier B) and 21.8% (Supplier A) (**Figures 3-4**). Comparative analysis demonstrated that one of the proposed replacement materials was not compositionally equivalent despite similar supplier descriptions.



Material	Glass Fiber Content (% weight)
Incumbent	31.5%
Supplier A	21.8%
Supplier B	30.2%

Figure 3: Example thermogravimetric analysis revealed that Supplier A contained substantially less inorganic reinforcement than the incumbent material despite both being marketed as 30% glass-filled Nylon 6. The results demonstrate the value of analytical characterization during supplier qualification and material substitution programs. Thermal image generated for illustrative purposes for educational reasons.

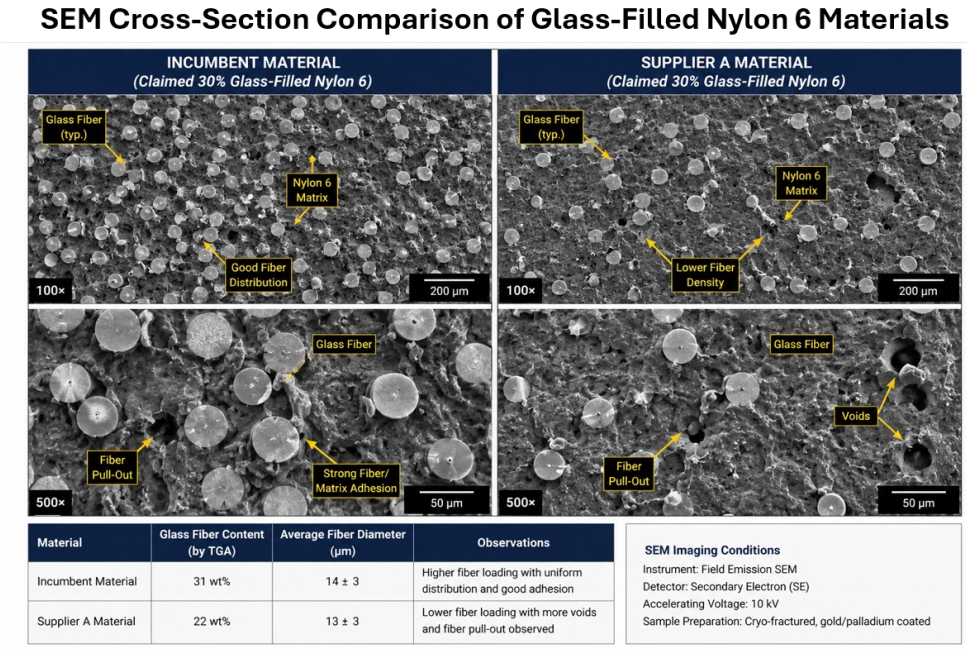


Figure 4: Scanning electron microscopy (SEM) cartoon revealed differences in reinforcement density and fiber distribution between suppliers. The incumbent material exhibited a higher glass fiber loading and more uniform reinforcement network than Supplier A. Image generated for illustrative purposes only.

LIKELY FAILURE MECHANISM

Supplier A's material was not compositionally equivalent to the incumbent material despite being marketed as 30% glass-filled Nylon 6. Analytical characterization revealed significantly lower reinforcement content and formulation differences that would likely have reduced mechanical performance and long-term durability.

Property	Incumbent	Supplier A	Supplier B
Polymer Identification	PA6, 30% GF	PA6, GF	PA6, GF
Glass Fiber Content	31.5 wt%	21.8 wt%	30.2 wt%
Py-GC/MS Result	Nylon 6 Confirmed	Nylon 6 Confirmed	Nylon 6 Confirmed
Thermal Stability	438°C	425°C	436°C
Supplier Equivalency	Baseline	Not Equivalent	Equivalent
Qualification Recommendation	Approved	Do Not Qualify	Qualify

Figure 5: Summary of analytical characterization results for the incumbent material and candidate suppliers. While all materials were identified as Nylon 6, differences in glass fiber content and thermal behavior were observed. Supplier B demonstrated the closest analytical equivalency to the incumbent material and was recommended for qualification.

RECOMMENDED CORRECTIVE ACTIONS

1) Established analytical acceptance criteria for incoming materials
2) Qualified two alternative suppliers
3) Added FTIR verification for critical components
4) Created supplier equivalency requirements
5) Documented material composition for future procurement activities

POTENTIAL BUSINESS IMPACT

- **Qualified two alternative suppliers**
- **Avoided qualification of a non-equivalent material**
- **Reduced supply-chain risk**
- **Achieved an estimated 15–20% material cost reduction**
- **Established analytical acceptance criteria for future sourcing activities**

KEY TECHNICAL INSIGHT

Materials with identical supplier descriptions are often chemically and structurally different. Analytical characterization provides objective evidence needed to support supplier qualification claims, material substitutions, cost-reduction initiatives, and long-term reliability decisions.

Ready to solve your materials challenge?

Whether you are investigating a product failure, contamination issue, material identification question, supplier qualification concern, or need an independent technical perspective, ClearRoot Materials LLC can help.

Typical areas of support

- Polymer and elastomer failure analysis
- Adhesive and bonding failures
- Materials identification and characterization
- Contamination investigations
- Supplier material verification
- Technical consulting and root-cause analysis

The ClearRoot difference

Independent & unbiased

Testing recommendations are driven by the problem - not laboratory utilization.

Ph.D.-level expertise

Deep expertise in polymers, elastomers, adhesives, coatings, and material characterization.

Actionable solutions

Clear findings and practical recommendations for technical and business decisions.

Clear communication

Complex analytical data translated into decision-ready insights.

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