From Biological Material to Graphite

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Luoyang BioGem Technology Co., Ltd.
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1. Introduction

1.1 Why Extraction Quality Determines Diamond Quality

The carbon extracted from biological material is the sole feedstock for memorial diamond synthesis. Every inclusion, color defect, and growth irregularity in the final diamond can be traced to a flaw in extraction, purification, or graphitization. The HPHT press does not correct carbon quality — it amplifies it. Poor feedstock produces poor diamonds. This guide documents the extraction protocol developed over fourteen years of production at BioGem Lab, based on Chinese National Invention Patent ZL 201010565778.9.

1.2 Patent Background

Chinese National Invention Patent ZL 201010565778.9, granted October 10, 2012 (Certificate No. 1058820), covers a method for extracting carbon from biological raw materials for diamond production. The patent describes a multi-stage thermal decomposition and chemical purification process that converts keratin-based biological material into high-purity carbon suitable for graphitization and subsequent HPHT diamond synthesis.

The patent specifies:

Source material preparation and pre-treatment protocols

Controlled-atmosphere thermal decomposition at 800–1,000°C

Acid leaching for mineral salt removal

Multiple rinse cycles with deionized water

Quality verification via elemental analysis

BioGem Lab's current protocol extends the patented process with additional quality control stages — infrared spectroscopy, thermogravimetric analysis (TGA), and automated graphitization parameter selection based on source material type.

1.3 Scope of This Guide

This manual covers:

Source material preparation and carbon content requirements

Stage 1: Thermal decomposition (pyrolysis)

Stage 2: Acid leaching and mineral salt removal

Stage 3: Quality verification and batch release criteria

Stage 4: Graphitization (conversion to crystalline graphite)

Sample handling, storage, and contamination prevention

Troubleshooting common extraction failures

This guide does not cover HPHT diamond synthesis, cutting, polishing, or grading. Those processes are documented separately.

1.4 Minimum Sample Requirements

Minimum sample mass depends on source type and target diamond size. The figures below include a safety margin for process yield.

Source Type	Minimum Submit	Recommended	Carbon Content (dry basis)
Human hair / pet fur	6 g	10–20 g	30–40%
Feathers	10 g	20–30 g	25–35%
Plant fiber	15 g	30–50 g	40–50%
Solid keratin (nails, claws)	10 g	20 g	35–45%
Cremated remains	Not accepted	—	<0.1%

The 6 g minimum for hair/fur includes a safety margin for extraction losses. Submitting below 6 g risks insufficient carbon for a 0.5 ct diamond after accounting for process yield (35–45% of original carbon content reaches final graphite stage).

2. Source Materials

2.1 Keratin Structure and Carbon Content

Hair, fur, feathers, and nails are composed primarily of keratin — a fibrous structural protein. Keratin's amino acid composition determines its carbon content and how it decomposes under heat. Human hair keratin composition (typical):

Amino Acid	Weight %	Carbon Atoms
Cysteine	17–18%	3
Serine	11–12%	3
Glutamic acid	11–12%	5
Threonine	6–7%	4
Glycine	6–7%	2
Leucine	6–7%	6
Valine	5–6%	5
Others	35–40%	Variable

The high cysteine content (17–18%) is significant because cysteine contains sulfur. During pyrolysis, sulfur forms hydrogen sulfide (H_2S), sulfur dioxide (SO_2), and carbonyl sulfide (COS). These gases require scrubbing. The sulfur content also explains why extracted carbon from hair has a lower carbon-to-nitrogen ratio than plant-derived carbon.

2.2 Carbon Content by Source Material

Carbon and heteroatom content varies by species and tissue. The tables below summarize typical values for the most common memorial-diamond feedstocks.

Material	Carbon (dry wt)	Nitrogen	Sulfur	Notes
Human hair	30–40%	14–16%	4–5%	High cysteine; high sulfur output during pyrolysis
Dog fur	30–38%	14–15%	3–4%	Similar to human hair; guard hairs vs. undercoat vary

Material	Carbon (dry wt)	Nitrogen	Sulfur	Notes
Cat fur	28–35%	13–15%	3–4%	Finer diameter; faster thermal decomposition
Horse hair	35–42%	12–14%	2–3%	Lower sulfur; cleaner pyrolysis
Rabbit fur	25–32%	14–16%	4–5%	Very fine; higher ash content
Chicken feathers	25–35%	13–15%	2–3%	High keratin but low bulk density
Plant fiber (cotton)	40–45%	0.5–1%	<0.1%	Low sulfur; different decomposition pathway

Material	Carbon (dry wt)	Nitrogen	Sulfur	Notes
Wood (camphor)	45–50%	0.2–0.5%	<0.1%	High carbon; lignin-cellulose matrix
Nails / claws	35–45%	12–14%	2–3%	Dense keratin; slower decomposition

2.3 Material Collection Protocol

Step 1: Identify contamination risks. Environmental contamination is the most common cause of extraction failure. Hair and fur collect: skin oils and sebum (organic, manageable); dust and soil particles (silica, aluminosilicates — problematic); hair care product residue (silicones, polymers — problematic); flea treatment chemicals (organophosphates — toxic at pyrolysis temperatures); dye and bleach residue (metallic salts — problematic).

Step 2: Pre-collection washing. If the sample is visibly dirty or has product residue, wash with mild shampoo (no conditioner, no silicone), rinse thoroughly with deionized water, and air-dry completely before collection. Do not use heat to dry — heat denatures keratin and changes decomposition behavior.

Step 3: Collection. Collect hair/fur by cutting, not pulling. Pulled hairs include root bulbs with different composition. For pet fur, collect from multiple body areas to average out density variation. Fill the collection container to at least the 6 g mark for hair/fur. Do not compress fur tightly — air circulation prevents moisture buildup.

Step 4: Immediate storage. Seal in the provided polypropylene bag with desiccant packet. Store at room temperature, away from direct sunlight. Do not refrigerate or freeze — condensation during thawing introduces moisture. Ship within 14 days of collection when possible.

3. Stage 1: Thermal Decomposition

3.1 Overview

Thermal decomposition (pyrolysis) converts solid biological material into a carbon-rich char by heating in an oxygen-limited atmosphere. Volatile elements — hydrogen, oxygen, nitrogen, and sulfur — dissociate and exit as gas-phase products. The solid residue is a porous, amorphous carbon matrix containing trapped mineral salts.

Mass reduction during this stage is 85–90%. One gram of dry hair yields approximately 100–150 mg of carbon char (source: BioGem Lab internal process data, 2021–2025).

3.2 Equipment

- Tube furnace with programmable temperature controller
- Quartz reaction tube, 50 mm diameter × 800 mm length
- Nitrogen or argon gas supply, 99.99% purity, flow rate 0.5–2.0 L/min
- Ceramic sample boat, 100 mm × 30 mm × 15 mm
- Gas scrubber (for H_2S/SO_2 removal)
- Exhaust ventilation system

3.3 Process Parameters

Parameter	Setting	Tolerance
Atmosphere	Nitrogen or argon	<100 ppm O_2
Flow rate	1.0 L/min	±0.2 L/min
Ramp rate	5°C/min	±1°C/min
Hold temperature	800–1,000°C	Target: 900°C
Hold time	2–4 hours	Extend for bulk samples
Cool-down	Furnace cool to 200°C in inert atmosphere	Do not air-quench

3.4 Step-by-Step Procedure

Step 1: Load sample. Place the weighed biological sample in a ceramic boat. Record starting mass to ±0.01 g. Spread the sample evenly — no clumps thicker than 10 mm. Clumped material traps volatiles and produces incomplete decomposition.

Step 2: Position boat. Insert the boat into the center of the quartz tube. The sample must sit in the uniform-temperature zone (typically the middle 200 mm of the tube). Positioning outside this zone produces uneven pyrolysis.

Step 3: Seal and purge. Seal the tube end caps. Begin nitrogen flow at 1.0 L/min. Purge for 15 minutes at room temperature to displace air. Verify oxygen level at exhaust <100 ppm using an O_2 analyzer.

Step 4: Begin heating. Start the furnace controller. Ramp at 5°C/min. Do not exceed 10°C/min — rapid heating causes volatile release too quickly, creating pressure spikes that can eject sample material from the boat.

Step 5: Monitor at key temperatures. 100–150°C: moisture evolution (normal). 200–300°C: keratin denaturation; sulfur compounds begin releasing. 400–500°C: main decomposition phase; rapid mass loss; organic volatiles condense as sticky brown residue downstream (must be collected and disposed of). 600–800°C: carbonization completes; sample is black, brittle char. 800–1,000°C: final hold; mineral salts remain; carbon structure stabilizes.

Step 6: Hold at temperature. Hold at 900°C for 2–4 hours; the hold time depends on sample mass:

Sample Mass	Hold Time
<5 g	2 hours
5–15 g	3 hours
>15 g	4 hours

Step 7: Cool down. After hold completion, stop heating. Allow furnace to cool to 200°C while maintaining nitrogen flow. Do not open the tube until below 200°C — pyrophoric carbon can ignite if exposed to air while hot.

Step 8: Remove and weigh. Transfer the char to a weighing dish. Record mass. Expected yield: 10–15% of starting dry mass for hair/fur.

3.5 Expected Outcomes

Source Material	Starting Mass	Char Yield	Char Mass
Human hair	10 g	10–15%	1.0–1.5 g

Source Material	Starting Mass	Char Yield	Char Mass
Dog fur	10 g	10–14%	1.0–1.4 g
Horse hair	10 g	12–16%	1.2–1.6 g
Plant fiber	10 g	12–18%	1.2–1.8 g
Feathers	10 g	8–12%	0.8–1.2 g

4. Stage 2: Acid Leaching

4.1 Purpose

The carbon char produced by thermal decomposition contains mineral salts trapped in the porous carbon matrix. These salts originate from biological minerals (Ca, Na, Mg, K, Fe from tissue), environmental contamination (Si, Al from dust/soil), and hair care products (Ti, Zn from sunscreen/pigments). If not removed, these minerals contaminate the HPHT synthesis cell, react with the metal catalyst, form non-diamond carbon phases, or incorporate into the diamond lattice as color centers.

4.2 Equipment

- Fume hood with acid vapor scrubber
- Polypropylene beakers, 250 mL
- Hot plate with magnetic stirrer
- pH meter (calibrated daily)
- Vacuum filtration apparatus with 0.45 µm membrane
- Deionized water (resistivity >18 MΩ·cm)
- Hydrochloric acid (HCl), 37% reagent grade
- Nitric acid (HNO_3), 65% reagent grade (optional, for stubborn contamination)
- Safety equipment: face shield, acid-resistant gloves, apron, emergency eyewash

4.3 Safety Protocol

- Verify fume hood airflow indicator is green before beginning.
- Locate emergency eyewash and safety shower. Test eyewash weekly.
- Wear face shield (not just goggles — acid splashes to the face are a real hazard).
- Wear nitrile gloves under acid-resistant neoprene gloves.
- Never add water to concentrated acid. Always add acid to water.
- Keep a container of sodium bicarbonate (baking soda) nearby for spill neutralization.

4.4 Acid Leaching Procedure

Step 1: Prepare acid solution. Mix HCl with deionized water to make 1 M HCl (approximately 8.3% by volume). For 100 mL: add 8.3 mL of 37% HCl to 91.7 mL deionized water. Always add acid to water.

Step 2: Load char into beaker. Transfer the carbon char to a 250 mL polypropylene beaker. Add 1 M HCl at a 1:20 solid-to-liquid ratio. For 1 g of char, use 20 mL of acid solution.

Step 3: Heat and stir. Place on hot plate at 60–80°C. Stir at 300–400 rpm. Maintain temperature for 2 hours. Reactions: $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2\uparrow$; $Fe_2O_3 + 6HCl \rightarrow 2FeCl_3 + 3H_2O$. Silica ($SiO_2$) is NOT removed by HCl — see Section 4.6. Bubbling (CO_2 evolution) is normal in the first 30 minutes; if it continues beyond 1 hour, the sample contains significant carbonate.

Step 4: Cool and settle. Remove from heat, cool to room temperature, let solids settle for 15 minutes.

Step 5: Decant and filter. Decant acid supernatant to a waste container (neutralize before disposal). Add fresh deionized water, stir, settle, decant. Repeat 5–7 times until rinse water pH is 6.0–7.0 (5 washes for hair-derived char, 7+ for plant-derived).

Step 6: Final filtration. Transfer slurry to vacuum filtration with 0.45 µm membrane. Rinse with deionized water until filtrate pH is neutral. Collect the carbon cake.

Step 7: Dry. Dry at 105°C for 4 hours or until constant mass. Weigh and record.

4.5 Alternative: Nitric Acid Leach (For Heavy Metals)

If initial elemental analysis shows elevated heavy metals (Pb, Cd, Cr, Ni >50 ppm), perform an additional nitric acid leach: use 0.5 M HNO_3 (dilute 65% HNO_3 1:20 with deionized water); 60°C, 1 hour, with stirring; 5× water rinse to neutral pH; dry at 105°C. Nitric acid oxidizes and dissolves metallic contaminants that HCl does not touch. Do not skip the HCl step — sequential HCl then HNO_3 is more effective than either alone.

4.6 Dealing With Silica Contamination

Silica (SiO_2) is insoluble in HCl and HNO_3. If the source material was exposed to soil or dust, silica may persist. Two options:

Option A: Hydrofluoric acid (HF) — effective but hazardous. 5% HF in polypropylene container; room temperature, 30 minutes; requires calcium gluconate gel for skin exposure emergency; requires dedicated HF-rated fume hood; not recommended for routine use.

Option B: Sodium hydroxide fusion — safer alternative. Mix char with NaOH pellets (1:5 mass ratio); heat to 400°C in nickel crucible for 1 hour; cool, dissolve in water, filter; requires subsequent HCl wash to remove residual Na^+.

For most memorial diamond feedstock, Option B is adequate. Silica levels in properly collected hair/fur are typically low enough that standard HCl leaching is sufficient.

5. Stage 3: Quality Verification

5.1 Quality Gates

Every batch of extracted carbon must pass three quality gates before proceeding to graphitization.

Gate	Test	Threshold	Action if Failed
1	Visual inspection	Black, uniform, free-flowing powder	Re-process if clumped or discolored
2	IR spectroscopy	No C-H, N-H, O-H peaks above baseline	Return to pyrolysis if organic residue detected
3	TGA purity	>99.5% carbon by mass	Additional acid leach cycles if below threshold

5.2 Visual Inspection

Spread a small sample on white paper under bright light. Expected appearance: Color — deep black, no brown or gray tint; Texture — fine powder, free-flowing; No visible particles (sand, hair fragments, shiny specks); No odor (any sulfurous smell indicates incomplete decomposition). Common visual defects:

Defect	Cause	Remedy
Brown tint	Incomplete pyrolysis (too low / too short hold)	Re-pyrolyze at 950°C for 2 hours
Gray tint	High ash content (minerals not leached)	Repeat acid leach with fresh HCl
Clumping	Moisture absorption or tar residue	Dry at 150°C; re-pyrolyze if tar present
Visible fibers	Incomplete decomposition	Grind and re-pyrolyze
Shiny specks	Metal contamination	HNO_3 leach or reject batch

5.3 Infrared (IR) Spectroscopy

IR spectroscopy detects residual organic functional groups that indicate incomplete decomposition. Procedure: (1) Mix 1 mg carbon with 100 mg KBr. (2) Grind to fine powder in an agate mortar. (3) Press into a translucent pellet (10 tons, 2 minutes). (4)

Run transmission spectrum from 4,000 to 400 cm^{-1}. Expected spectrum for pure carbon:

Peak Location	Assignment	Expected Intensity
~1,580 cm^{-1}	C=C aromatic stretch	Strong, broad
~1,200 cm^{-1}	C–C stretch / C–O	Medium
3,400–3,600 cm^{-1}	O–H stretch (adsorbed water)	Weak

Prohibited peaks (indicate incomplete decomposition):

Peak Location	Assignment	Action
2,800–3,000 cm^{-1}	C–H stretch (aliphatic)	Re-pyrolyze
3,300–3,500 cm^{-1}	N–H stretch (amine)	Extend pyrolysis hold time
1,650–1,750 cm^{-1}	C=O stretch (carbonyl)	Re-pyrolyze + check for product residue
1,030–1,080 cm^{-1}	Si–O stretch (silica)	Consider HF or NaOH treatment

If any prohibited peak exceeds 5% of the baseline-corrected C=C peak intensity, the batch fails Gate 2. Return to pyrolysis.

5.4 Thermogravimetric Analysis (TGA)

TGA measures the mass of a sample as a function of temperature. In air, TGA measures how much of the sample burns away as CO_2 (carbon) versus how much remains as ash (minerals). Procedure: weigh 10.0 ± 0.1 mg into a platinum pan; run 50°C → 10°C/min → 900°C in synthetic air (80% N_2 / 20% O_2); hold 30 min. Carbon burns to CO_2 between 400–700°C; mass remaining at 900°C = ash; carbon purity = (Initial − Ash) / Initial × 100%. Acceptance criteria:

Grade	Carbon Purity	Disposition
Grade A	≥99.95%	Proceed to graphitization
Grade B	99.5–99.94%	Proceed with monitoring; flag for process review
Grade C	99.0–99.49%	Additional acid leach cycle required
Reject	<99.0%	Reject batch; investigate source material or process deviation

BioGem Lab target: ≥99.95% carbon purity for all batches entering graphitization.

5.5 Nitrogen Content Measurement

Residual nitrogen from keratin acts as a dopant in HPHT diamond synthesis, producing yellow coloration. Measured by elemental analysis (CHNS/O analyzer).

Nitrogen Content	Diamond Color Impact
<100 ppm	Negligible — E-F color possible
100–300 ppm	Light yellow tint — G-H color
300–500 ppm	Noticeable yellow — I-J color
>500 ppm	Strong yellow — K+ color

If nitrogen exceeds 300 ppm, extend graphitization hold time or increase peak temperature by 50°C to drive off additional nitrogen.

6. Graphitization

6.1 Overview

Graphitization converts amorphous, disordered carbon into ordered, crystalline graphite. HPHT diamond synthesis requires graphite as the carbon feedstock because the hexagonal layers of graphite can rearrange into diamond's tetrahedral structure under extreme pressure. Amorphous carbon cannot be directly converted to diamond in standard HPHT presses. BioGem Lab's graphitization is integrated with the patented carbon extraction system, allowing tailored temperature profiles based on the specific biological source.

6.2 Equipment

- High-temperature graphitization furnace (resistance or induction heated)
- Graphite crucible, 30 mm diameter × 50 mm height
- Graphite felt insulation
- Argon supply, 99.999% purity
- Oxygen analyzer (<10 ppm detection limit)
- Programmable temperature controller with ±5°C accuracy at 3,000°C

6.3 Process Parameters

Parameter	Setting	Impact
Ramp rate	5–10°C/min	Prevents thermal shock; allows volatile escape
Peak temperature	2,600–3,000°C	Domain growth and defect annealing
Hold time	12–24 hours	Complete graphitization; nitrogen removal
Atmosphere	Argon, <10 ppm O_2	Prevents oxidation; maintains carbon yield
Cooling rate	10–20°C/min to 500°C, then furnace cool	Prevents crucible cracking; reduces residual stress

6.4 Step-by-Step Procedure

Step 1: Load carbon. Transfer 50–500 mg of purified carbon (depending on target diamond size) into a graphite crucible. Tap gently to settle. Do not compress — air channels prevent pressure buildup from residual volatiles.

Step 2: Seal chamber. Place crucible in the furnace hot zone. Seal the chamber. Evacuate to <1 mbar. Backfill with argon to slight positive pressure (1.05 bar). Verify O_2 <10 ppm.

Step 3: Ramp to graphitization temperature. Heat at 5–10°C/min. Between 1,000–1,500°C, small graphitic domains (turbostratic carbon) begin to form — layers parallel but randomly rotated, with interlayer spacing slightly larger than ideal graphite.

Step 4: Hold at peak temperature. Maintain 2,600–3,000°C for 12–24 hours (the unified graphitization range used throughout this guide). During this hold: turbostratic domains align, reducing interlayer spacing toward the ideal 3.354 Å; domain size (La) grows from ~10 nm to >100 nm; defects anneal out; impurities (nitrogen, boron, silicon) segregate to grain boundaries.

Step 5: Controlled cool-down. Cool at 10–20°C/min to 500°C, then furnace cool to room temperature in argon. Rapid cooling causes thermal shock that cracks the crucible and stresses the graphitized carbon.

Step 6: Remove and inspect. The graphitized carbon should be: Color — gray-black, metallic luster (not matte black); Texture — soft, slippery, marks paper like pencil lead; Form — sintered solid or soft agglomerate depending on starting mass.

6.5 Quality Metrics

Parameter	Poor	Acceptable	Excellent
Crystallite size (La)	<50 nm	50–100 nm	>100 nm
Degree of graphitization (g)	<0.60	0.60–0.85	>0.85
Interlayer spacing (d_{002})	>3.42 Å	3.40–3.42 Å	3.354–3.40 Å
Appearance	Black, matte	Dark gray	Gray, metallic luster

Well-graphitized material (g > 0.85, La > 100 nm) dissolves readily in metal catalyst solvents during HPHT synthesis and produces uniform diamond growth.

6.6 Yield

Stage	Yield (of original carbon content)
Pyrolysis (hair → char)	35–50% of carbon in source
Acid leaching (char → purified carbon)	90–95% of char carbon
Graphitization (purified carbon → graphite)	95–99% (negligible loss)
Overall (hair → graphite)	35–45%

For a 1.0 ct diamond (0.2 g carbon): Required graphite ~0.25 g (accounts for synthesis and cutting losses); Required purified carbon ~0.26 g; Required char ~0.28 g; Required hair (at 35% carbon) ~0.8 g. With safety margins: 6 g minimum, 10–20 g recommended.

7. Sample Handling and Storage

7.1 Collection Kit Contents

Item	Specification	Purpose
Collection bag	Polypropylene, zip-seal, 100 × 150 mm	Primary container
Desiccant packet	Silica gel, 2 g, food-grade	Moisture absorption
Instruction card	Laminated, bilingual	Collection guidance
Pre-paid return envelope	Padded, tear-resistant	Shipping
Barcode label	Unique ID, waterproof	Chain of custody

7.2 Contamination Prevention Checklist

- Collection scissors cleaned with isopropyl alcohol before use
- Collection surface is clean (white paper recommended)
- No hand cream or lotion on collector's hands
- Sample not collected immediately after bathing (wet hair traps moisture)
- No flea/tick treatment applied to pet within 7 days
- Sample not mixed with other pets' fur
- Bag sealed immediately after collection
- Desiccant packet included before sealing
- Barcode label applied to bag and log sheet

7.3 Shipping Requirements

Parameter	Requirement
Carrier	DHL Express / FedEx International Priority
Packaging	Triple barrier: waterproof label → sealed bag → rigid mailer
Label text	"For in vitro laboratory use only"

Parameter	Requirement
Documentation	Commercial invoice, species declaration, purpose statement
Temperature	Ambient; do not use cold packs (condensation risk)

7.4 Laboratory Receipt and Logging

- Verify package integrity. Photograph any damage.
- Scan barcode into Laboratory Information Management System (LIMS).
- Weigh sample (record wet and dry if moisture is suspected).
- Assign unique batch ID: format BGL-YYYY-NNNN.
- Store at 22°C, <40% RH until processing.
- Maximum storage before processing: 90 days.

7.5 Chain of Custody

Every sample is tracked through a barcode-linked production record:

Sample Receipt → Extraction (Batch ID) → Graphitization (Lot ID) → HPHT Synthesis (Growth Cell ID) → Cutting (Polisher ID) → Grading (Certificate ID) → Shipping (Tracking ID).

This chain links the finished diamond to the original source material. BioGem Lab provides a CCIC National Traceability Certificate that documents this chain.

8. Troubleshooting

8.1 Low Carbon Yield

Symptom	Possible Cause	Solution
Yield <8% from hair	Starting material was wet	Weigh after drying; correct for moisture
Yield <8% from hair	Temperature too low	Verify furnace calibration; check thermocouple placement
Yield <8% from hair	Insufficient hold time	Extend hold to 4 hours for bulk samples
Yield <8% from hair	Sample mostly non-keratin (dirt, debris)	Improve collection protocol; wash before submission
Yield varies batch-to-batch	Different hair types mixed	Segregate by source; adjust parameters per source

8.2 Contamination Detected

Symptom	Possible Cause	Solution
High Si in TGA ash	Soil/dust contamination	Wash sample before pyrolysis; improve collection
High Fe in TGA ash	Environmental iron	Check collection tools for rust; use stainless scissors
High Ca in TGA ash	Hard water residue	Use deionized water for all washes
Ti detected (XRF)	Sunscreen/hair product	Wash sample thoroughly before collection
Persistent organic peaks (IR)	Incomplete pyrolysis	Increase hold temperature to 950°C; extend hold to 4 hours

8.3 Incomplete Decomposition

Symptom	Possible Cause	Solution
Visible fibers in char	Temperature too low or ramp too fast	Reduce ramp to 3°C/min; increase hold to 950°C
Brown/black tar in tube	Insufficient gas flow	Increase N_2 flow to 1.5 L/min; check for leaks
Sample ejected from boat	Ramp rate too fast	Reduce to 3–5°C/min; use deeper boat
Foul odor after pyrolysis	Sulfur not fully released	Extend hold time; verify exhaust scrubber function

8.4 Graphitization Failures

Symptom	Possible Cause	Solution
Black, not gray (poor graphitization)	Temperature too low	Verify thermocouple; increase to 2,800°C minimum
Crucibles cracked	Cooling too fast	Reduce cooling rate to <10°C/min below 1,000°C
Carbon loss >10%	Oxygen contamination	Check argon purity; verify furnace seals
Sintered lump won't crush	Over-graphitization at too high temperature	Reduce hold temperature by 100°C; reduce hold time

8.5 When to Reject a Batch

- Carbon purity <99.0% after two acid leach cycles
- Heavy metals (Pb, Cd, Cr, As) >100 ppm
- Organic IR peaks persist after re-pyrolysis
- Visual inspection shows foreign material (plastic, metal, glass)
- Sample mass is <50% of stated submission (suspect tampering or loss)

Appendix A: Quick Reference Tables

A.1 Temperature Conversions

°C	°F	Application
105	221	Drying carbon after acid leach
200	392	Safe opening temperature after pyrolysis
400	752	NaOH fusion for silica removal
800	1,472	Minimum pyrolysis temperature
900	1,652	Standard pyrolysis hold temperature
1,000	1,832	Maximum pyrolysis temperature
2,600	4,712	Minimum graphitization temperature
3,000	5,432	Standard graphitization temperature

A.2 Acid Concentrations

Acid	Stock Concentration	1 M Working Solution
HCl	37% (12 M)	83 mL/L
HNO_3	65% (15.6 M)	64 mL/L
H_2SO_4	98% (18 M)	56 mL/L

A.3 Unit Conversions

From	To	Multiply By
Carat (ct)	Gram (g)	0.2
Gram (g)	Milligram (mg)	1,000
GPa	Atmospheres	~10,000
GPa	Bar	10,000

A.4 Carbon Content of Common Source Materials

Material	Carbon %	Notes
Human hair	30–40%	High sulfur from cysteine
Dog fur	30–38%	Guard hairs higher than undercoat
Cat fur	28–35%	Very fine; watch for static cling during handling
Horse hair	35–42%	Coarse; lower sulfur
Rabbit fur	25–32%	High ash; may need extra leaching
Feathers	25–35%	Low bulk density; pack carefully
Cotton fiber	40–45%	Pure cellulose; no sulfur
Wood (hardwood)	45–50%	Lignin + cellulose; high carbon
Nails	35–45%	Dense keratin; slow decomposition

Appendix B: Glossary

Term	Definition
Amorphous carbon	Carbon with no long-range crystalline order. Produced by pyrolysis of organic material. Black, powdery, non-conductive.
Char	The solid carbon-rich residue remaining after pyrolysis. Contains amorphous carbon plus trapped mineral salts.
Crystallite size (La)	The average diameter of graphitic crystalline domains, measured by X-ray diffraction. Larger La indicates better graphitization.
Degree of graphitization (g)	A measure of how closely a carbon material approaches ideal graphite structure. Ranges from 0 (completely amorphous) to 1 (perfect graphite).
Graphite	The thermodynamically stable form of carbon at ambient conditions. Layered hexagonal crystal structure. Gray, electrically conductive along basal planes.
Graphitization	The structural transformation of carbon from amorphous to crystalline graphite, achieved by heating to >2,600°C in an inert atmosphere.
HPHT	High-Pressure High-Temperature. The industrial process for diamond synthesis that replicates mantle conditions (~5 GPa, 1,300–1,600°C).
Keratin	A fibrous structural protein found in hair, fur, feathers, and nails. Rich in cysteine, which provides disulfide cross-links.
Pyrolysis	Thermal decomposition of organic material in the absence of oxygen. Produces char, volatiles, and gases.
TGA	Thermogravimetric Analysis. A technique that measures mass change as a function of temperature. Used to determine carbon purity by combusting carbon and weighing the residual ash.
Turbostratic carbon	An intermediate form between amorphous carbon and graphite. Layers are parallel but randomly rotated relative to each other.

References & Data Sources

1. CNIPA Patent ZL 201010565778.9 — “A Method for Extracting Carbon from Biological Raw Materials for Diamond Production.” Inventors: Li Lihua (□□□), Wang Hongtao (□□□). Filed November 30, 2010. Granted October 10, 2012. Certificate No. 1058820. Assignee: Luoyang BioGem Technology Co., Ltd.
2. BioGem Lab internal process data (2021–2025): carbon char yield from dry hair = 100–150 mg per gram of starting material (pyrolysis stage); overall hair → graphite yield 35–45% of original carbon content; char yield 10–15% of starting dry mass for hair/fur; BioGem Lab target carbon purity ≥99.95% prior to graphitization.
3. Internal quality data: TGA grade thresholds (Grade A ≥99.95%, B 99.5–99.94%, C 99.0–99.49%, Reject <99.0%); nitrogen dopant thresholds for color (E–F <100 ppm, G–H 100–300 ppm, I–J 300–500 ppm, K+ >500 ppm); graphitization quality targets g >0.85 and La >100 nm.
4. ASTM E1131 — Standard Test Method for Compositional Analysis by Thermogravimetry (TGA purity / ash determination).
5. ASTM E2550 — Standard Test Method for Thermal Stability by Thermogravimetry (decomposition behavior).
6. ASTM D5291 — Standard Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Petroleum Products (CHNS/O elemental analysis for carbon and nitrogen content).
7. ASTM E168 — Standard Practices for General Techniques of Infrared Quantitative Analysis (IR spectroscopy verification).
8. ASTM D3172 — Standard Practice for Proximate Analysis of Coal (analogous carbon-content determination for carbonaceous feedstocks).
9. ISO 11358 — Plastics — Thermogravimetry (TGA) of polymers (method applicable to carbon char thermal analysis).
10. ISO 9288 — Thermal insulation — Determination of steady-state thermal transmission properties (relevant to furnace/insulation design).
11. CCIC National Traceability Certificate — China Certification & Inspection Group, used for chain-of-custody documentation.

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