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Scriptwriter Name: Pallavi Sharma

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Title: Preparation of Carbon Fiber and Bamboo Fiber Reinforced Poly (Butylene Adipate-Co-Terephthalate) Foams by Supercritical Carbon Dioxide Foaming

Authors and Affiliations:

Guanxian Qiu^{1,2}, Ce Sun^{1,3,4}, Haoran Yang¹, Xiaojian Zhou², Haiyan Tan¹, Guoming Xu⁴, Yanhua Zhang¹

¹Northeast Forestry University Engineering Consulting and Design Research Institute Co., Ltd

²Guangxi Eco-engineering Vocational and Technical College, Liuzhou, China

³Key Laboratory of National Forestry and Grassland Administration on Highly-Efficient Utilization of Forestry Biomass Resources in Southwest China, Southwest Forestry University

⁴Hangzhou Longju Synthetic Material Co., Ltd

Corresponding Authors:

Ce Sun	(sunce@nefu.edu.cn)
Guoming Xu	(nihaoa147852@126.com)
Yanhua Zhang	(zhangyanhua@nefu.edu.cn)

Email Addresses for All Authors:

Guanxian Qiu	(2022011226@nefu.edu.cn)
Haoran Yang	(WHITEPOPLARDZCL@nefu.edu.cn)
Xiaojian Zhou	(xiaojianzhou@swfu.edu.cn)
Haiyan Tan	(tanhaiyan@nefu.edu.cn)
Ce Sun	(sunce@nefu.edu.cn)
Guoming Xu	(nihaoa147852@126.com)

Yanhua Zhang

[\(zhangyanhua@nefu.edu.cn\)](mailto:zhangyanhua@nefu.edu.cn)

Author Questionnaire

1. We have marked your project as author-provided footage, meaning you film the video yourself and provide JoVE with the footage to edit. JoVE will not send the videographer. Please confirm that this is correct.

✓ Correct

2. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

3. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **No**

4. Proposed filming date: To help JoVE process and publish your video in a timely manner, please indicate the proposed date that your group will film here: 28/09/2025

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Current Protocol Length

Number of Steps: 24

Number of Shots: 45

Introduction

- 1.1. **Yanhua Zhang:** This research focuses on developing PBAT/CF/BF composite foams using scCO₂ foaming technology to elucidate how fiber synergy enhances anti-shrinkage properties, reduces density, and improves compression resilience of the foams.
- 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

What significant findings have you established in your field?

- 1.2. **Guanxian Qiu:** The PBAT/CF/BF composite foam studied provides an effective solution for the manufacture of degradable, shrink-resistant, lightweight and high-strength polyester foam, which has application prospects in packaging, thermal insulation, and other fields.
- 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

NOTE: Due to quality issues, omit 1.3 and 1.4

~~What advantage does your protocol offer compared to other techniques?~~

- ~~1.3. **Ce Sun:** Our protocol uses a synergistic fiber blend (CF/BF) with scCO₂ foaming. This combination significantly reduces foam shrinkage while enhancing strength. It provides a green, efficient manufacturing solution for high-performance biodegradable foams.~~
- ~~1.3.1. INTERVIEW: Named talent says the statement above in an interview style shot, looking slightly off-camera. *Suggested B-roll: 4.2*~~

~~How will your findings advance research in your field?~~

- ~~1.4. **Ce Sun:** Our findings offer a novel fiber synergy strategy to suppress foam shrinkage. This enables high expansion biodegradable foams for sustainable applications.~~
- ~~1.4.1. INTERVIEW: Named talent says the statement above in an interview style shot, looking slightly off-camera.~~

What questions will future research focus on?

- 1.5. **Guanxian Qiu:** Future research may focus on exploring the long-term degradation behavior of composite foam in different environments and assessing the economic feasibility and environmental impact of composite foam production.
 - 1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera.

Protocol

2. Weighing, Pre-Mixing, and Melt-Extrusion of PBAT/CF

Demonstrator: Guanxian Qiu

2.1. To begin, place the PBAT (*P-Bat*), CF (*C-F*), and BF (*B-F*) in an oven set at 80 degrees Celsius and incubate for 8 hours [1]. Using an electronic balance, weigh PBAT and CF proportionally to make a total of 200 grams [2].

2.1.1. Talent placing PBAT, CF, and BF samples loaded in a tray into the oven.

2.1.2. Talent weighing PBAT and carbon fiber.

2.2. Pour the weighed PBAT and carbon fiber into a polyethylene bag [1]. Mix the contents thoroughly by shaking and kneading the bag for 5 minutes to achieve a uniform preliminary dispersion [2].

2.2.1. Talent pouring the weighed PBAT and carbon fiber into a polyethylene bag.

2.2.2. Talent kneading and shaking the bag continuously on the bench for 5 minutes.

2.3. Then, turn on the power switch of the twin-screw extruder [1]. Set the temperature of each heating zone on the extruder to 135, 145, 155, 165, and 160 degrees Celsius, respectively [2].

2.3.1. Talent flipping the main power switch on the twin-screw extruder machine.

2.3.2. Show the extruder control panel as the operator adjusts zone temperatures.

2.4. Set the host screw rotation speed to 5 revolutions per minute and the feeder rotation speed to 3 revolutions per minute [1].

2.4.1. Show the host speed setting being adjusted to 5 revolutions per minute on the control panel.

2.5. Next, add pure PBAT pellets into the feed hopper of the extruder and operate the machine for 10 minutes to clean the screw [1]. Switch the feedstock to the PBAT and 20CF premixed material and extrude continuously [2].

2.5.1. Talent pouring pure PBAT pellets into the extruder feed hopper and starting the machine.

2.5.2. Talent pouring the PBAT and carbon fiber premix into the extruder hopper.

2.6. Then, collect the extruded material from the outlet [1] and crush it into granules using a powder granulator [2].

2.6.1. Talent collecting the extruded strand.

2.6.2. Talent feeding the extrudate into the powder granulator and operating the machine to produce granules.

3. Compression Molding of Crushed PBAT/CF Premix

Demonstrator: Ce Sun

3.1. Turn on the power switch of the flat vulcanizing machine [1]. Then, set the temperature of both the upper and lower plates to 165 degrees Celsius [2].

3.1.1. Talent switching on the flat vulcanizing machine at the control panel.

3.1.2. Display the temperature control screen while setting the upper and lower plates to 165 degrees Celsius.

3.2. Measure 60 grams of the prepared granules according to the mold dimensions [1-TXT]. Lay a polytetrafluoroethylene film over a flat gasket [2] and immediately position the mold on top [3].

3.2.1. Talent weighing out exactly 60 grams of crushed granules on an electronic balance. **TXT: Dimensions: 100 mm × 100 mm × 4 mm**

3.2.2. Talent laying a polytetrafluoroethylene film neatly over the surface of the flat gasket.

3.2.3. Talent placing the mold directly on top of the film-covered gasket.

3.3. Evenly distribute the weighed granules into the mold cavity [1]. Cover the mold with another polytetrafluoroethylene film [2] and place a second flat gasket on top [3].

3.3.1. Talent spreading the 60 grams of material evenly within the mold using a spatula or gloved hands.

3.3.2. Talent placing a second polytetrafluoroethylene film over the filled mold.

3.3.3. Talent placing a flat gasket carefully over the film-covered mold.

3.4. Then, place the assembled mold setup at the center of the heating plate of the flat vulcanizing machine [1].

3.4.1. Talent positioning the mold assembly at the center of the heated plate.

- 3.5. Initiate the mold closing process on the flat vulcanizing machine, apply a pressure of 1 megapascal [1], and maintain the pressure for 3 minutes to expel trapped air and prevent bubble formation [2].
 - 3.5.1. Display the pressure setting being adjusted to 1 megapascal.
 - 3.5.2. Shot of the machine while the mold closing process is running.

- 3.6. Continue the mold closing operation, increase the pressure to 10 megapascals [1], and maintain this pressure for 10 minutes to ensure the material melts and fills the mold uniformly [2].
 - 3.6.1. Display the pressure adjustment to 10 megapascals.
 - 3.6.2. Talent monitoring the system.

- 3.7. Then, turn off the heating system [1], activate the cooling mechanism on the vulcanizing machine [2], and wait until the temperature drops below 40 degrees Celsius before depressurizing and removing the mold [3].
 - 3.7.1. Talent turning off the heating controls on the machine.
 - 3.7.2. Show the cooling system being activated on the control interface.
 - 3.7.3. Talent checking the temperature display, then carefully opening the mold and removing it.

4. ScCO₂ Foaming Process

Demonstrator: Guanxian Qiu

- 4.1. Using a blade, cut the molded sheet into pieces [1-TXT].
 - 4.1.1. Talent cut the flat molded sheet into pieces. **TXT: Dimensions: 10 mm × 10 mm × 4 mm**

- 4.2. Place the cut sample panels into the reaction vessel [1]. Using a wrench, tighten the bolts of the reactor lid and close the reactor securely [2]. Then, close the exhaust valve of the reaction kettle to seal the system [3].
 - 4.2.1. Talent gently places multiple cut panels into the open chamber of the reactor.
 - 4.2.2. Talent uses a wrench tool to fasten each bolt around the reactor lid and seal the chamber completely.

- 4.2.3. Talent turns the exhaust valve knob on the reaction kettle to the closed position.
- 4.3. Now, open the valve of the carbon dioxide cylinder [1]. After that, open the intake valve of the booster pump [2].
 - 4.3.1. Talent rotating the main valve on the carbon dioxide cylinder.
 - 4.3.2. Talent adjusting the intake valve on the booster pump.
- 4.4. Then, open the inlet valve of the reactor to inject carbon dioxide gas into the chamber [1]. After that, close the inlet valve of the reactor and allow the chamber to stabilize for 3 minutes [2].
 - 4.4.1. Talent opens the reactor's inlet valve.
 - 4.4.2. Talent closing the reactor inlet valve and monitoring the pressure gauge.
- 4.5. To discharge air from inside the chamber open the exhaust valve of the reactor [1].
 - 4.5.1. Talent opening the reactor exhaust valve.
- 4.6. Then, turn on the power switches of both oil baths [1] and set their temperatures to 165 degrees Celsius and 100 degrees Celsius, respectively [2].
 - 4.6.1. Talent switching on the two oil baths at their respective control panels.
 - 4.6.2. Show the temperature settings being adjusted to 165 degrees Celsius on one oil bath and 100 degrees Celsius on the other.
- 4.7. Place the reaction vessel containing the sample into the oil bath set at 165 degrees Celsius and incubate for 10 minutes [1].
 - 4.7.1. Talent lowering the sealed reaction vessel into the 165 degrees Celsius oil bath.
- 4.8. Open the inlet valve of the reactor to pressurize it with carbon dioxide, set the pressure to 10 megapascals, and maintain the temperature for 10 minutes [1].
 - 4.8.1. Talent opening the inlet valve and adjusting the pressure regulator to 10 megapascals.
- 4.9. Close the ventilation valve of the carbon dioxide cylinder [1], the intake valve of the booster pump [2], and the inlet valve of the reaction kettle [3].
 - 4.9.1. Talent rotating the ventilation valve on the carbon dioxide cylinder to the closed

position.

4.9.2. Talent turning the intake valve on the booster pump to the off position.

4.9.3. Talent securing the inlet valve on the reaction kettle to the closed position.

4.10. Then, transfer the reaction vessel to the second oil bath set at 100 degrees Celsius and maintain both temperature and pressure for 60 minutes [1].

4.10.1. Talent carefully lifting the reaction vessel from the 165 degrees Celsius bath and placing it into the 100 degrees Celsius oil bath.

4.11. Open the exhaust valve of the reactor and rapidly release the internal pressure within 3 seconds to obtain the foamed material [1].

4.11.1. Talent opens the exhaust valve of the reactor and releases the internal pressure.

Results

5. Results

5.1. Visual inspection confirmed clear differences in foam appearance and expansion with varying fiber content [1].

5.1.1. LAB MEDIA: Figure 2A. *Video editor: Slowly pan across the labeled foam samples from left to right to show the color and thickness changes.*

5.2. The density of pure PBAT foam was found to be 0.19 grams per cubic centimeter [1], with a foaming ratio of 6.23 [2] and a stabilized shrinkage rate of 55.63% [3].

5.2.1. LAB MEDIA: Figure 2B. *Video editor: Highlight the orange bar labeled "PBAT/10CF/10BF"*

5.2.2. LAB MEDIA: Figure 2C. *Video editor: Highlight the orange bar labeled "PBAT/10CF/10BF"*

5.3. Scanning electron microscopy revealed that the PBAT and 20CF foam had the largest cell size [1], followed by PBAT and 20BF [2], while foams with combined CF and BF showed intermediate sizes [3].

5.3.1. LAB MEDIA: Figure 3B. *Video editor: Zoom in on the large circular cell structures labeled "CF nucleation sites."*

5.3.2. LAB MEDIA: Figure 3F. *Video editor: Highlight the visibly large pores surrounded by "BF nucleation sites."*

5.3.3. LAB MEDIA: Figure 3C–E *Video editor: Cycle through these three panels, briefly highlighting the moderate-sized cells in each.*

5.4. The PBAT, CF, and BF foams exhibited the most uniform cell size distribution compared to CF-only or BF-only formulations [1].

5.4.1. LAB MEDIA: Figure 4. *Video editor: Show the bell-shaped red curve in 4C, E and F*

5.5. The PBAT, 5CF, and 15BF foam achieved the highest cell density at 3.63 million cells per cubic centimeter [1].

5.5.1. LAB MEDIA: Figure 5. *Video editor: Highlight the tall cyan-colored bar labeled*

"PBAT/5CF/15BF", which reaches the highest point on the y-axis.

5.6. The compressive strength was highest in PBAT,15CF, and 5BF foam, reaching 0.26 megapascals [1]. All composite foam samples exhibited consistent compressive resilience across the 0-50% strain range [2].

5.6.1. LAB MEDIA: Figure 6A. *Video editor: Highlight the tall blue bar labeled "PBAT/15CF/5BF"*

5.6.2. LAB MEDIA: Figure 6B–F. *Video editor: Sequentially show each of the line graphs, emphasizing the upward curves extending to 50 percent strain.*

1. Polyethylene
Pronunciation link: <https://www.merriam-webster.com/dictionary/polyethylene>
IPA: /ˌpɑːliˈɛθəˌliːn/
Phonetic Spelling: paa·lee·eth·uh·leen
2. Carbon fiber
Pronunciation link: <https://www.merriam-webster.com/dictionary/carbon%20fiber>
IPA: /ˈkɑːrbən ˌfaɪbər/
Phonetic Spelling: kar·buhn fy·ber
3. Polytetrafluoroethylene
Pronunciation link: <https://www.merriam-webster.com/dictionary/polytetrafluoroethylene>
IPA: /ˌpɑːliˈtɛtrəˌfluɔroʊˈɛθəˌliːn/
Phonetic Spelling: paa·lee·teh·truh·floor·oh·eth·uh·leen
4. Extruder
Pronunciation link: <https://www.merriam-webster.com/dictionary/extruder>
IPA: /ɪkˈstruːdər/
Phonetic Spelling: ik·stroo·der
5. Vulcanizing
Pronunciation link: <https://www.merriam-webster.com/dictionary/vulcanizing>
IPA: /ˈvʌlkəˌnaɪzɪŋ/
Phonetic Spelling: vul·kuh·nyz·ing
6. Megapascal
Pronunciation link: <https://www.merriam-webster.com/dictionary/megapascal>
IPA: /ˌmegəˈpæskəl/
Phonetic Spelling: meg·uh·pas·kuhl
7. Granulator
Pronunciation link: <https://www.merriam-webster.com/dictionary/granulator>

IPA: /'græn.jə.leɪ.tər/

Phonetic Spelling: gran·yuh·lay·ter

8. Compression molding

Pronunciation link: <https://www.merriam-webster.com/dictionary/compression%20molding>

IPA: /kəm'preʃən 'moʊldɪŋ/

Phonetic Spelling: kuhm·presh·uhn mohld·ing

9. Carbon dioxide

Pronunciation link: <https://www.merriam-webster.com/dictionary/carbon%20dioxide>

IPA: /'kɑːrbən daɪ'ɑːksaɪd/

Phonetic Spelling: kar·buhn dy·ok·syd

10. Scanning electron microscopy

Pronunciation link: <https://www.merriam-webster.com/dictionary/scanning%20electron%20microscopy>

IPA: /'skæniŋ ɪ'lektrən mə'kraskəpi/

Phonetic Spelling: skan·ing ih·lek·tron my·krah·skuh·pee

11. Incubate

Pronunciation link: <https://www.merriam-webster.com/dictionary/incubate>

IPA: /'ɪŋkjəˌbeɪt/

Phonetic Spelling: ing·kyuh·bayt

12. Reaction vessel

Pronunciation link: <https://www.merriam-webster.com/dictionary/reaction%20vessel>

IPA: /ri'ækʃən 'vesəl/

Phonetic Spelling: ree·ak·shuhn ves·uhl