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From Principles to Practice: Teaching Polymer Science with Eucommia Ulmoides Gum Case Studies to Foster Innovative Thinking

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Abstract: *This teaching case study employs Eucommia Ulmoides Gum (EUG), a unique bio-based polymer, as a core model to bridge theoretical principles in polymer chemistry and physics with practical material innovation. It systematically explores the molecular mechanisms behind the "isomerism yet divergent properties" of EUG and natural rubber, with a focused explanation of EUG's distinctive "rubber-plastic duality" and its innovative applications in cutting-edge fields such as shape-memory materials, self-healing systems, and green tires. Structured around a progressive instructional framework-"Fundamental Theory - Applied Innovation -Industrial Practice"—the case library is designed to help students comprehend material properties from the perspective of molecular structure and foster innovation through multi-scale design. This resource aims to enhance students' core scientific literacy and serve as exemplary teaching material for cultivating talent in the field of bio-based polymer materials.*

Keywords: *Eucommia ulmoides Gum; Teaching Case Study; Rubber-Plastic Duality; Structure-Property Relationship; Functional Materials; Industry-Academia-Research Integration*

1. Introduction

Why choose Eucommia ulmoides gum as a teaching case? In polymer science education, a significant challenge is helping students deeply understand the fundamental principle that molecular structure determines material properties, as well as developing their preliminary material design skills. Eucommia ulmoides gum, a biobased polymer unique to China and of strategic value, serves as an ideal teaching model to illustrate the core polymer science principle that “structure determines performance”.

Its unique characteristic of being isomeric yet exhibiting vastly different properties compared to natural rubber can significantly stimulate students' interest and curiosity. This case study aims not only to help students master specific knowledge about Eucommia ulmoides gum but also to cultivate their ability to apply this knowledge in materials design and analysis. Students will learn to understand the complete process, from laboratory research to industrial application.

1) Cognitive Conflict to Stimulate Interest

Eucommia ulmoides gum and natural rubber have the same chemical composition ($(C_5H_8)_n$). However, due to slight differences in their cis/trans configurations, they display significantly different behaviors at room temperature, ranging from plastic to rubber.[1] This notable cognitive conflict serves as an excellent starting point to ignite students' curiosity. By confronting this apparent contradiction, students are prompted to question and explore the underlying structural causes, thereby transforming abstract chemical concepts into tangible, observable phenomena. This approach aligns with constructivist learning theories, where cognitive dissonance drives knowledge integration and conceptual change.

2) Theoretical Understanding Throughout

The unique “dual nature of elastomer and plastic” along with Professor Yan Ruifang's “three-stage vulcanization” theory offer concrete and vivid theoretical frameworks for grasping abstract concepts, such as polymer chain motion, crystallization, and crosslinking. These frameworks provide students with mental models that simplify complex polymer behaviors, enabling them to predict material performance based on structural parameters. The three-stage vulcanization process, in particular, serves as a powerful

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illustration of how controlled chemical modification can progressively alter material properties, offering a practical demonstration of the structure-property relationship central to materials science.

3) Cutting-Edge and Industrial Relevance

The applications of Eucommia ulmoides gum, which range from shape-memory and self-healing materials to eco-friendly tires, address both advanced material needs and national strategic priorities. This makes it an ideal topic for integrating curriculum ideologies with modern engineering education. As a result, this case library aims to equip students with scientific methodologies and encourage innovative thinking through the exploration of this particular material. By connecting fundamental science with real-world applications, students develop an appreciation for the translational nature of materials research and its impact on sustainable development and technological advancement.

2. Design of Case Library Content and Teaching Implementation Path

2.1. Basic Theory Level: Tracing the Molecular Origins of Performance Differences

1) Core Knowledge Points

This section covers the configurational differences between cis and trans-1,4-polyisoprene, its crystallization behavior, the dual nature of rubber and plastic, and the three-stage vulcanization theory.

2) Teaching Implementation

To engage students, we present real samples or videos of Eucommia ulmoides gum (which is hard and tough) and natural rubber (which is soft and elastic). This activity encourages students to infer the molecular chain configurations and packing arrangements based on their observatiof appearance and texture, introducing the theme that "structure determines property. This hands-on, inquiry-based approach fosters observational skills and hypothesis generation, fundamental to scientific thinking.

Guide students to compare the molecular structure models of Eucommia ulmoides gum and natural rubber by utilizing 3D molecular animations. These animations will vividly demonstrate how the trans configuration aligns neatly, resembling a "ruler," forming crystalline regions (exhibiting plasticity). In contrast, illustrate how the cis configuration coils up like a "spring," maintaining an amorphous state (showing high elasticity). This visual representation helps bridge the macroscopic a we can illustrate how the cis configuration coils up like a "spring," maintaining an amorphous state (showing high elasticity). This visual representation helps bridge the macroscopic and nanoscopic worlds, making abstract concepts more accessible.

Organize discussions centering around Professor Yan Ruifang's "three-stage vulcanization theory." The first step was to pose the question: How did the degree of cross-linking act as a magical key, gradually transforming Eucommia gum from a thermoplastic material into a thermoplastic elastomer, and ultimately into a rubber elastomer? Next, the students were encouraged to draw diagrams and construct a correlation map linking "cross-linking density, microstructure, macroscopic properties, and application fields." This exercise trains students in systems thinking and helps them recognize the interconnectedness of chemical structure, processing parameters, and final material performance.

Lastly, stimulate students' thinking about how the "degree of crosslinking" acts as a key to unlock various applications of Eucommia ulmoides gum, allowing transitions from plastic to rubber. We need to encourage students to propose novel application solutions based on controllable cross-linking technology, thereby cultivating their innovative thinking and the ability to apply theoretical knowledge. To further deepen understanding, instructors can introduce computational modeling exercises where students use molecular simulation software to visualize how trans-polyisoprene chains pack more efficiently than cis-chains, leading to higher crystallinity and thus different mechanical behaviors. This hands-on computational approach bridges the gap between theoretical concepts and tangible molecular interactions, reinforcing the structure-property relationship in a dynamic and interactive manner.

2.2. Application Innovation Layer: Function Realization Based on Molecular Design

1) Core Knowledge Points

This section covers extraction techniques,[2-4] various chemical and physical modification strategies,[5-7] and functional applications such as shape memory, self-healing, high damping, and electromagnetic shielding composites. [8-13]

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2) Teaching Implementation

• Problem-Oriented Learning

For example, pose the question, “How can Eucommia gum remember its shape?” to direct students toward understanding its function as a thermally-induced shape memory material.[14-17] Similarly, one student can ask, “How does Eucommia gum self-repair after damage?” This can guide students to explore reversible chemical reactions, including Diels-Alder reactions and disulfide bonds. This discussion can introduce the concept of dynamic bond chemistry in self-healing materials, [18-21] demonstrating how innovative molecular design can give materials the ability to “self-repair” like living organisms. These problem-based scenarios not only teach specific chemical concepts but also illustrate the biomimetic approach to materials design, where biological principles inspire technological innovation.

• In-Depth Case Analysis

Using Linglong Tire's friction nanogenerator integrated into green intelligent tires as a case study,[22] not only explain how EUG reduces rolling resistance and wear but also prompt students to consider the interdisciplinary integration of materials, energy, and information. Students can engage in discussions about the future of “smart material systems”. For this activity, they can form groups to research and present the latest advancements in a specific application. This collaborative, project-based approach mirrors real-world research and development processes, preparing students for interdisciplinary teamwork in their future careers.

• Experimental Design Challenge

To further enhance the application innovation layer, an experimental design challenge can be incorporated, requiring students to propose modification methods for EUG tailored to specific functional applications. For instance, students might be tasked with designing an EUG-based composite with enhanced electromagnetic interference shielding performance—a project that necessitates the selection of appropriate fillers, prediction of interfacial behavior, and design of processing routes. Alternatively, a broader project-based module could be introduced, challenging students to develop novel EUG materials addressing real-world issues—such as shape-memory sustainable packaging for simplified recycling or self-healing coatings for automotive applications. Through these tasks, students learn to integrate knowledge of molecular design, modification strategies, and processing parameters, thereby bridging the gap between theoretical instruction and research practice.

Additionally, a comparative analysis activity can be implemented, in which students evaluate EUG against other bio-based polymers—such as polylactic acid (PLA) or polyhydroxyalkanoates (PHA)—to contextualize its unique advantages and limitations within the broader landscape of sustainable polymers. This exercise fosters critical thinking regarding material selection, life cycle assessment, and the trade-offs among performance, processability, and environmental impact, thereby strengthening students’ systematic thinking and capacity for sustainable material design.

2.3. Industrial Practice Level: Bridging Laboratory Research to Market Applications

1) Core Cases

• Sailun Group’s High-Speed Aviation Tires

Emphasize the analysis of how collaboration among industry, universities, and research institutions addresses engineering challenges. Precise control of the vulcanization system and mixing processes is discussed as a means to balance the dynamic fatigue performance and heat build-up of Eucommia rubber/natural rubber blends, fulfilling the demanding requirements of aviation tires and enabling the practical realization of Eucommia rubber’s high-performance advantages. This case illustrates the critical role of process optimization in scaling up laboratory discoveries to industrial production, highlighting the importance of reproducibility, quality control, and performance consistency.

• Jishou University’s “Four-in-One” Comprehensive Utilization Model

Use this example to guide students in performing a SWOT analysis, focusing on how bio-based material development enterprises can create synergy and confront challenges related to economic benefits, social value, and ecological efficiency under the “dual carbon” strategy. This exercise introduces business and sustainability perspectives to materials education, encouraging students to consider the broader implications of technological development.

• Guizhou University’s Bio-Enzymatic Extraction Technology

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As a model for "green chemistry" education, instruct students to compare conventional solvent extraction methods with bio-enzymatic techniques in terms of process efficiency and environmental impact. They are required to prepare a concise technical assessment report that analyzes how these sustainable and efficient extraction technologies can establish a solid raw material foundation for the industrial production of Eucommia rubber. This exercise introduces business and sustainability perspectives to materials education, encouraging students to consider the broader implications of technological development.

2) Teaching Implementation

- **Organize seminars for case study discussions**

Students will form teams to assume different roles (e.g., R&D personnel, business managers, investors) and engage in thorough discussions about the key aspects of technological breakthroughs, models of industry-university-research collaboration, and the prospects and challenges of commercialization. This role-playing approach helps students understand diverse perspectives in technology development and commercialization, preparing them for various career paths in the materials industry.

- **Industry Expert Invited Lectures**

To complement classroom activities, invite industry professionals to share their experiences with EUG development and commercialization. These firsthand accounts provide valuable insights into real-world challenges and opportunities, making the learning experience more authentic and career-relevant. Following these lectures, students can submit reflection papers connecting the expert's insights with course concepts, further reinforcing their learning.

3. Teaching Value and Effectiveness of the Case Library

The teaching value of this case library is reflected in three aspects:

1) Deepening Theoretical Understanding

By internalizing the abstract "structure-performance" relationship through the specific model of Eucommia gum, students develop a solid cognitive framework that helps them establish a robust theoretical knowledge system. The concrete example of EUG makes abstract polymer concepts more tangible and memorable, enhancing long-term knowledge retention.

2) Training Systematic Thinking

Through comprehensive case studies that cover the full chain from "molecular design" to "modification" and "application", students cultivate multi-scale, systematic skills in materials design and engineering practice. This holistic approach helps students understand that material development requires consideration of multiple factors across different scales, from molecular architecture to industrial processing.

3) Shaping Innovation and Industrial Perspective

By incorporating cutting-edge research developments and real industrial practices into the classroom, students' enthusiasm for innovation is stimulated, allowing them to gain early insights into industry demands and development trends. This industry-academia integration prepares students for smooth transitions from academic settings to professional environments.

Finally, to effectively evaluate learning outcomes under this case-based model, a multifaceted assessment framework can be implemented. This includes traditional examinations to assess theoretical understanding, project reports to evaluate applied skills, presentation assessments to measure communicative competence, and reflective essays to capture metacognitive growth. In addition, pre- and post-course surveys may be administered to monitor shifts in students' interest in polymer science and their confidence in addressing real-world materials design challenges. Together, these diversified tools offer a holistic picture of student progress and the educational impact of the case library approach.

4. Conclusion

The Eucommia Case Library is a dynamically evolving and vibrant teaching resource. It transcends

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the mere transmission of singular knowledge points and achieves an organic integration of knowledge, skills, and literacy through an integrated teaching design that includes “theoretical exploration, innovative design, and industrial insight”. This case-based teaching model, grounded in real-world problems, imparts not only knowledge but, more importantly, cultivates students' scientific thinking, innovative awareness, and comprehensive abilities to solve complex engineering challenges. It serves as a reference paradigm for nurturing top-notch innovative talent in the field of new materials in China, particularly within the context of emerging engineering education. By demonstrating how a specific bio-based material can serve as a rich educational resource, this work contributes to the broader goal of sustainable materials education and development.

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References

[1] Yang, B.; Zhao, H.; Zhang, C.; Zhang, X.; Dong, X.; Liu, G.; Wang, D., The role of crystallization and crosslinking in the hysteresis loss of vulcanized Eucommia ulmoides gum. Crystengcomm 2023, 25 (4), 567-578.

[2] Liu, X.; Wang, X.; Kang, K.; Sun, G.; Zhu, M., Review on extraction, characteristic, and engineering of the Eucommia ulmodies rubber for industrial application. Ind. Crop. Prod. 2022, 180, 114733.

[3] Zhang, C. H.; Qin, L. J., Extraction and characterization of Eucommia ulmoides gum from Eucommia leaves by fermentation with Coprinellus disseminatus. J. Appl. Microbiol. 2025, 136 (6).

[4] Qin, L.; Wang. J., Zhang, Y., Zhang, J., Fan, Y., Technical progress in extraction of natural polymer Eucommia ulmoides gum. Mod. Chem. Ind. 2021, 12 (41), 53-58.

[5] Xie, L.; Zhang, Z., Ji, C.; He, Y.; Tao, H., Current Situation in Extraction and Large-scale Production of Eucommia ulmoides Gum and Its Development Issues. Biomass. Chemi. Engin. 2021, 4 (55), 34-42.

[6] Han, Z; Wang, Q.; Li, Y.; Liao, X.; Sun, R.; Xie, M., Enhancing mechanical, self-healing and damping properties of dual-modified Eucommia ulmoides gum by introducing epoxy and perfluoroalkyl groups. Polymer. 2024, 290, 126525.

[7] Wu, Y.; Wei, J.; Huang, H.; Cui, M., Hot melt processing strategy to modify eucommia ulmoides gum by click reaction. J. Appl. Polym. Sci. 2023, 140 (28), 54034.

[8] Ni, Q.; Wu, J.; Kong, P.; Wang, Y.; Li, Y.; Li, Y.; Peng, X., Inverse Vulcanization Polymer-Modified Eucommia ulmoides Gum with Enhanced Shape Memory Capability and Sound Absorption Property. Acs Appl. Polym. Mater. 2022, 4 (7), 4689-4698.

[9] Han, Z.; Zhang, H.; Li, Y.; Quan, Y.; Xie, M., Unique Damping Properties of Modified Eucommia Ulmoides Gum Bearing Polar and Branched Pendants. Chinese. J. Polym. Sci. 2023, 41 (6), 915-925.

[10] Liu, H.; Chen, W.; Yan, Q.; Chen, Q.; Hong, M.; Zhou, Z.; Fu, H., Modified Natural Eucommia Ulmoides Gum Effectively Improves the Toughness and Strength of Epoxy Resins. Acs Appl. Polym. Mater. 2024, 6 (5), 2567-2575.

[11] Yue, P.; Leng, Z.; Rao, J.; Chen, G.; Hao, X.; Bian, J.; Zhu, M.; Peng, F., Flexible conductive gasket based on Eucommia ulmoides gum and carbon fillers. Ind. Crop. Prod. 2022, 176, 114347.

[12] Han, L.; Kang, H.; Luo, T.; Hu, J.; Cui, Y.; Li, D.; Li, L.; Zhang, J.; Fang, Q., Enhanced EMI shielding effectiveness of green Eucommia ulmoides gum composites through heterogeneous and crystalline structures. Ind. Crop. Prod. 2024, 219, 119033.

[13] Kang, H.; Luo, S.; Du, H.; Han, L.; Li, D.; Li, L.; Fang, Q., Bio-Based Eucommia ulmoides Gum Composites with High Electromagnetic Interference Shielding Performance. Polymers-Basel. 2022, 14 (5), 970.

[14] Wang, Y.; Xia, L.; Xin, Z., Triple shape memory effect of foamed natural Eucommia ulmoides gum/high-density polyethylene composites. Polym. Advan. Technol. 2017, 29 (1), 190-197.

[15] Wang, Y.; Pei, X.; Xia, L.; Zhang, Z.; Wang, Q.; Wang, T., Bio-based Eucommia ulmoides gum/low density polyethylene shape memory composites reinforced by zinc methacrylate. Polym. Int. 2021, 70 (12), 1659-1667.

[16] Kang, H.; Xu, M.; Wang, H.; Li, L.; Li, J.; Fang, Q.; Zhang, J., Heat-responsive shape memory Eucommia ulmoides gum composites reinforced by zinc dimethacrylate. J. Appl. Polym. Sci. 2024, 141 (31), 49133.

[17] Shao, J. M.; Qiu, C.; Dong, X.; Wang, D. J., Progress in Modification Methods and Shape Memory

ISSN 2663-8169 Vol. 8, Issue 3: 33-38, DOI: 10.25236/IJNDE.2026.080305

Applications of trans-1,4-Polyisoprene (Eucommia ulmoides Gum). Acta. Polym. Sin. 2025, 56 (5), 734-753.
[18] Olejnik, O.; Masek, A., Recent progress in bio-based elastomers with intrinsic self-healing mechanisms - part I: Natural rubber modifications. J. Saudi. Chem. Soc. 2023, 27 (4), 101676.
[19] Chen, B.; Xiong, W.; Yu, X.; Xu, Z.; Liu, Y., Study on the preparation of hydroxylated Eucommia ulmoides gum and the modification of UV-curable polyurethane self-healing coating. Paint. Coatings. Ind. 2024, 54 (9), 30-37.
[20] Yue, P.; Zhang, M.; Zhao, T.; Liu, P.; Peng, F.; Yang, L., Eco-friendly epoxidized Eucommia ulmoides gum based composite coating with enhanced super-hydrophobicity and corrosion resistance properties. Ind. Crop. Prod. 2024, 214, 118523.
[21] Li, D.; Zhou, J.; Kang, H.; Li, L.; Han, W.; Fang, Q.; Wang, N.; Yang, F., Synthesis and properties of an efficient self-healing material based on Eucommia ulmoides gum. Ind. Crop. Prod. 2022, 187, 115385.
[22] Wu, W.; Cao, X.; Zou, J.; Ma, Y.; Wu, X.; Sun, C.; Li, M.; Wang, N.; Wang, Z.; Zhang, L., Triboelectric Nanogenerator Boosts Smart Green Tires. Adv. Funct. Mater. 2019, 29 (41), 1806331.