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Research on the Teaching Integration of the Structure-Property Relationship of Absorbing Materials in the Basic Course of Materials Science

Rui Guo[1,2,3]

[1]College of Materials Science and Engineering, Hebei University of Science and Technology, Shijiazhuang 050018, Hebei, China
[2]Hebei Key Laboratory of Flexible Functional Materials, School of Materials Science and Engineering, Hebei University of Science and Technology, Shijiazhuang 050000, Hebei, China
[3]Hebei Short Process Steelmaking Technology Innovation Center, Hebei University of Science and Technology, Shijiazhuang 050000, Hebei, China

Abstract: To address the pedagogical challenges of theoretical abstraction and practical disconnection in fundamental materials science courses, and to align with the demand for applied talent cultivation in new engineering disciplines, this study explores an integrated teaching approach for investigating the structure-property relationships of microwave-absorbing materials. By establishing a three-dimensional "theory-practice-advancement" instructional framework, complemented by diversified teaching methodologies and scientific evaluation mechanisms, and leveraging modern simulation tools alongside collaborative teaching concepts, this model achieves deep integration between abstract theories and engineering practices. Teaching practice demonstrates that this approach effectively stimulates students' learning interest, enhances interdisciplinary application and innovation capabilities, and provides a feasible reference and practical paradigm for the reform of materials science courses.

Keywords: Microwave-absorbing materials; Structure-property relationship; Materials science; Course teaching

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1. Introduction

In the context of new engineering education, the cultivation of materials science and engineering professionals emphasizes comprehensive application and innovation capabilities. However, foundational materials science courses often fail to engage students due to abstract content and a disconnection between theory and practice. The structure-property relationship in microwave-absorbing materials, centered on the "structure-performance" correlation, encompasses fundamental theories like atomic structures and crystal defects, as well as applications for performance modulation. This relationship serves as a crucial bridge between basic sciences and engineering fields. By integrating multi-stakeholder collaborative teaching, research-driven pedagogy, and modern simulation technologies, this paper systematically explores teaching integration approaches from three dimensions: core values, content design, and implementation evaluation. The aim is to enrich instructional content, innovate teaching models, and enhance both course quality and talent development outcomes.

2. The core logic and teaching value of incorporating the structure-property relationship of absorbing materials into the basic course of materials science

The structure-property relationship of microwave-absorbing materials serves as a concrete example of the "structure-performance" correlation, making its integration into teaching highly valuable. Under the new engineering education framework, material science talent cultivation emphasizes comprehensive knowledge application and practical innovation [1]. The structure-property relationship of microwave-absorbing materials bridges fundamental theories (e.g., atomic structure, crystal defects) with practical performance optimization, effectively connecting theoretical knowledge with engineering applications and aligning with the goals of applied talent development. Given the abstract nature of basic materials science courses, students often struggle to establish connections between theory and performance. By using specific systems like metamaterials and composite materials, this relationship transforms abstract concepts (e.g., atomic arrangements, phase structures) into observable performance patterns, reducing learning difficulty, stimulating interest, and enhancing teaching effectiveness. As a cross-disciplinary field, integrating this relationship into teaching breaks down disciplinary barriers, fosters interdisciplinary thinking, and meets the requirements of collaborative teaching for comprehensive competency development. Tools like FDTD simulation software demonstrate how material structures influence microwave absorption performance, enriching teaching methods and cultivating students' digital application skills and scientific inquiry mindset. Moreover, as critical materials in defense and electronics, teaching this relationship helps students understand cutting-edge research and industry demands, strengthens professional identity, and delivers high-quality talents with solid foundations and innovative thinking, driving deep alignment between courses, industries, and disciplinary frontiers.

3. Design of teaching content of basic course of materials science with structure-property relationship of absorbing materials

3.1. Integration of basic theory and structure-property relationship

The foundational theoretical module should anchor core curriculum knowledge points to organically integrate structure-property relationships. In the atomic structure and chemical bonds chapter, the electromagnetic wave absorption mechanism serves as a starting point to demonstrate the intrinsic connections between atomic electronegativity, chemical bond types, and dielectric/damping losses. By analyzing the wave-absorption performance differences among metallic elements, oxides, and carbon materials, this section illustrates how atomic structure fundamentally influences absorption properties. The crystal structure and defect chapter focuses on how vacancies, dislocations, and grain boundaries regulate carrier mobility and magnetic domain structures in absorbers. Using ferrite materials as examples, it demonstrates how increased dislocation density affects permeability and absorption bandwidth, helping students understand the structure-property correlation in crystal systems. The phase structure and transformation chapter examines phase composition and morphological changes in absorbers, comparing single-phase and multiphase materials. Through analyzing composite material interface mechanisms, it reinforces the "structure-determines-performance" core theory. Adopting a multi-stakeholder collaborative teaching approach, comparative case studies of ferrite, carbon-based composites, and metal-organic framework derivatives demonstrate how structural variations impact absorption performance, cultivating students' analytical and logical reasoning skills. The thermodynamics and kinetics chapter bridges material preparation processes with microstructural formation, explaining how sintering temperatures and holding times regulate material properties, thereby completing the theoretical-practical integration chain.

3.2. Selection of practical application cases

The practical application module cases adhere to the principles of typicality, relevance, and practicality, effectively bridging theory and practice. Taking metamaterial absorptive chips as the core case, combined with FDTD simulation results, it demonstrates the structure-property relationships between structural parameters (unit size, arrangement method, geometric shape) and three-band absorptive performance, allowing students to intuitively perceive the precise impact of microstructural regulation on absorptive performance. The graphene/polymer composite material serves as a classic case, analyzing the correlation between graphene sheet structure, dispersion, absorptive bandwidth, and absorption intensity. By comparing performance data under different dispersion states, it illustrates the optimization mechanism of structural design on absorptive performance. The carbonyl iron powder/ceramic composite case explains the structure-property rules of particle size, content ratio, material hysteresis loss, and absorptive efficiency, enabling students to grasp the fundamental approach of component structure regulation in composite materials. Case selection balances classical and cutting-edge examples, including traditional materials like ferrites and carbonyl iron powder to solidify foundational knowledge, as well as novel cases such as two-dimensional material composites and smart-responsive absorptive materials to broaden perspectives. Additionally, case design integrates interdisciplinary concepts, combining knowledge from chemical synthesis, physical characterization, and electronic engineering to guide students in analyzing structure-property relationships from a cross-disciplinary perspective and cultivate comprehensive application skills. Each case is accompanied by design thinking questions and practical tasks, such as "Adjusting the impact of metamaterial unit size on absorptive peak," to reinforce students' understanding and application of structure-property relationships.

3.3. Supplementary content on cutting-edge advances

The Cutting-edge Advances module aims to broaden students' academic horizons and equip them with knowledge of research hotspots and trends. Aligning with the talent development needs of new engineering disciplines, it introduces the structural-property design of multi-level absorptive materials, explaining the design concepts and absorptive advantages of core-shell structures, porous structures, and layered structures, while demonstrating how multi-level structures enhance absorptive performance through synergistic effects [2]. The module also explores the structural-performance modulation mechanisms of intelligent-responsive absorptive materials, such as the structural changes and performance switching patterns of temperature- and pH-responsive materials, showcasing cutting-edge application scenarios. It presents machine learning-based structural-property relationship prediction methods, demonstrating the application of big data and artificial intelligence in material structure design and performance prediction—such as rapidly screening optimal structural parameters through algorithmic models—to reflect interdisciplinary integration trends. Rooted in the "research-driven teaching" philosophy, the module shares practical research team experiences, including case studies on optimizing absorptive performance through material microstructure modification, enabling students to understand research workflows and methodologies. It supplements with real-world applications of absorptive materials in 5G communications, electromagnetic shielding, and defense equipment, highlighting the guiding significance of structural-property relationship research for product development and enhancing engineering practice awareness and innovation motivation. Accompanied by cutting-edge literature interpretation tasks, the module guides students to track disciplinary developments and improve their literature analysis skills.

4. Teaching and evaluation of the basic course of materials science with the structure-property relationship of absorbing materials

4.1. Application of diversified teaching methods

To enhance teaching effectiveness, a diversified approach should be adopted in instructional implementation. The case-based teaching method is employed, where in-depth analysis and group discussions of typical cases such as metamaterial absorptive chips, graphene composites, and iron carbonyl powder/ceramic composites guide students to actively explore the "structure-performance" correlation mechanism [3]. Each case follows a four-step process: "theoretical explanation–data presentation–problem investigation–rule summarization," cultivating students' analytical and problem-solving skills. Virtual simulation teaching is conducted using FDTD simulation software, establishing an online simulation platform equipped with a model library, operational guidelines, and data processing tools. Students can independently adjust material structural parameters (size, morphology, composition ratio) and observe real-time changes in absorptive performance curves, intuitively understanding the dynamic structure-property relationship. The platform also features a Q&A module to promptly address operational challenges and enhance digital application capabilities. Project-based teaching is implemented through research projects such as "Structural Design and Absorptive Performance Prediction of a Composite Material" and "Optimization Design of Absorptive Materials Based on Structure-Property Relationships." Students work in 3–4 person groups to complete literature review, scheme design, simulation, result analysis, and report writing. Teachers provide regular progress supervision and targeted guidance to foster teamwork and scientific innovation capabilities [4]. Industry experts and researchers are invited to deliver specialized lectures, sharing cutting-edge achievements and engineering application experiences in absorptive material structure-property relationships, such as structural design requirements for absorptive materials in defense equipment and process optimization points in large-scale production. Interactive Q&A sessions are arranged after lectures to broaden students' perspectives. The blended learning model combines online and offline components. Online resources include literature, simulation videos, and case analyses, complemented by phased quizzes and discussion forums. Offline activities feature interactive sessions such as case studies, hands-on experiments, and group discussions. Through teacher guidance and peer collaboration, students deepen their understanding of the subject matter, achieving a synergistic effect between self-directed learning and in-depth interaction.

4.2. Optimization of practical teaching

The practical teaching component serves as a pivotal platform for integrating structure-property relationships. It requires coordinated advancement of course experiments, research practices, corporate internships, and extracurricular innovation activities to establish a comprehensive practical framework. Within the experimental teaching module, three specialized experiments have been introduced: "Microstructural Control and Absorption Performance Testing of Carbon-Based Composites," "Impact of Crystal Defects on Absorptive Material Properties," and "Structural Parameter Optimization and Simulation Validation of Metamaterials." Each experiment comes with detailed operational guidelines and data logging forms, enabling students to systematically master structural characterization methods (e.g., XRD, SEM) and performance testing techniques (e.g., vector network analyzer). Comparative analysis of experimental data verifies the theoretical structure-property relationships [5]. The experimental process features progressive tasks, ranging from basic parameter testing to self-designed structural optimization schemes, gradually increasing practical difficulty and innovation demands. Instructors provide continuous guidance throughout, promptly addressing operational and conceptual challenges. Leveraging university research platforms, students participate in scientific research projects related to absorptive material structure-property relationships, such as “Preparation and Performance Study of Multi-Stage Structured Absorptive Materials.” Under researchers’ supervision, students undertake specific tasks including material preparation, structural characterization, and performance testing, deepening their understanding of structure-property relationships, learning standardized research methodologies and experimental skills, and enhancing research practice capabilities. Collaborate with enterprises specializing in microwave-absorbing materials to establish practical teaching bases, arranging 2–4 week internships for students. The internship curriculum covers production process learning, structural modification techniques, and product performance testing, with a focus on understanding how parameters like sintering temperature, pressure, and dispersant dosage in powder metallurgy and sol-gel preparation processes affect material structure and properties. This approach integrates theoretical knowledge with engineering practice. Students are encouraged to participate in innovation and entrepreneurship projects, “Challenge Cup” competitions, and other academic contests, conducting innovative designs centered on the structure-property relationship of microwave-absorbing materials. For instance, the project “Design of High-Efficiency Lightweight Microwave-Absorbing Materials Based on Structure-Property Relationships” receives experimental platforms, funding support, and mentor guidance from the university, helping students transform ideas into practical achievements and cultivate innovation capabilities. By integrating practical teaching resources from universities, enterprises, and research institutions, a diversified practical platform is established. Shared experimental equipment, research projects, and internship positions provide students with abundant practical opportunities and resource support.

4.3. Construction of teaching evaluation system

The teaching evaluation system should focus on integration objectives, adopting a comprehensive approach that combines formative and summative assessments to fully and objectively reflect students’ learning outcomes and overall competencies. Formative assessment accounts for 60% of the total score, emphasizing the learning process and skill development. This includes: Classroom performance (20%), covering the logical depth of case analysis presentations, active participation in group discussions, and accuracy in responding to classroom questions, evaluated through a combination of teacher feedback and peer reviews; Online learning (15%), including the completion rate of learning resources, online test scores (3–4 periodic assessments), and discussion forum engagement quality (relevance and depth of posts), assessed through platform data analytics and teacher reviews; Practical teaching components (25%), evaluating standardized experimental skills, data accuracy and completeness, project quality (rationality of design plans, reliability of results, report formatting), internship report details and theoretical relevance, and innovative thinking uniqueness, with joint evaluation by instructors and industry mentors. Formative assessments enable timely tracking of students’ progress and knowledge acquisition, providing personalized guidance for addressing issues and informing instructional adjustments. Summative assessment accounts for 40% of the total score, combining closed-book exams with course papers. The closed-book exam (20%) focuses on core knowledge points, including fundamental theories of structure-property relationships, material structure-property correlations, and basic principles of microwave-absorbing materials. Question types include multiple-choice questions, short-answer questions, and case analysis questions, with the latter emphasizing students' ability to apply structure-property relationship theories to solve practical problems. The course paper (20%) requires students to write a 3,000 to 4,000-word academic paper on a specific research direction in microwave-absorbing materials, incorporating cutting-edge developments or practical projects. This evaluates students' abilities in literature review, scientific thinking, data analysis, and academic writing. A diversified evaluation system is implemented, including student self-assessment (10%), peer review (10%), and industry mentor evaluation (5% for internship components). Self-assessment should summarize learning achievements and shortcomings, peer review focuses on project contributions, and mentor evaluation emphasizes practical skills and professional ethics during internships, ensuring objective and fair results. The evaluation framework covers three dimensions: knowledge mastery, capability enhancement, and competency development. Knowledge dimensions include fundamental theories of structure-property relationships, material structure-property correlations, basic principles of microwave-absorbing materials, and cutting-edge developments. Capability dimensions encompass experimental operations, simulation modeling, scientific innovation, teamwork, interdisciplinary applications, and academic writing. Competency dimensions cover learning attitudes, professional identity, engineering ethics, innovative awareness, and professional ethics. Each dimension has clearly defined evaluation levels and standards, providing data support for continuous teaching reform through a scientifically structured evaluation system.

5. Conclusion

The integration of the structure-property relationship of microwave-absorbing materials into the "Fundamentals of Materials Science" course represents a valuable exploration in curriculum reform under the new engineering education framework. Through systematic analysis of core educational values, this study establishes a three-dimensional teaching framework comprising "theoretical foundations, practical case applications, and cutting-edge advancements." Complemented by diversified teaching methodologies and scientific evaluation mechanisms, the model achieves organic integration of fundamental theories with engineering practices, traditional pedagogy with modern technologies, and course instruction with disciplinary frontiers. This approach effectively addresses the challenges of abstract concepts and disconnected practical applications, enhances student engagement and knowledge acquisition, and cultivates interdisciplinary application skills, research innovation capabilities, and engineering competencies—all aligning with the talent development requirements of new engineering education. Future initiatives should focus on expanding teaching case repositories, deepening the integration of virtual simulations and physical experiments, refining multi-stakeholder collaborative teaching mechanisms, conducting long-term instructional tracking research, and continuously optimizing integration pathways through data analysis and feedback. These efforts will provide robust theoretical support and practical references for curriculum reform in materials science and engineering disciplines.

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