

環境に配慮したマルチファンクショナル複合材料の設計・開発・評価

Design, development and evaluation of multi-functional composite materials



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本研究室では、Digital transformation (DX) 社会の実現に導く環境発電 (エネルギーハーベスティング) 材料やセンサ材料の設計・開発・評価に取り組んでいる。特に、圧電セラミック粒子や磁歪合金ワイヤを利用した複合材料に注目し、強度・機能特性と信頼性・耐久性の向上を目指して理論的・実験的研究を進めている。また、環境汚染を食い止めるための極低環境負荷構造材料の創製を目指し、和紙強化ポリマー複合材料や機能性絹糸を設計・開発して、力学・物理特性、生分解性、微細構造などを評価している。

Our laboratory is engaged in research to design and develop composite materials for energy-harvesting and sensor applications, which helps realize a digital transformation (DX) society. We focus on composite materials with piezoelectric ceramic particles or magnetostrictive alloy wires and address improving their strength and functional properties or reliability and durability through both theoretical and experimental research. In addition, to mitigate environmental pollution, we are developing eco-friendly structural materials with extremely low environmental impact, such as Japanese washi paper-reinforced polymer composites and functional silk threads. We evaluate these materials for their mechanical and physical properties, biodegradability, and microstructures.

圧電複合材料

圧電セラミックスは脆く、また、高圧電特性のチタン酸ジルコン酸鉛 (PZT) には有害物質 (鉛) が含まれているため、柔軟な非鉛系圧電材料の開発が要望されている。本研究室では、鉛フリー圧電ナノ粒子分散ポリマーを作製し、炭素繊維強化プラスチック (CFRP) を積層して電極として用い、コロナ放電分極に成功している。また、ポリマー内部の圧電粒子体積含有率を段階的に変化させた傾斜機能圧電粒子分散ポリマーの作製方法を提案し、構造を制御して試作後、圧縮衝撃・曲げ振動発電機能と傾斜組成分布との相関を解明している (Fig. 1)。今後の展開が期待される。

磁歪複合材料

超磁歪特性を示す Tb-Dy-Fe 合金は、脆さや渦電流発生などが問題となっており、高価格であるという欠点も有している。Fe-Ga 合金も同様に超磁歪特性を示すが、加工の難しさが製品化の障害となっている。本研究室では、Fe-Co ワイヤ / 樹脂複合材料を開発し、振動・衝撃発電に成功している。また、Fe-Co ワイヤを擦ってアルミニウム合金に埋め込む技術を確立し、衝撃を電気に変換する軽金属複合材料を開発して、高出力化も実現している。さらに、物質が付着した際の磁歪複合材料の共振周波数・出力電力変化に着目し、磁歪ウイルスセンサの実現に向けた研究を進めている (Fig. 2)。

Piezoelectric Composites

The design and development of flexible lead-free piezoelectric materials are crucial due to the brittleness of piezoelectric ceramics and the inclusion of toxic lead in high-performance piezoelectric materials like lead zirconate titanate (PZT). In our laboratory, we have successfully developed lead-free piezoelectric nanoparticle-dispersed polymers and laminated carbon-fiber-reinforced polymers (CFRPs) as electrodes. Corona discharge polarization was applied successfully to these composites. Additionally, we proposed a fabrication method for functionally graded piezoelectric particle-dispersed polymers, where the volume fraction of piezoelectric particles was varied in thickness direction. By controlling the structure and fabricating prototypes, we clarified the correlation between compressive shock and bending vibration power-generation functions and the graded composition distribution (see Fig. 1). Future developments are expected.

Magnetostrictive Composites

Magnetostrictive alloys such as Tb-Dy-Fe exhibit excellent magnetostrictive properties, but their brittleness, eddy current generation, and high cost pose challenges for practical applications. However, the difficulty in machinability and the fabrication cost inhibit their applications as magnetostrictive devices. We have developed Fe-Co wire-resin composites and have succeeded in generating vibration and impact. We have also established a technology to embed twisted Fe-Co wires in aluminum alloy and developed a light metal composite material

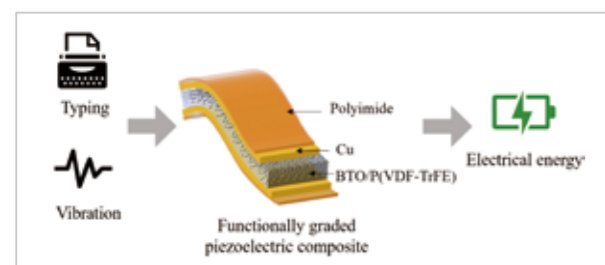


Fig. 1 Schematic illustration of functionally graded piezoelectric composites for energy harvesting.

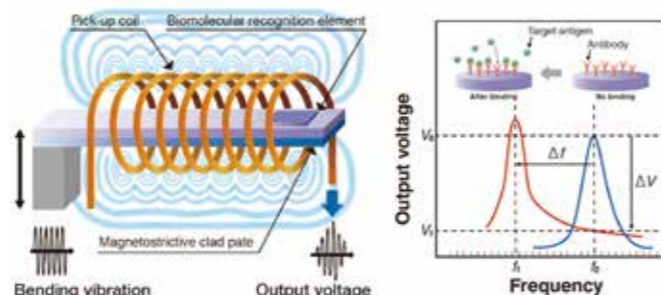


Fig. 2 Schematic illustration of magnetostrictive virus sensor mechanism.

低環境負荷複合材料

本研究室では、木質繊維を極限まで破碎して得られるセルロースナノファイバーや、和紙と生分解性ポリマーを組み合わせた高強度・低環境負荷複合材料 (グリーンコンポジット) の開発に取り組んでおり、分解過程における力学特性変化に注目した研究も進めている。また、蚕にセルロースナノファイバーを給餌し、高強度絹糸の創製に成功しており、衰退しつつある日本の養蚕業復活への貢献が期待されている (Fig. 3)。

その他の活動

<受賞>

- International Symposium on Green Processing for Advanced Ceramics (IGPAC 2025) Young Scientist Award Gold Prize (丸山衡平)
- 令和7年度 環境科学研究科奨学賞 (趙子文)
- 2025 Tohoku University & Taipei Tech Joint Symposium "Excellent Paper Award" (丸岡なな子)
- Joint-Symposium on Mechanics of Advanced Materials & Structures 2025 "Best Presentation Award" (趙子文)

<教育>

- 書籍 "Piezoelectric Materials, Composites, and Devices: Fundamentals, Mechanics, and Applications (Elsevier)" 出版, F. Narita and Z. Wang
- 書籍「楽しく学ぶ機械製図 (朝倉書店)」編集・出版, 編者: 成田史生他1名, 著者: 王真金, 栗田大樹, 成田史生他5名

<その他>

- 大阪・関西万博 ギャラリー WEST 日本赤十字社展示スペース「未来の野外診療所〜ゼロ・エミッションの災害医療〜」開発研究および展望の紹介
- 小学生向け科学教室「空も未来も飛び越える! ドローンと“ふしぎ素材”の大冒険」開催「学都仙台・宮城サイエンスデイ」



Fig. 3 Cellulose nanofiber reinforced cocoon of a silkworm.

that converts impact into electricity. Furthermore, we are investigating the changes in resonant frequency and output power of magnetostrictive composites caused by material adhesion, aiming to develop magnetostrictive virus sensors (see Fig. 2).

Eco-friendly (Green) Composites

In our laboratory, we develop high-strength, low-environmental-impact (i.e., green) composites by combining cellulose nanofibers (obtained by thoroughly pulverizing wood fibers) and washi (Japanese traditional paper) with biodegradable polymers. We also conduct research focusing on changes in mechanical properties of the composites during the degradation process. Additionally, we successfully created high-strength silk by feeding silkworms cellulose nanofibers, which is expected to contribute to the revival of the declining Japanese sericulture industry (see Fig. 3).

Other Activities

<Award>

- Young Scientist Award (Gold Prize), International Symposium on Green Processing for Advanced Ceramics (IGPAC 2025) (Kohei Maruyama)
- Graduate School of Environmental Studies Scholarship Award (FY 2025) (Zibun Zhao)
- Excellent Paper Award, 2025 Tohoku University & Taipei Tech Joint Symposium (Nanako Maruoka)
- Best Presentation Award, Joint Symposium on Mechanics of Advanced Materials & Structures 2025 (Zibun Zhao)

<Education>

- Publication of the book Piezoelectric Materials, Composites, and Devices: Fundamentals, Mechanics, and Applications (Elsevier), F. Narita and Z. Wang
- Editing and publication of the book Fun and Easy Mechanical Drawing (Asakura Publishing), Editors: F. Narita et al.; Authors: Z. Wang, H. Kurita, F. Narita et al.

<Others>

- Presentation of research and future perspectives at the Japan Red Cross Society exhibition space, "Future Outdoor Medical Facilities: Zero-Emission Disaster Medicine," Gallery WEST, Osaka-Kansai Expo
- Organization of a science workshop for elementary school students, "Fly Beyond the Sky and the Future! An Adventure with Drones and Mysterious Materials," at Gakuto Sendai-Miyagi Science Day



Fig. 4 Group photo of summer trip