Johns Hopkins University
Department of Mechanical Engineering
2021 Fall Seminar Series: Class 530.803

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REGISTRATION LINK | ZOOM LINK | Passcode: 156138
In-person Class Held in Malone G33/35 (open to first 50 people)

"Self-adaptive materials, structures, and devices"

Presented by Professor Sung Hoon Kang
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Adaptability is one of the hallmarks of living systems that provide resilience to survive and flourish in dynamically changing environment. I will present our ongoing efforts about how we can realize materials, structures, and devices that can adapt to mechanical environment changes by adjusting their mechanical properties or shapes autonomously.

First, I will present self-adaptive materials that can change their mechanical properties depending on loading conditions. Nature produces outstanding materials for structural applications such as bones and woods that can adapt to their surrounding environment. For instance, bone regulates mineral quantity proportional to the amount of stress. It becomes stronger in locations subjected to higher mechanical loads. This leads to the formation of mechanically efficient structures for optimal biomechanical and energy-efficient performance. However, it has been a challenge for synthetic materials to change and adapt their structures and properties to address the changes in loading conditions. To address the challenge, we are inspired by the findings that bones are formed by the mineralization of ions from blood onto scaffolds. I will present a material system that triggers mineral deposition from ionic solutions on scaffolds upon mechanical loadings so that it can self-adapt to mechanical loadings. For example, the mineralization rate could be modulated by controlling the loading condition and a 30-180% increase in the modulus of the material was observed upon cyclic loadings whose range and rate of the property change could be modulated by varying the loading condition. Moreover, our preliminary results showed that the material system showed improved fatigue resistance from its damage mitigation mechanism. We envision that our findings open new strategies for making synthetic materials with self-adaptable mechanical properties.

Second, an architected material (or metamaterial) is a class of materials that provide new properties that are not observed in natural materials or from a bulk material that the "material" is made of. I will present adaptive energy-absorbing "materials" with extreme energy dissipation and improving energy absorption with increasing strain rate by the interplay of nonlinear behaviors of materials and structures. We utilize energy dissipation mechanisms across different length scales by utilizing architected liquid crystalline elastomers. As a result, our energy-absorbing materials show about an order of magnitude higher specific energy dissipation at quasi-static condition compared with the previous studies and even higher energy dissipation at faster strain rates with power-law relation, whose exponent can be tuned by controlling the mesoscale alignment of molecules using a simple strain control-based approach. We also found that we can further enhance the specific energy absorption by vertical stacking due to viscoelasticity. The findings from our study can contribute to realizing extremely lightweight and high energy dissipating materials, which will be beneficial for various applications, including aerospace, automotive, and personal protection.

Third, I will present self-adaptive cardiovascular implant devices that can accommodate the growth of pediatric patients. Right ventricle–to–pulmonary artery (RV-PA) conduits are used as a surgical palliative treatment for various congenital heart diseases. Due to the growth of the infant or child, these conduits require replacement as they cannot grow, which involves several major open-heart surgeries. To address this issue, we have investigated self-adaptable RV-PA conduits that "grow" via tailored self-unfolding mechanisms triggered by flow and pressure change associated with growth so that fewer surgeries are required from infancy to adulthood. I will present our simulation results for design of self-adaptable implants, followed by experimental results of testing 3D printed implant devices using an in vitro testing set-up. The results showed that our self-adaptable implants can make shape changes to accommodate the growth of children. We anticipate that our approaches and findings can contribute to improving patient welfare by customized designs with growth potential based on patient anatomy, which can minimize the number of required surgeries and associated danger, trauma, and expenses.

Sung Hoon Kang is an Assistant Professor in the Department of Mechanical Engineering at Johns Hopkins University. He earned a Ph.D. degree in Applied Physics at Harvard University and M.S. and B.S. degrees in Materials Science and Engineering from MIT and Seoul National University, respectively. Sung Hoon has been investigating bioinspired solutions to address the current challenges in engineering materials and mechanical systems with applications including resiliency, healthcare, sensing, and energy. His research has been supported by AFOSR, NSF, NIH, ARO, ONR, State of Maryland, and private foundations. Throughout his career, Sung Hoon has co-authored 51 peer-reviewed papers, has given over 130 presentations (including over 70 invited talks), and has six patents and three pending patents. His honors include 2021, 2020 Air Force Summer Faculty Fellowship, 2020 Johns Hopkins University Catalyst Award, 2019 Johns Hopkins University Whiting School of Engineering Research Lab Excellence Award, Invitee for 2019 China-America Frontiers of Engineering Symposium, FY 2018 Air Force Office of Scientific Research Young Investigator Program Award, Alumnus of 2016 National Academy of Engineering US Frontiers of Engineering Symposium, and 2011 Materials Research Society Graduate Students Gold Award. He served as an editorial board member of Scientific Reports and a guest editor of Materials Research Society Bulletin. Currently, he serves as an early career researcher board member of Multifunctional Materials and an editorial board member of Sensor. He also serves as a reviewer for journals including Nature, Science, Advanced Materials, Science Advances, Science Robotics, Advanced Functional Materials, Additive Manufacturing, Proceedings of the National Academy of Sciences, ACS Materials & Interfaces, Nanoscale, Journal of the Mechanics and Physics of Solids, Extreme Mechanics Letters, Soft Matter, Smart Materials and Structures, and Bioinspiration & Biomimetics. He has been co-organizing ~35 symposia on bioinspired materials, 3D printing, and mechanical metamaterials at international conferences. He is a member of American Society of Mechanical Engineers (ASME), American Physical Society (APS), Materials Research Society (MRS), and Society of Engineering Science (SES). He served as the Chair, Vice Chair, Secretary, and Editor of ASME Technical Committee on Mechanics of Soft Materials.