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LA SOCIÉTÉ CANADIENNE DE GÉNIE MÉCANIQUE
SPRING/PRINTEMPS 2021

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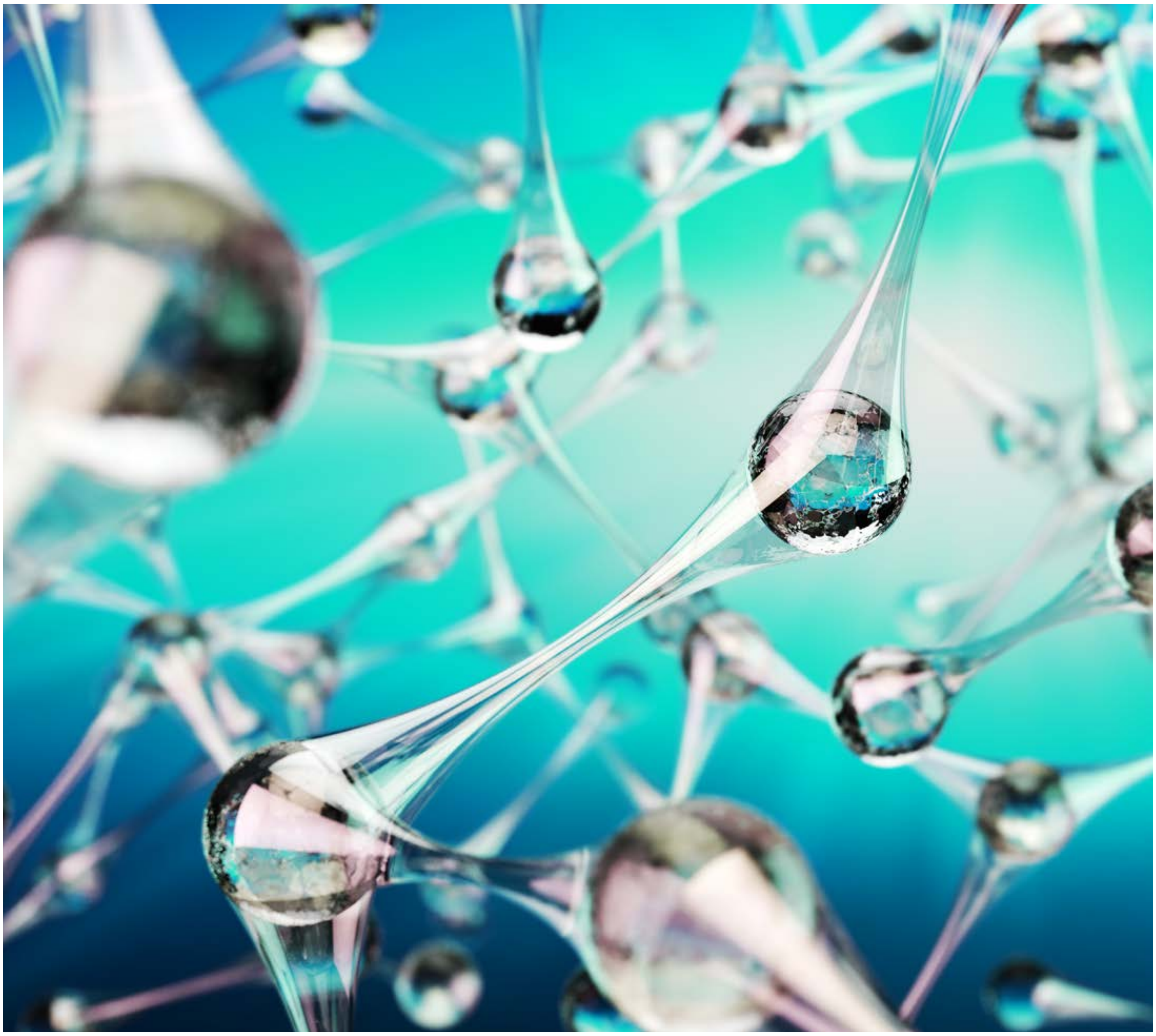

SPECIAL ISSUE ON

Advanced Materials

CONTENT

SPRING/PRINTEMPS 2021

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Editor's Letter

AS WE CONTINUE TO FEEL THE EFFECTS OF the coronavirus pandemic, our profession has had to adapt to virtual work and meetings. Now, thanks to human ingenuity, several vaccines are inching us closer to the end of a devastating pandemic and a return to life "as we knew it". The development of multiple vaccines in approximately one year highlights how far human ingenuity can take us as well as the necessity of an excellent research and development ecosystem that allows scientists and engineers to share ideas freely and translate them into workable solutions.

The *2021 CSME International Congress* is an important part of the Canadian mechanical engineer's research and development ecosystem. It is an excellent venue to share recent advancements in the field of mechanical engineering with other CSME members. This year's CSME Congress will be held virtually and will be hosted by the University of Prince Edward Island. For this issue's ME Chair's Corner, we asked Dr. **Peters**, interim Dean of the Faculty of Sustainable Design Engineering at UPEI, to provide an overview of their university so that those attending the congress can hear his perspective of the hosting university.

The development of novel COVID-19 vaccines is a result of multiple developments in the areas of bio- and nano-technology. Nanotechnology has also played a key role in helping mechanical engineers develop advanced materials, the topic of this issue. Novel nanomaterials rely on the adjustment of the material nanoscale structure to achieve improved properties such as higher strength. In this issue, the work of CMSE members in the areas of advanced materials, as well as bio- and nano-technology is featured. The feature articles by Dr. **A. Suleman**, Dr. **J. Hogan** and Dr. **D. Chen** highlight recent advancements in the optimal and reliable design of advanced composite structures, advanced tools to study ceramic materials at nano- to macro-scales, and the superior mechanical properties of metal matrix composites, respectively. Dr. **Packirisamy's** article shows how plasmonic nanoparticles can be used for the detection of bovine growth hormones, exosomes and other biological species. Finally, Dr. **X. Chen** reviews current research in bioinks for bioprinting of 3D cell-incorporated constructs such as human tissue and organs.

The *New Faculty Spotlight* articles are by professors **Lee** (U of Toronto) and **Romanyk** (U of Alberta). They describe their exciting research programs in the areas of nano-structured composites and cranial biomechanics. One of the *ME News* piece by our Technical Editor, Prof. **Ryan Willing**, describes how automation and artificial intelligence can help in our quest for advanced and new materials. We also invite you to read updates from the Editor of *Transactions of the CSME* and the chairs of the *Technical committees*, *CSME Student Affairs committee* and *Professional Affairs committee*. The next CSME *Bulletin* issue will be dedicated to computer-aided design (CAD) and big data analytics. We invite all the researchers in this area to watch for our call for feature articles by email in early July 2021. Please send us your abstracts for evaluation by the editorial board. It is your contributions that make the CSME *Bulletin* a publication that the CSME community can be proud of. We thank all the contributors to this issue and hope you enjoy reading this issue.

We wish you all health and a fast recovery from the COVID-19 impacts.

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Transactions of the Canadian Society for Mechanical Engineering (TCSME)

I am happy to report on the accomplishments of the *Transactions of the Canadian Society for Mechanical Engineering* (TCSME) for the year 2020. Last year, we have published four issues with a total number of 58 articles. We have received and processed 261 manuscripts which indicate an acceptance rate of 22%. Up to now, the most cited article published in 2020 is:

"Generation of regression models and multi-response optimization of friction stir welding technique parameters during the fabrication of AZ80A Mg alloy joints"
By: Sevvel, P; Satheesh, C; Kumar, RS
Transactions of the Canadian Society for Mechanical Engineering (TCSME)
Volume: 44 Issue: 2 Pages: 311-324 Published: 2020

MARIUS PARASCHIVOIU, PhD, FCSME, FEIC
Editor-in-Chief, TCSME
Professor, Mechanical, Industrial and Aerospace Engineering
Vice-Provost, Planning and Student Experience
Concordia University

President’s Message

Message de la présidente

PHOTO: SCHOOL OF ENGINEERING AT UBC OKANAGAN

A future of so many possibilities...

As the new president of the CSME, I am honoured and excited to serve the mechanical engineering community in this new role. I would like to acknowledge my predecessor, Dr. **Maciej Floryan**, for his many contributions. Our membership has steadily grown thanks to his establishing a streamlined membership process and providing our students with a seamless transition to full membership upon graduation. I want to take this opportunity to thank him for his leadership in bringing us together as a society, especially during the pandemic. I also want to acknowledge the work of our researchers, industry partners and students in creating innovative solutions towards critical challenges of our time. The pandemic taught us to be resilient and think outside the box, whether it is the design of an anti-fog mask, or an effective online teaching tool to educate students across the globe. This year, we aim to continue supporting our society through (I) efficiently managing membership intake and retention; (II) representing the new technical areas of the fast-growing mechanical engineering field; and (III) supporting the 2021 CSME Congress. For the latter, I would like to acknowledge the efforts of our Congresses Committee and the Congress co-chairs for making the 2021 virtual congress possible.

I look forward to having an integral role in promoting equity, diversity and inclusion (EDI) not only in the CSME, but also in the mechanical engineering profession at large. We have formed an EDI committee to establish strategies, raise awareness of anti-racism and create initiatives and opportunities in the profession, as well as identify accessible EDI training.

I would also like to announce that our CSME History Committee has been re-activated. Key initiatives include reserving engineering achievements through interviews of senior mechanical engineers and raising awareness by publication of a series of articles in the CSME *Bulletin* in areas related to diversity in mechanical engineering, the environment and sustainability.

Finally, I am excited to report that despite the pandemic, our Student Affairs Committee and the Professional Affairs Committee have been very active, coordinating and organizing a few successful events with virtual attendance in the hundreds. With a return to in-person learning, we plan to revitalize our chapters by organizing a series of webinars highlighting the profession to CSME student members.

I would like to thank you for your continuous support and wish you a healthy and successful year.

MINA HOORFAR, PhD, P.Eng., FCSME
CSME *President*
Director and Professor, School of Engineering
The University of British Columbia, Okanagan Campus | Syilx Okanagan Nation Territory

Un avenir aux multiples possibilités...

Chers collègues et membres,

En tant que nouvelle présidente de la SCGM, je suis honorée et ravie de servir la communauté du génie mécanique dans ce nouveau rôle. Je tiens à remercier mon prédécesseur, le Dr Maciej Floryan, pour ses excellentes contributions. Notre adhésion n'a cessé de croître grâce à la mise en place de processus simplifiés et en offrant à nos étudiants une transition plus soutenue vers l'adhésion à part entière après l'obtention de leur diplôme. Je veux profiter de cette occasion pour le remercier de son leadership en nous rassemblant en tant que société, en particulier pendant la pandémie. Je tiens également à saluer le travail de nos chercheurs, partenaires industriels et étudiants dans la création de solutions innovantes face aux défis critiques de notre temps. La pandémie nous a appris à être résilients et à sortir des sentiers battus, qu'il s'agisse de la conception d'un masque antibuée ou d'un outil d'enseignement en ligne efficace pour éduquer les étudiants du monde entier. Cette année, nous visons à continuer de soutenir notre société en (I) gérant efficacement l'admission et la rétention des membres; (II) représentant les nouveaux domaines techniques du domaine grandissant de génie mécanique; et (III) soutenir le Congrès 2021 de la SCGM. Concernant ce dernier, je voudrais saluer les efforts de notre comité sur les congrès et des coprésidents du Congrès pour rendre possible notre congrès 2021 de façon virtuelle.

Je suis impatiente de jouer un rôle global dans la promotion de l'équité, de la diversité et de l'inclusion (EDI) non seulement au sein de la SCGM, mais aussi dans la profession d'ingénieur mécanique en général. Nous avons formé un comité EDI pour établir des stratégies, sensibiliser le besoin de lutter contre le racisme et créer des initiatives et des opportunités dans la profession, ainsi que pour identifier des formations sur EDI facilement accessibles.

Je voudrais également annoncer que notre comité d'histoire de la SCGM a été réactivé. Leurs principales initiatives comprennent la documentation des réalisations importantes en ingénierie au moyen d'entretiens avec des ingénieurs mécaniques seniors et la sensibilisation par la publication d'une série d'articles dans le Bulletin de la SCGM traitant des domaines liés à la diversité en génie mécanique, à l'environnement et à la durabilité.

Enfin, je suis ravie d'annoncer qu'en dépit de la pandémie, nos comités des affaires étudiantes et des professionnels ont été fort actifs, coordonnant et organisant plusieurs événements réussis avec une présence virtuelle par centaines. Avec un retour à l'apprentissage en présentiel, nos chapitres seront revitalisés par le biais d’une série de webinaires mettant en valeur la profession aux près des membres étudiants de la SCGM.

Je tiens à vous remercier pour votre soutien continu et vous souhaite une année saine et fructueuse.

Mina Hoorfar, PhD, P.Eng., FCSME
Présidente

Welcome New CSME members

1 October 2020 to 30 April 2021

Mr. Salih Abouassali, *Gastops Ltd.*
Mr. Erik Alson, *MEG Energy*
Mr. Christiansun Antony Alumkal, *GE Aviation Czech s.r.o*
Dr. Kiari Goni Boulama, *Royal Military College of Canada*
Mr. Tho-Tan Bui, *CDS*
Mr. Eric Burelle, *Oil Changers*
Prof. Changhong Cao, *McGill University*
Mr. Sergio Catlyn, *NWT Power Corporation*
Mr. Dusan Curcic, *IBM Canada Ltd.*
Mr. Greg Mark Derige, *Shaw Almex Industries*
Mr. Kumar Gaurav, *L&T Technology Services Ltd.*
Dr. Elli Gkouti, *York University*
Ms. Patricia Greig, *CMC Microsystems*
Prof. Ronald Hanson, *York University*
Mr. Alex Jokuty
Mr. Jason Kalapurakal, *APEGA*
Dr. Chun-il Kim, *University of Alberta*
Dr. Seama Koohi, *Ontario Tech University*
Dr. Huiyuan Liu, *University of Waterloo*
Prof. Susan McCahan, *University of Toronto*
Mr. Ranjit Paramanathan, *Arctic Coatings Inc., Concord*
Mr. Christopher Perrier
Mr. Celestine Ugoeze Eso, *Nigeria LNG Ltd.*
Prof. XiaYu Wu, *University of Waterloo*
Dr. Burak Yenigun, *York University*
Dr. Jian Zhao, *University of Waterloo*

Engineering by Design

THE UNIVERSITY OF PRINCE EDWARD ISLAND is located in Charlottetown, the birthplace of Confederation and the capital city of Prince Edward Island. The campus is home to about 5,000 students and offers a wide range of programs and degrees to undergraduate, graduate, and doctoral students.

Within the Faculty of Sustainable Design Engineering, we offer both undergraduate and graduate level programs. Our Bachelor of Science in Sustainable Design Engineering program is home to almost 300 students with additional growth expected in the coming years. We also have a very active Master of Science in Sustainable Design Engineering program with about 25 active students working in areas such as design, precision agriculture, manufacturing, robotics, bioprinting, biosensors, mechatronics and sustainable energy. Additionally, we are working toward a new PhD program in Sustainable Design Engineering which we hope will be in place very soon.

Our Bachelor of Science in Sustainable Design Engineering program focuses on engineering design as an engineering discipline in itself. Sustainable design engineers are problem solvers. They use design skills, engineering knowledge, math and science to deliver innovative and sustainable solutions to modern-day problems. A sustainable solution is one in which all factors and stakeholders are considered. It goes beyond just providing an efficient, attractive, on-time, and on-budget solution. It also cares about how such goals are achieved and about its impact on people, the environment and society.

Our program provides students with a solid technical foundation which supports the development of their design skills. Just as important, though, the program also provides the professional skills necessary to succeed as a professional engineer. To achieve this, we have created a unique and innovative design clinic model that is integrated throughout all years of the program. In the design clinics, students are immersed in hands-on, experiential learning while working on real projects for a wide range of external partners from the community, municipalities, government, industry and others. Our students do not learn to become sustainable design engineers by simply reading textbooks or attending lectures. Instead, they accomplish this by doing what real engineers actually do - use their design and professional skills, combined with technical knowledge, to provide real solutions to real problems for real partners. And, in our program, this starts right from day one.

Sustainable design engineering is interdisciplinary by its very nature and typically involves teams of engineers, scientists, technicians, technologists, and others across multiple disciplines. Consistent with this, our program allows students in the upper years to focus their studies and apply their design skills in three areas: mechatronics; bioresources; and sustainable energy. Very often, then, design clinic projects and the interests of project team members cover each of these areas.

With a strong interdisciplinary background in engineering design, strengthened by solid professional and technical skills, our graduates are well-positioned to work in a diverse range of industry sectors such as: bio and food processing, robotics, industrial automation, aerospace, automotive, advanced manufacturing, sustainable and alternative energy, marine applications, and many others. Our graduates also pursue careers in research and development by enrolling in graduate programs either here at UPEI or at other schools. Some of our graduates move on to medical school and some even start their own companies.

On behalf of all faculty, staff and students at UPEI's Faculty of Sustainable Design Engineering, we look forward to the delegates of the CSME 2021 Congress joining us here at UPEI (virtually, at least) this coming summer. We hope you like what you see.

Dr. WAYNE PETERS, PhD, P.Eng.
Associate Professor & Interim Dean
Faculty of Sustainable Design Engineering
University of Prince Edward Island
Dr. Peters is a mechanical engineer with a research background in fluid mechanics and hydraulics. He is currently the Interim Dean in the Faculty of Sustainable Design Engineering at the University of Prince Edward Island.

PHOTOS COURTESY OF UPEI

We are delighted to announce that the 2022 CSME Congress will be held on June 5 – 8, 2022, at the Faculty of Engineering of the University of Alberta in Edmonton.

The **University of Alberta**, founded in 1908, is located in Edmonton (Alberta), is a member of the U15 (Canada's 15 research-intensive universities), and frequently recognized as one of the top six universities in Canada. Around 39,000 students study in 18 faculties at the university. Around 6,000 students study in the five departments of the Faculty of Engineering (Biomedical Engineering, Chemical and Materials Engineering, Civil and Environmental Engineering, Electrical and Computer Engineering, and Mechanical Engineering). The Department of Mechanical Engineering at the University of Alberta is one of the largest mechanical engineering departments in Canada, with approximately 1,000 undergraduate and 350 graduate students. It is ranked as one of the top ten departments of mechanical engineering in Canada. The Department has 56 full-time faculty members and leads active research programs in the fields of Biomedical, Biomechanics, and Human Mechanical Systems, Design and Manufacturing, Energy and Environment, Engineering Management, Fluid Mechanics and Systems, Mechanical Systems and Control, Mechanics and Materials, and Reliability Engineering, Standards, and Safety Engineering. The Faculty of Engineering and the Department of Mechanical Engineering have world-class facilities that support internationally recognized collaborative research and development activities.

Edmonton is the capital city of the Province of Alberta and is located on the North Saskatchewan River. Edmonton is the 5th largest municipality in Canada, with a population of more than 900,000. Edmonton is also a cultural and educational hub and hosts several festivals and cultural events throughout the year. The City has a vibrant R&D and business environment, with local and multinational companies active in R&D projects based in Edmonton.

We invite researchers to submit an abstract or a paper to the 2022 CSME International Congress by **January 15, 2022** (further information will be available in June 2021 on www.csmecongress.org). The 2022 CSME International Congress will feature several symposia, including: 1) Advanced Manufacturing, 2) Advanced Energy Systems, 3) Biomechanics and Biomedical Systems, 4) Computational Mechanics, 5) Engineering Design, 6) Environmental Engineering, 7) Fluid Mechanics, 8) Heat Transfer, 9) Machines and Mechanisms, 10) Materials Engineering, 11) Mechatronics, Robotics, Control and Automation, 12) Microtechnology and Nanotechnology, 13) Solid Mechanics, and 14) Transportation Systems.

For further information, please contact Dr. Hossein Rouhani or Dr. André McDonald at csme2022@ualberta.ca.

ADVANCED MANUFACTURING:

A BUTTRESS IN THE DESIGN OF NOVEL COMPOSITE STRUCTURES

Prof. DR. AFZAL SULEMAN, PhD, P.Eng., FCAE, FRAeS

Dr. Suleman is the Canada Research Chair in Computational and Experimental Mechanics and Professor of Mechanical Engineering at the University of Victoria. He is also the Director of the Center for Aerospace Research. He obtained his BSc (Hons.) and MSc in Aeronautical Engineering from Imperial College, London. His PhD in Space Dynamics was obtained from the University of British Columbia, followed by a Postdoctoral Fellowship at Wright Patterson AFB, U.S. His research interests span the Aeronautics and Space domains. He has been inducted into the Canadian Academy of Engineering, the Royal Aeronautical Society and Academy of Sciences of Lisbon as a Fellow.

Prof. ABDOLRASOUL SOHOULI, PhD

Dr. Sohouli is a Postdoctoral Fellow in the Department of Mechanical Engineering at University of Victoria. Dr. Sohouli received his PhD from University of Lisbon on Design of Advanced Composite Structures in 2017. His research interest is in the structural design optimization of large-scale composite structures, topology optimization, reliability-based design optimization, time-variant reliability analysis, and structural power composites. In these fields, he published more than 28 contributions in international journals and international conference proceedings.

IMAGES COURTESY OF THE RESEARCHERS

RECENT DEVELOPMENTS IN AUTOMATED manufacturing have led to the emergence of new design techniques to engineer innovative and efficient composite structures. At the University of Victoria Center for Aerospace Research, we have been exploring optimal designs of advanced composite structures based on additive and fiber placement manufacturing techniques.

Variable Stiffness Composite Laminates (VSCL) were first introduced several decades ago, but only recently, researchers have been actively exploring new designs based on the VSCL concept due to the advances in manufacturing. VSCL can be achieved by either changing the fiber volume fraction in the laminate, by dropping or adding plies to the laminate, or by using curvilinear fibers. The design space is significantly expanded when considering variable stiffness composites compared to the classical stacking sequence design problem, and it results in structural improvements under the same weight constraints. However, the stiffness properties of VSCL need to be designed and tailored judiciously to maximize the structural performance. Metaheuristic approaches are not effective to design and optimize VSCL due to the high number of design variables. To overcome the high computational cost of the optimization process, a new gradient-based optimization has been proposed known as the Discrete Material Optimization (DMO) and it is a generalization of the multi-phase topology optimization problems[1]. Here, a Decoupled DMO (DDMO) approach has been proposed to separate material optimization from fiber orientation steps in each optimization loop to decrease the number of design variables and improve the convergence problem in DMO. The framework was developed to find the optimal design for different automated manufacturing techniques such as additive manufacturing and automated fiber/patch placement manufacturing techniques. In the case of additive manufacturing, the print time of a given structure was also included into the objective functions for the path planning of continuous fiber reinforced composite structures[2].

The structural performance of composite structures is highly sensitive to the anisotropic material properties and the applied loads. Hence, it is critical to consider uncertainties in material properties and loading histories in the design optimization of VSCLs. To design a composite structure with a given reliability threshold, a Reliability-Based Design Optimization (RBDO) technique was developed to provide cost-effective design considering uncertainties in the design process. Due to the high computational cost, reliability-based design optimization of composite structures has not been readily adopted in the design of advanced composite structures. We proposed two efficient decoupled RBDO strategies into our proposed design tool to optimize material distribution and fiber orientation of composite structures under loading and material uncertainties[3].

The design framework should also include the service lifetime cost/benefit evaluation of VSCL in the early design phases. To this end, we incorporated a time-variant reliability analysis in the framework[4]. The time-variant reliability is calculated using the PHI2 method as a type of outcrossing approach. Accordingly, the reliability level and the time of maintenance action of variable stiffness composite structures can be estimated during service lifetime. Then, a cost model was developed to estimate maintenance costs by combination of the time-variant reliability analysis and a probabilistic scheme. This cost model allows designers to make decisions on trade-offs between initial cost and life-cycle cost based on the various composite materials. The final design can be selected according to the initial costs, maintenance costs and service lifetime of the designs under different discount rates and undiscounted costs.

More recently, we have been working on a novel multi-material topology optimization tool for structures with discontinuities. Mesh-based methods such as the finite element method (FEM) are frequently used to carry out the structural analysis during the topology optimization process. However, a few limitations may

(a) Design domain of the bridge with two interior cracks (L=2H and 96 x 192 particles)

(b) Optimal result of the three-material bridge structure

(c) Optimal result of the three-material cracked birdge structure. Crack (l_c = 0.11H and at t_c = 0.1L) bridge structure

FIG. 1: OPTIMAL RESULT FOR THE THREE-MATERIAL BRIDGE STRUCTURE USING PD-BASED TOPOLOGY OPTIMIZATION (ELASTIC MODULI, E_i=[2, 1, 1E-9]=[RED ,BLUE, WHITE]; AND VOLUME CONSTRAINTS, V_f=[35%, 25%, 40%])[5].

be encountered if cracks are present. Therefore, these methods require re-meshing and are prone to inaccuracies. Meshless methods could be considered as a more viable alternative where the complexities associated with the mesh are eliminated. Peridynamics (PD) is a non-local theory and accounts for non-local interactions among material points, thus providing a simpler and more efficient computational implementation. One of the main benefits of PD is that it enables damage prediction without special techniques. Considering PD's ability in permitting and predicting discontinuities, PD-based topology optimization can provide a powerful tool in accounting for such imperfections to improve structural topology at the conceptual design phase of the engineering structures. Hence, we proposed a PD-based Topology Optimization (PD-TO) to find an optimal multi-material topology considering embedded cracks within the structure[5]. Different cases were investigated to illustrate the performance and feasibility of the proposed topology optimization framework. *Figure 1(a)* shows the design domain of a bridge where two vertical cracks are placed at the bottom edge of the bridge. The optimal solutions to the bridge problem with no cracks and with cracks are shown in *Figure 1(b)-(c)* for three materials. The optimal topologies of the cracked structures show that the definition of a crack in a design domain changes the optimal topology. It has been shown that the PD-TO is a robust and effective tool in finding optimal topologies for structural engineering applications.

Other research streams in this area include design of Fiber Metal Laminates (FMLs) and Structural Power Composites (SPCs). Fiber metal laminates (FMLs) are hybrid composite structures based on thin sheets of metal alloys and plies of fiber reinforced composite materials and they exhibit high strength, low density, excellent corrosion and moisture resistance, high fatigue resistance and energy absorbing capacity, and great impact resistance compared to monolithic materials and fiber-reinforced composites. The stacking sequence of metal layers and the fiber direction of composite layers in FMLs is one of the governing parameters for the direction of delamination. Integration of the thermal management in SPCs which are batteries designed to bear mechanical loads, is still an emerging area of research. The high heat generation and constrained space results in accumulation of heat during the operation, which may cause volume expansion or even explosion. To address the heating challenge, a multidisciplinary design optimization framework is being considered, including battery thermodynamics, fluid dynamics, materials and structures, and lifetime models.

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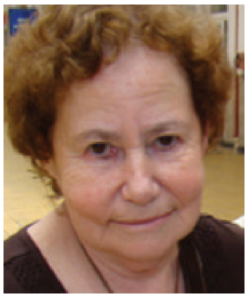
Nanoplasmonic Materials and Applications



SIMONA BADILESCU, PhD

Dr. Badilescu is a senior scientist with a background in physical chemistry and a rich experience in teaching and research. She received her PhD from the University of Bucharest (Romania) and specialized in molecular spectroscopy, surface science, and analytical applications of infrared spectroscopy. After three years of teaching in Algeria, she joined the Spectroscopy Laboratory of the Université de Montréal in Canada, and later on, a multidisciplinary research group at the University of Moncton in New Brunswick. Since 2006, she has been part of the Optical-Bio Microsystems Lab at Concordia University in Montreal. Her research interest is focused on nanomaterials, plasmonic sensing, interaction of nanoparticles with cells, Indian traditional medicines, etc. Badilescu is the author of several books and book chapters and almost 300 articles and conference papers.

MUTHUKUMARAN PACKIRISAMY, PhD, FNAI, FINAE, FCAE, FEIC, FASME, FIEI, FCSME

Dr. M. Packirisamy is a Professor and Concordia Research Chair at the Department of Mechanical Engineering at Concordia University and Director of the Micro-Nano-Bio Integration Center and Optical Bio Microsystems Lab. He a member of Royal Society of Canada College and Fellows of National Academy of Inventors (US), Indian National Academy of Engineering, Canadian Academy of Engineering, Engineering Institute of Canada, American Society of Mechanical Engineers, Institution of Engineers India, Canadian Society for Mechanical Engineering He is a recipient of CMSE's I.W.Smith award, Concordia University Research Fellow, Petro Canada Young Innovator Award and ENCS Young Research Achievement Award. He works in the multidisciplinary area of micro-nano-integrated-Lab-on-Chips. He is a member of the editorial boards of Nature Microsystems Nanoengineering, Science Research, Nature Scientific Report, Applied Sciences, Micromachines, and Aerospace Sciences and Technologies.

IMAGES COURTESY OF THE RESEARCHERS

ALMOST FIFTEEN YEARS PASSED SINCE ON the door of our lab, a new name tag appeared: Optical-Bio Microsystem Laboratory. This tag reflected the new orientation of our research projects that gradually extended, from classical mechanical engineering projects such as those on aerospace applications, to projects that converged, more and more, towards bio sciences. Among these projects, those on pollen grains, growth hormones, exosomes and other biomolecules and biological species, not only enriched our knowledge but also considerably widened our expertise.

At the same time, new instruments were purchased and new protocols, specific to bio sciences have been implemented. As our lab focuses on developing non-invasive detection platforms for bio and aerospace applications, we have been developing and applying plasmonic nanoparticles (NPs) and structures suitable to this purpose. We investigated a quite unusual resonance, involving the conducting electrons in a confined system termed as plasmonics and, more recently, nanoplasmonics. This concerted resonance with the incoming light, having a wavelength inferior or near to the size of the nanostructure, results in the appearance of a strong absorption and scattering band in the UV-Visible wavelength range of the spectrum of noble metals, called "plasmon band", or Localized Surface Plasmon Resonance (LSPR) band. Its position strongly depends on the size and shape of the nanoparticles or structures, their morphology and composition as well as on the local dielectric environment. Taking advantage of the extreme sensitivity of the position of the plasmon band to the surrounding environment, highly accurate and selective label-free biosensing methods have been developed and explored in our lab, by using a range of plasmonic platforms based on gold nano-islands and gold-polymer nanocomposites as well as microfluidic chips for point-of-care (POC) clinical analysis[1]. This article describes various plasmonic platforms and material platforms, such as in-situ and ex-situ nanocomposites, in-situ and ex-situ synthesis of nanoparticles, gold decorated carbon nanotubes and flexible nanocomposite platform that were used for aerospace applications, and detection of bovine growth hormones, exosomes and other biological species[2-5].

Nanoparticles with different shapes and sizes have been prepared by various chemical and biological methods, through both traditional and microfluidic synthesis. To this purpose, microfluidic devices fabricated in our lab, using glass or/and polymers such as Polydimethylsiloxane (PDMS), were used. The nanoparticles synthesized in a microfluidic environment have been found uniform, with a narrow size distribution and, therefore, suitable for sensing applications. Gold and silver nanospheres, prepared on glass and PDMS substrates by thermal convection and in-situ methods, and subsequently, treated thermally at high temperatures to form nano-islands, have been proved to be ideal building blocks for elaborate plasmonic platforms. By developing sensing protocols adequate for the target biomolecules and biological species, we were able to detect them with high sensitivity and accuracy. The figures of merit of the analytical methods were additionally enhanced by transferring the detection protocol in a microfluidic environment. In this way, the amounts of chemicals were, substantially, reduced and the time of the analytical process became much shorter. Novel platforms, called surface gold nanocomposites were also developed, by introducing gold nanoparticles (AuNPs) into the surface layer of polymers such as PDMS. Another

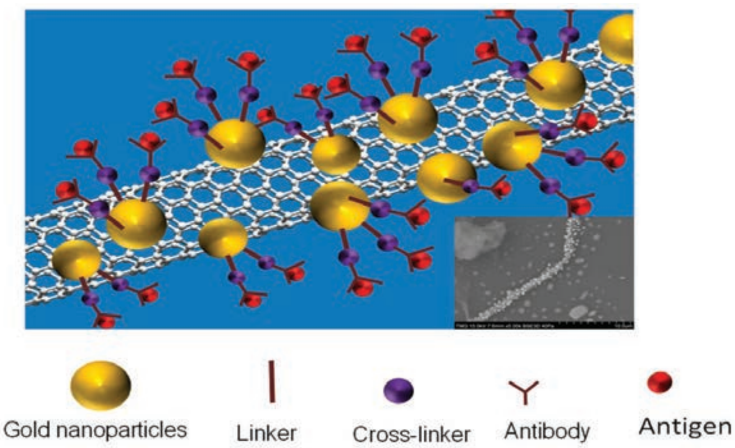


FIG. 1: DIAGRAM SHOWING THE AU – MWCNT NANOCOMPOSITE PLATFORM FOR THE DETECTION OF RECOMBINANT BOVINE GROWTH HORMONE (RBST)

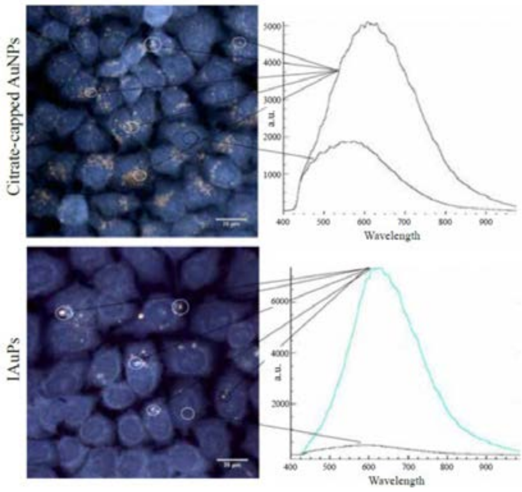


FIG. 2: HYPERSPECTRAL MICROSCOPY IMAGES OF HELA CELLS WITH INCINERATED GOLD PARTICLES (IAUPS) AND CITRATE-CAPPED AUNPS ARE SHOWN. THE CORRESPONDING SPECTRAL PROFILES FOR A SELECTED PARTICLE CAN BE SEEN IN THE RIGHT SIDE OF THE IMAGE.

interesting plasmonic platform, gold decorated Multiwall Carbon Nano-tubes (MWCNTs) were prepared and used for the detection of traces of bovine growth hormone in milk, and this sensitive method contributed considerably to the safety of milk and milk products.

In addition to using the plasmonic nanoparticles for analytical purposes, a completely novel research field has been developed in our lab, namely, intracellular plasmonics. This project aimed to investigate the interactions between different nanoparticles and human cells as well as their possible toxic effects. A new technique, hyperspectral microscopy was used to evaluate the distribution of gold nanoparticles incubated into the cells, principally, ancient nano metal bhasmas, nanospheres and nanostars. The position of the gold plasmon band reflects the interactions of gold nanoparticles with different subcellular systems, including particle-nucleus interactions. Our results revealed the effect of the different intracellular interactions on the aggregation pattern of gold nanoparticles, inside the cells. This novel technique opens the door to intracellular plasmonics, an entirely new field, with important potential applications in life sciences. Similarly, the characterization of AuNP inside the cell was validated using traditional methods such as light microscopy and scanning electron microscopy. Under the conditions studied in this work, gold nanoparticles were found to be non-toxic to HeLa (cervical cancer) cells.

Even though there are numerous applications of AuNP, the issue of their toxicity is still debated in the scientific community. It is well established that the cytotoxicity and the mechanism of cellular uptake of nanoparticles depend on their size, shape, and surface charge. Moreover, the incubation time and the concentration of AuNPs are key parameters controlling the internalization of nanoparticles and their effect on the cells. While gold itself may be non-toxic, the traces of surfactants and other molecules used for the synthesis of nanoparticles may affect the viability of cells. AuNPs show a characteristic strong LSPR band in the visible spectrum that can be seen in the hyperspectral profile of internalized NPs. Taking into account the dependency of the position of Au plasmon band on the surrounding environment, we have postulated the idea that the spectral profile of NPs located close to, or in the nucleus, should be different from that of particles situated at the periphery of the cell. This is based on the different environments surrounding NPs. This novel idea of intracellular diagnosis through plasmonic properties of AuNPs could open the door to many applications[6]. The effect of subcellular systems on the spectral profile of the internalized NPs could reveal the conditions of cells and subcellular organelles. In addition, the study of the long- and short-term biological effects of gold nanoparticles will contribute to the understanding of their biological behavior and will advance nanotechnology for biomedical applications.

Gold nanoparticles (AuNPs) are used for a number of imaging and therapeutic applications in east and western parts of the world. For thousands of years, the traditional Indian Ayurvedic approach to healing involves the use of incinerated gold ash called Swarna Bhasma, prepared with a variety of plant extracts and minerals, depending on the region. We have investigated the incinerated gold particles (IAuPs) in HeLa (human cells derived from cervical cancer) and HFF-1 (human foreskin fibroblast cells) in comparison to synthesized citrate-capped gold nanoparticles. We found that, while individual IAuP crystallites are around 60 nm in size, they form large aggregates with a mean diameter of 4711.7 nm, some of which can enter cells. Fewer cells appeared to have IAuPs compared to AuNPs, although neither type of particle was toxic to cells. Imaging studies revealed that IAuPs were present in vesicles, cytosol, or in the nucleus. We found that their nuclear accumulation likely occurred after nuclear envelope breakdown during cell division. We also found that larger IAuPs entered cells via macropinocytosis, while smaller particles entered via clathrin-dependent receptor-mediated endocytosis[7].

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Multi-Scale Mechanics of Ceramic-Based Materials:

Recent Advancements and Important Challenges

INTRODUCTION

Development of better-performing and longer-lasting advanced ceramics and ceramics-based composites are important in Canadian defence, aerospace, energy, and manufacturing industries, where these light-weight materials are widely used in extreme environments (e.g., high-speed tool wear, vehicle armor, space debris shielding). Recent advancements in additive manufacturing (e.g., via laser-additive[1] and impact deposition) has enabled fabrication of spatially tailored microstructures (e.g., composition, porosity) and architectures[1] that have resulted in increased functionality and performance (e.g., longer-lasting thermal barrier coatings). At the same time, industry-ready and university-accessible fabrication capabilities have energized creative design pursuits that make use of understanding foundational structure-property-performance relationships in materials. At the core of these new understandings is experimental and computational mechanics, whose fields have been driven by developments in new advanced diagnostics (e.g., laser-based probes[2]) and multi-scale physics-based modelling approaches (e.g., phase-field[3]). This article will outline recent progress in experimental and computational mechanics of ceramic-based materials, and will identify important challenges for further scientific and practical gains in these areas.

RECENT ADVANCEMENTS

Fundamentally, experimental and computational mechanics of materials research focuses on understanding structure-property-performance relationships. The goal is to determine the length-scale and time-scale dependent failure mechanisms within materials for a given loading situation (e.g., ballistic impact). Once understood, we seek to improve material performance by controlling how they fail, and this is accomplished through design and fabrication. In some applications, one seeks to promote failure in a controlled manner in order to improve performance (e.g., transparent ceramic windshields), while in other cases one seeks to suppress failure in order to improve performance (e.g., armor). Typically, a "mechanics" researcher will lay out failure mechanisms of interest in a length scale vs. time scale plot, where the mechanisms are mapped at their inherent scales of action. An example of a mechanism map from the author's research program is shown in *Figure 1*, where the experimental or computational approach is also listed for each bubble. In this example, development of multi-functional protective armor is the "end-use" of the research, although similar maps could be constructed depending on the application. The main takeaway from *Figure 1* is that there exists both regionality and synergy of the types of experiments and models that are needed at different length scales to understand the failure processes that govern performance of protective structures made of ceramics-based materials. The following two sub-sections outline some of the most exciting recent advancements in experimental and computational mechanics of ceramic-based materials.

EXPERIMENTAL MECHANICS

Recent advancements in diagnostics and tools have enabled experimental mechanics researchers to probe material responses at increasingly smaller length scales and faster time scales (towards the bottom left in *Figure 1*). In impact mechanics, this has been driven by the need for a more fundamental understanding of mechanisms at these scales (e.g., phase transformation[3]), which have been shown to be important in impact performance (e.g., ballistic protection). Examples of length-scale dependent failure processes and experimental approaches from the author's research program are shown in *Figure 2*. Experimentally, new test setups are being developed that can be placed inside scanning (< 100 μm) or transmission electron microscopes (< 100 nm), and these in situ capabilities are used to yield new insights into sub-grain and atomistic scale deformation behaviors (e.g., twinning). Across the world, synchrotron facilities are being utilized to perform, for example, in situ x-ray phase contrast imaging and diffraction measurements in order to reveal new insights occurring inside of materials during deformation (e.g., crack tip propagation[4]). Scalable and high through-put impact facilities are becoming more common at universities (e.g., laser shock), and these are providing rapid assessments of material design strategies. Correspondingly, new ultra-high-speed cameras are becoming more widely available that enable capturing events that occur over a few microseconds, and these capabilities are providing new insights into important dynamic failure processes that influence material performance (e.g., fracture growth rates[4]). Very recently, laser-based diagnostics capable of acquiring data at sub-nano-second rates (e.g., Photon Doppler Velocimetry) that were previously only available at the US Department of Energy Laboratories are gradually being developed in academic research facilities[2]. Photon Doppler Velocimetry, as the example, is an interferometer system that measures out-of-plane surface velocity spectro-

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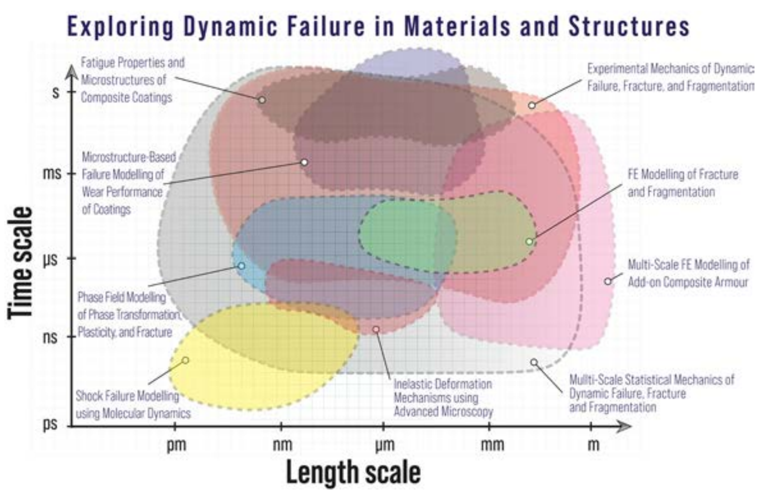

FIG. 1: A MAP OF THE IMPORTANT SCALE-DEPENDENT FAILURE MECHANISMS NEEDED TO UNDERSTAND STRUCTURE-PROPERTY-PERFORMANCE RELATIONSHIPS IN MULTI-FUNCTIONAL CERAMIC-BASED PROTECTION SYSTEMS. THE MECHANISMS ARE MAPPED AT THEIR INHERENT SCALES OF ACTION AND THE EXPERIMENTAL OR COMPUTATIONAL MECHANICS APPROACH IS LISTED FOR EACH BUBBLE.

grams spanning ~1 m/s to >10 km/s, enabling simultaneous measurement of nano-second (e.g., phase transitions in ceramics[3]) to milli-second events (e.g., structural bending). Coupled with these new diagnostics is greater capabilities and access to low-cost data analysis tools (e.g., digital image correlation software; signal processing toolboxes in Matlab) that can be used to better extract key insights into structure-property-performance relationships, and, more importantly, inform computational models describing these behaviors at previously in-accessible length and time scales (described next).

COMPUTATIONAL MECHANICS

Recent advancements in computational mechanics have focused on development of highly-parallelized multi-scale models that provide increasingly accurate structural response predictions (towards the right in *Figure 1*). Examples of length-scale dependent mechanisms and computational modelling approaches from the author's research program are shown in *Figure 2*. Increasingly, computational mechanics models are being validated by time-resolved multi-dimensional data acquired from experiments that have informed about important failure processes (e.g., crack growth[4]), and microstructural features and evolutions. An increase in access to computing resources (e.g., Compute Canada) is enabling more detailed and explicit modelling of the length-scale dependent failure features (e.g., phase changes[3]) towards the goal of higher fidelity models. At smaller length scales (<nm), molecular dynamics simulations with quantum considerations are being used to provide insights into initiation and growth of crystal lattice plasticity[5]. The integration of sub-scale information into higher scale continuum-based models (e.g., finite element) is becoming more common through homogenization approaches[6], and this is leading to improved predictive capabilities. At the structural length scales (~cm to ~m), richer experimental data sets, acquired through wider access to in-situ diagnostics, are driving the refinement of models to provide more quantitative insights into "performance" (e.g., projectile erosion rates) beyond previously mostly qualitative assessments. Across all length scales, open source platforms (e.g., FEniCS project) with capabilities for solving highly parallelized multi-scale models are gaining popularity. These platforms are driving new ways of thinking about solving constitutive models (e.g., Fast Fourier Transform analysis[7]) and data visualization. Altogether, recent advancements in multi-scale modeling has yielded insights into spatially- and temporally-evolving failure processes that are not easily accessible through experimentation (e.g., phase transformation leading to dynamic fracture[3,4]). These processes are important to understand and, eventually, control in order to improve the performance of ceramic-based materials in the future.

IMPORTANT CHALLENGES

Further advancements in ceramic-based materials development will be driven by improvements in multi-scale computational design tools, and their wider adoption into industry. Computationally, models need to be faster, contain more physics across length scales, and be more robustly validated with experiments. To address challenges with having faster models, open source platforms (e.g., FEniCS, GROMACS 4.5[7]) offer opportunities for highly parallelized and computationally-efficient numerical algorithms that are more industry-friendly. To refine these models, efforts are needed to address challenges with passing information from the sub-element to multi-element scales (e.g., implicit damage to explicit fracture[8]; discrete to continuum behaviors[9]), where machine learning-based approaches offer a promising means for scale-bridging and homogenization[6]. At the same time, gaps in our knowledge on failure evolution during history-dependent loading and multi-functional behaviors (e.g., coupled thermal-mechanical) need to be addressed before use in most industrial applications. Once models are developed, efforts are needed to overcome current challenges with model validation by improving the robustness of validation with experimental data by, for example, comparing temporally- and spatially-resolved field measurements (e.g., temperature), and better evaluating and appreciating inherent variability and stochasticity in both experiments and models (e.g., real microstructures accounting for grain and boundary features[10]). To bolster experimental validation, concerted efforts are needed to develop and support national research facilities with specialized in-situ measurement capabilities at increasingly smaller length scales and faster time scales needed to overcome gaps with our fundamental understanding of material behaviors (e.g., synchrotron[4], SEM-assisted micro-mechanical testing). When completed, these higher fidelity multi-scale models will provide new insights into the important mechanisms that govern performance of ceramic-based materials, and, in turn, can guide design of better-performing advanced materials with tailored microstructures and chemical compositions. Finally, to fully utilize new computational design tools towards the goal of becoming more globally competitive in engineering and manufacturing, there is a need to establish larger-scale industrial ceramic fabrication facilities in Canada (e.g., additive and hot-pressing) that can capitalize on our nation's knowledge in manufacturing and access to raw materials.

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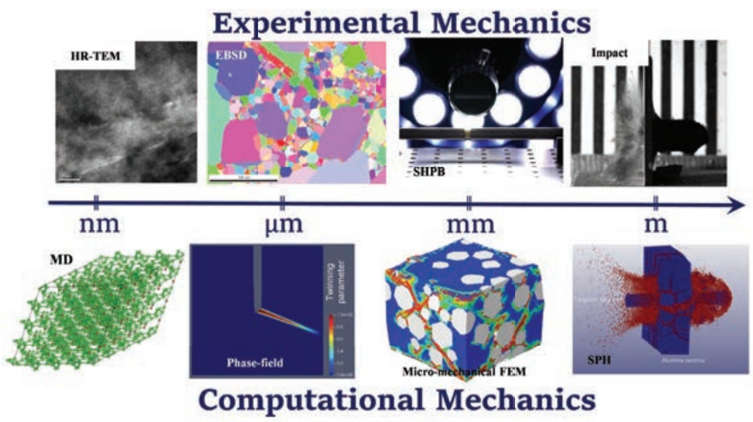

FIG. 2: A SCHEMATIC OF LENGTH-SCALE DEPENDENT FAILURE PROCESSES NEEDED TO UNDERSTAND STRUCTURE-PROPERTY-PERFORMANCE RELATIONSHIPS IN MULTI-FUNCTIONAL CERAMIC-BASED PROTECTION SYSTEMS. THE FIGURE HIGHLIGHTS RECENT ADVANCEMENTS IN IMAGING AND DIAGNOSTICS FOR EXPERIMENTAL MECHANICS, AND COMPUTATIONAL MECHANICS APPROACHES FOR MULTI-SCALE PREDICTIVE MODELLING. FOR EXPERIMENTS, EXAMPLES INCLUDE: IMAGING OF PHASE TRANSFORMATION IN NANO-GRAINED TIAL/TI_3AL-AL_2O_3 CERMETS USING HIGH-RESOLUTION TRANSMISSION ELECTRON MICROSCOPY (HR-TEM); CHARACTERIZATION OF GRAIN FEATURES IN BORON CARBIDE USING ELECTRON BACKSCATTER DIFFRACTION (EBSD); TESTING OF AN ARCHISTRUCTURED CERAMIC USING A SPLIT-HOPKINSON PRESSURE BAR (SHPB) APPARATUS; AND IMPACT TESTING INTO BORON CARBIDE CERAMIC TILES. FOR MODELLING, EXAMPLES INCLUDE: PHASE TRANSFORMATION MODELLING IN BORON CARBIDE USING MOLECULAR DYNAMICS (MD); MODELLING TWINNING IN BORON CARBIDE USING PHASE-FIELD APPROACHES; MICRO-MECHANICAL FINITE ELEMENT MODELLING (FEM) OF AL-AL_2O_3 COMPOSITE BEHAVIOR; AND MODELING IMPACT INTO ALUMINA CERAMICS USING A SMOOTH PARTICLE HYDRODYNAMICS (SPH) FRAMEWORK.

Bioinks for Bioprinting

INTRODUCTION

Bioinks are typically formulations of biomaterials and living cells, along with growth factors or other biomolecules. Bioprinting is an emerging technique used to create three-dimensional (3D) cell-incorporated constructs from bioinks (*Fig. 1)* with architectures and mechanical / biological properties that mimic those of native human tissue or organs[1,2]. Bioprinted constructs have been widely applied in biomedical engineering, including tissue engineering[2,3] and combating infectious diseases[4]. Successful bioprinting of constructs and their subsequent applications rely on the properties of the formulated bioinks, including the rheological, mechanical, and biological properties. This article reviews the development of bioinks for bioprinting, focusing on bioink synthesis and characterization, as well as the influence of bioink properties on bioprinting. Key issues and challenges are also discussed along with recommendations for future research.

BIOINKS AND PROPERTIES

Bioinks have been formulated or synthesized widely from polymers. Polymers are organic biomaterials possessing long chains with high water content, thus being able to provide a hydrated tissue-like environment that supports cell functions (including cell attachment, proliferation and differentiation) and tissue regeneration. Polymers are either natural or synthetic; natural polymers (e.g., alginate and collagen) have the intrinsic capability to support cell functions, while synthetic polymers (e.g., polycaprolactone (PCL) and polylactic acid (PLA)) are usually biologically inert, but exhibit strong and robust mechanical properties[2]. For bioprinting, polymers, available in forms of gels, powders, and/or particles, are often prepared in solution form by using water or other solvents. Polymers are either water soluble or non-water-soluble; a soluble polymer can be directly dissolved into water-based solvents, while a non-water-soluble polymer needs to be either dissolved in special organic solvents, e.g., chloroform, or thermally melted at elevated temperature[2].

Important bioink properties for bioprinting include rheological (or flow/deformation) behavior, physical properties, cross-linking mechanisms, mechanical properties, and biological properties. The flow behavior of a bioink, associated with its resistance to flow, is typically characterized by the relationship between the shear stress and shear rate within the bioink[5,6]. Bioink flow behavior can be regulated by polymer concentration, cell density, and temperature, with an example of an alginate-based bioink illustrated in *Fig. 2*. Notably, a bioink may also exhibit

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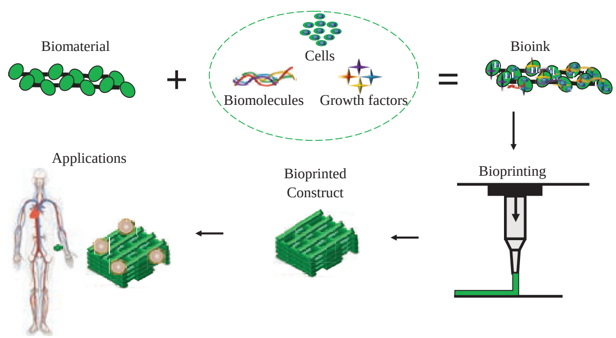

FIG. 1: CONSTRUCTS PRINTED FROM BIOINKS AND APPLICATIONS.

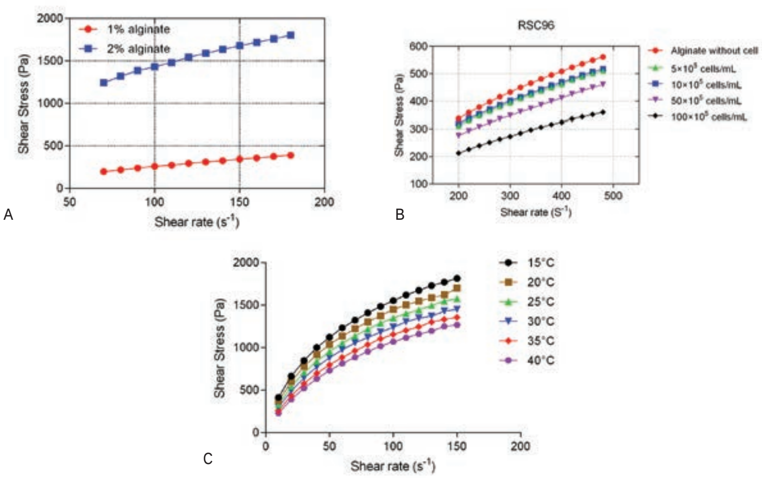

FIG. 2: FLOW BEHAVIOR OF ALGINATE-BASED BIOINK CHANGING WITH ALGINATE CONCENTRATION (A), CELL DENSITY (B), AND TEMPERATURE (C) [5].

both viscous and elastic characteristics when undergoing deformation. The viscoelastic properties are, typically, characterized by the storage modulus (for the energy stored) and loss modulus (for the energy dissipated)[2].

The surface tension and wettability of a bioink are important physical parameters for bioprinting. The surface tension of a bioink is the internal force exerted on the bioink surface, which plays an important role in the formation of bioink filaments once printed[2,7]. Wettability is the ability of the bioink to maintain contact with a solid surface, which affects the structure of the first layer of bioink deposited on the printing bed[2,7]. In bioprinting, one may need to crosslink the polymer solution, once printed, to form a gelled hydrogel so as to maintain the printed structure. The most commonly-used mechanisms or methods to crosslink bioinks include ionic, thermal, and photo crosslinking[2]. The mechanical properties of a gelled bioink typically refer to its mechanical strength and degradation. Like other biomaterials, bioink mechanical properties are characterized by the relationship between applied force and resulting deformation by means of compressive/tensile testing[2,8]. Biological properties of a bioink refer to its ability to support cell functions and tissue regeneration, while having limited or no negative effects (such as inflammation) on the host system. The biological properties of a construct are typically evaluated by in vitro (or in glass) and/or in vivo (or in animal and human) tests[1,2].

BIOINKS AND BIOPRINTING

Through bioinks, bioprinting allows for the incorporation of living cells within printed constructs. Notably, during the bioprinting process, cells are subjected to sustained process-induced forces, such as pressure, shear stress, and extensional stress, which cause the deformation and breach of cell membranes. Although cells have the elastic capability to resist a certain level of mechanical force, cell membranes may lose their integrity if the applied force exceeds a certain threshold; as a result, cells may be damaged and even lose their functionality and viability[9]. Meanwhile, during the bioprinting process, bioinks, once printed, are still in solution or semi-solution form, which can flow or spread on the print bed; as a result, the printed structure may become different from its design *(Fig. 3)*; the degree of such a difference is used to characterize one perspective of bioprinting performance, termed printability[2,10].

Bioink properties are critical to bioprinting performance, including the aforementioned cell viability and printability. Research has shown that the rheological behavior of a bio-ink has a significant effect on its printability[2,10,11]. The more viscous the bioink solution, the better printability it has as high viscosity tends to reduce the bioink flow/spreading. On the other hand, encapsulated cells survive better in less viscous bioink solutions; also less viscous bioinks require relatively small mechanical forces

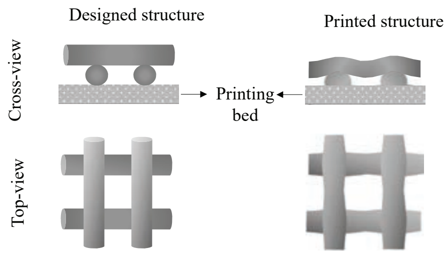

FIG. 3: SCHEMATIC OF THE DIFFERENCE BETWEEN DESIGNED AND BIOPRINTED STRUCTURES: CROSS-VIEW (A) AND TOP-VIEW (B).

for bioprinting, thus reducing process-induced forces and preserving cell viability. Research has also illustrated that the bioink crosslinking mechanism used and the mechanical properties once crosslinked, have significant effects on both cell viability and printability[2,12]. Rapid crosslinking of bioink is desired to printability. It is known that the printed constructs provide cells with a biomechanical environment for supporting cell functions and tissue regeneration. Notably, over time the polymer in the printed construct degrades, decreasing the mechanical strength; concurrently the cells grow and the tissue regenerates within the construct, imparting the mechanical strength. As a result, the mechanical strength of the construct is not constant but dynamic, or changes with time. It is generally accepted that the mechanical strength of a constructs should be similar to that of the tissue/organ being repaired for best support of cell function and tissue regeneration.

CONCLUSIONS AND FUTURE RESEARCH

Formulated from biomaterials and living cells, bioinks have been widely used in bioprinting to create 3D cell-incorporated constructs for biomedical engineering applications. Both natural and synthetic polymers have been used to formulate and prepare bioink. Bioink properties including rheological / mechanical / biological properties have been illustrated to be important to the success of bioprinting. Properly regulating these properties when preparing bioinks allows for achievement of the desired bioprinting performance.

Both natural- and synthetic-polymer bioinks have advantageous properties for bioprinting, including the biological activity of natural bioinks and superior printability of synthetic bioinks. While material science continues in developing and synthesizing new polymer bioinks with more appropriate properties for bioprinting, research has also begun to use two or more polymers or composite polymers to formulate bioinks, e.g., bioinks composed of alginate and gelatin[11]. Also, composites with the incorporation of inorganic fillers, e.g., hydroxyapatite to PCL for improved mechanical properties, carbon nanotubes for improved electrical properties, and addition of growth factors for improved biological properties, have been drawing considerable attention[2,3].

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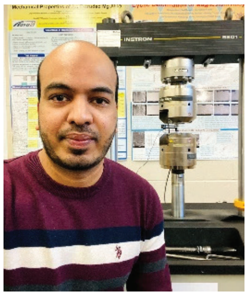

SOHAIL MOHAMMED, SMCSME

Mohammed is a PhD candidate in the Department of Mechanical and Industrial Engineering at Ryerson University (2017-present). His research focuses on advanced materials and their cyclic deformation, including metal matrix composites, cast alloys and fiber-reinforced composites. He is also involved in the research in the area of welding and joining.

Prof. ZONGYI MA , PhD

Dr. Ma is a Professor in the Institute of Metal Research, Chinese Academy of Science, Shenyang, China. He is an internationally acknowledged leader in the area of friction stir welding and processing, and metal matrix composites. He has published 350 peer-reviewed journal papers, with 17,000+ citations based on the Web of Science. He has written several highly-cited review papers, including "Friction stir welding and processing", Materials Science and Engineering – Reports*, 2005, 50, 1-78. He is Co-Editor-in-Chief of* Materials Characterization*, and serves on editorial boards of several other highly-regarded journals such as* Materials Science and Engineering A, Science and Technology of Welding and Joining*, and* Journal of Materials Science and Technology.

Prof. DAOLUN CHEN, Dr.rer.nat., PhD, PEng, AFCASI, FIMMM, FCSME, FCIM, FCAE

Dr. Chen is a Professor in the Department of Mechanical and Industrial Engineering, Ryerson University, Toronto. He is a world-leading researcher in the mechanical behavior of materials. Dr. Chen has authored 628 papers, including 342 refereed journal articles. His pioneering work on metal matrix nanocomposites leads to a well-known method that bears his name. He is a fellow of Canadian Academy of Engineering and several other professional societies, and a recipient of many prestigious awards, including the G.H. Duggan Medal, Canadian Metal Physics Award, MetSoc Award for Research Excellence, MetSoc Distinguished Materials Scientist Award, Premier's Research Excellence Award, etc. He currently serves on editorial boards of 28 highly-regarded journals.

IMAGES COURTESY OF THE RESEARCHER

BIMODAL-GRAINED METAL MATRIX NANOCOMPOSITES:

A NEW CLASS OF ADVANCED MATERIALS WITH SUPERIOR MECHANICAL PROPERTIES

THE PROBLEM STATEMENT: STRENGTH-DUCTILITY TRADE-OFF DILEMMA

The relentless quest for manufacturing lighter, stiffer and more durable new products has constantly driven the development and application of advanced materials with an excellent combination of mechanical properties. However, the strength-ductility trade-off has been a long-standing dilemma in materials science. At a microscopic level, materials are composed of tiny crystallites called grains that control their properties. Based on the idea that "smaller is stronger" (the well-known Hall-Petch effect of grain refinement strengthening), fine-grained materials are able to withstand higher loads due to the presence of stronger and greater numbers of grain boundaries that impede the motion of dislocations. In contrast, coarse grains in materials can promote deformation and improve ductility because of a higher dislocation storage capacity.

Throughout the previous two decades, nanostructured / ultrafine-grained materials have been extensively studied due to their high strength. However, their application has been limited as a result of their low ductility. As such, a judicious combination of fine and coarse grains, referred to as bimodal grain distribution, has been proposed to accommodate deformation and thus achieve a synergetic improvement in strength and ductility. This emerging class of bimodal-grained materials promises to resolve the strength-ductility trade-off predicament, and thus has attracted considerable interest, especially in the automotive and aerospace sectors.

BIMODAL-GRAINED MATERIALS: EXTRAORDINARY STRENGTH-DUCTILITY SYNERGY

Professor Daolun Chen's group at Ryerson University, in collaboration with Professor Zongyi Ma's group at the Institute of Metal Research, Chinese Academy of Sciences, is working on a unique bimodal-grained material fabricated via two-step high-energy ball milling (HEBM) and powder metallurgy, followed by extrusion. A schematic of the fabrication process is shown in *Figure 1(a)*. The bimodal-grained materials possess domains with significantly different grain sizes and exhibit a high degree of strength-ductility synergy when compared to their unimodal-grained counterparts, as outlined schematically in *Figure 1(b)*. The difference in the grain sizes range from nanoscale to microscale. Owing to the huge variations in the size, geometry, and nature of the domains/grains, these mate-

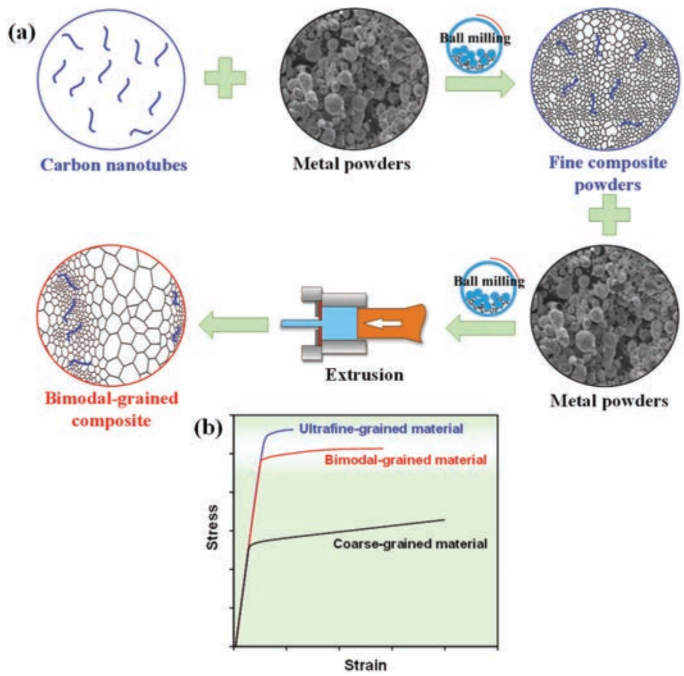

FIG. 1: SCHEMATIC DIAGRAMS ILLUSTRATING (A) FABRICATION PROCESS OF BIMODAL-GRAINED NANOCOMPOSITES, AND (B) FLOW CURVES OF MATERIALS WITH DIFFERENT GRAIN SIZE DISTRIBUTIONS.

rials can be classified as heterogeneous materials. The concurrent presence of hard and soft regimes in the bimodal-grained materials leads to a synergetic improvement in strength and ductility caused by the favorable delay in the onset of plastic instability, resulting in a higher strength, greater ductility and work-hardening rate. A significant increase in the tensile strength has been achieved in the bimodal-grained alloy without an obvious trade-off in the ductility, in comparison with the unimodal-grained counterparts. The volume fraction of coarse grains in the bimodal-grained material is a key factor for increasing ductility, and numerical simulations can be performed to optimize the proportion of coarse and fine grains and tailor an appropriate bimodal-grained material.

BIMODAL-GRAINED METAL MATRIX NANOCOMPOSITES

The strength of bimodal-grained materials can be further improved with the addition of reinforcement. Particulate-reinforced metal matrix nanocomposites (MMNCs) have been attractive candidate materials for aerospace, automotive and other applications. The challenges and prospects of carbon nanotube (CNT)-reinforced aluminum matrix composites are detailed in our recent invited review article published in the Hall of Fame series of Advanced Engineering Materials[1]. Reinforcing agents added in the bimodal-grained materials, such as CNTs and silicon carbide particles, open the door to a wider application of composites due to a superior combination of higher strength with ductility. Recently, we developed a bimodal-grained Al-Cu-Mg nanocomposite reinforced by CNTs. Some microstructural features and mechanical properties are presented in *Figure 2*. Electron backscatter diffraction (EBSD) and transmission electron microscopy (TEM) revealed a distinctive bimodal-grained distribution in the CNT-reinforced bimodal-grained nanocomposite *(Figure 2(a-c)),* which exhibited a significant increase in strength with a ductility of 6~7%, in comparison with the coarse-grained counterpart *(Figure 2(d))*. The underlying mechanisms of strengthening in the bimodal-grained MMNCs were explored in our recent study, in which we evaluated the dislocation density of the materials via X-ray diffraction and EBSD to estimate the strength increment[3]. Orowan strengthening (as a result of the looping of dislocations around reinforcement particles) was observed to be a predominant mechanism in the CNT-reinforced MMNCs along with modest load-bearing strengthening. Also, based on the strain energy density measurements via strain-controlled low cycle fatigue tests, we could predict the fatigue life of bimodal-grained alloys and MMNCs.

In closing, the culmination of decades of research effort is being implemented in practical applications by a simple concept of heterogeneous/bimodal grain distribution to achieve exciting concerted improvement in both strength and ductility. We believe this would just be a new beginning for developing advanced materials with superior balanced mechanical properties. In addition to our current powder metallurgy route, the novel idea of developing heterogeneous/bimodal-grained alloys and their composites could be extended to other fabrication routes such as additive manufacturing. These studies shed light on how strength-ductility synergy can be achieved via microstructural heterogeneity, thus laying the foundation for developing high-performance engineering materials for safer, lighter, and more durable load-bearing structural applications.

Professor Chen acknowledges the contributions made by his many excellent students, postdoctoral fellows, visiting scholars and collaborators, both in Canada and internationally. These contributions would not have been possible without fruitful research collaborations and financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC).

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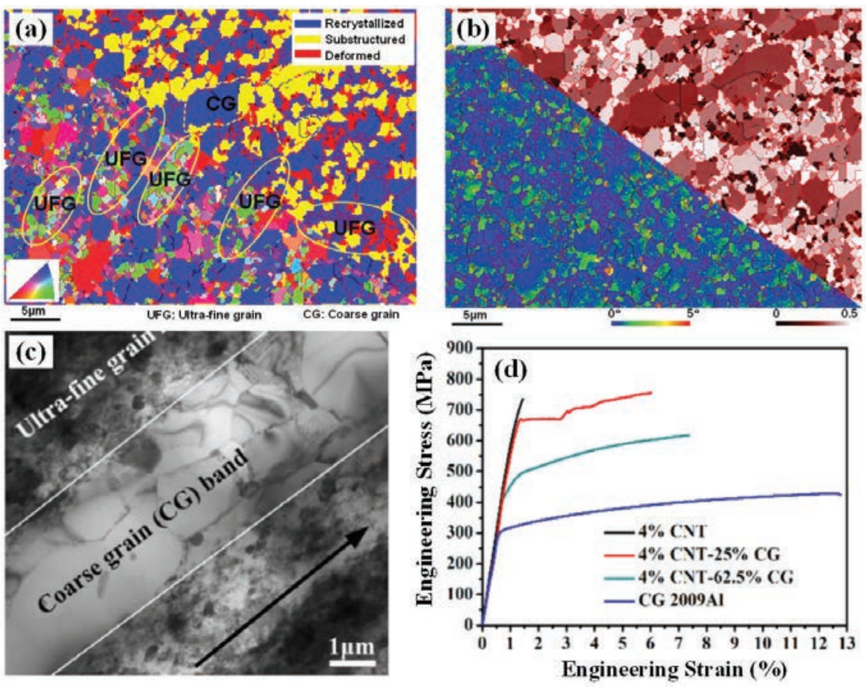

FIG. 2: (A) EBSD ORIENTATION MAPS (BOTTOM LEFT) AND THE EVOLUTION OF GRAINS (TOP RIGHT), (B) KERNEL AVERAGE MISORIENTATION MAPS (BOTTOM LEFT) AND SCHMID FACTOR MAPS (TOP RIGHT), (C) TYPICAL TEM IMAGE SHOWING THE DISTRIBUTION OF ULTRAFINE-GRAINED AND COARSE-GRAINED BANDS[2], AND (D) TYPICAL TENSILE CURVES OF COARSE-GRAINED 2009AL ALLOY AND BIMODAL-GRAINED CNT/2009AL COMPOSITE[2].

Automation Accelerating New Materials Discovery in Canada

In November 2015, world leaders met in Paris during the 21st Conference of the Parties (COP21) to discuss ambitious efforts to combat climate change, announcing a new initiative called Mission Innovation (MI). The following year, MI members launched seven Innovation Challenges, including Clean Energy Materials. This Innovation Challenge aims to accelerate the exploration, discovery, and use of new high-performance, low-cost clean energy materials. A later workshop identified the urgent need for a Materials Acceleration Platform (MAP), for accelerating advanced energy materials discovery by integrating high-throughput methods with artificial intelligence.

Canadian contributions to this goal were recently highlighted in a 2020 paper in Science Advances[1]. They describe a flexible and modular self-driving laboratory capable of autonomously synthesizing, processing, and characterizing organic thin films. Named "Ada", this system can train itself on how to find target parameters without any prior knowledge, enabling iterative experimental designs that maximize the amount of information obtained per sample. By automating material synthesis and characterization, experimental optimization studies can be machine driven and completed more rapidly. The power of Ada is demonstrated by using it to maximize hole mobility of organic hole transport materials (HTMs) commonly used in perovskite solar cells and consumer electronics. A materials optimization process which usually takes months, Ada was able to complete in less than 30 hours. Interestingly, the authors observed a non-intuitive favorable performance of high-dopant/high-annealing time films; an observation facilitated by using an autonomous platform, which searched over a larger range of doping and annealing conditions than is typically explored in studies of organic HTMs.

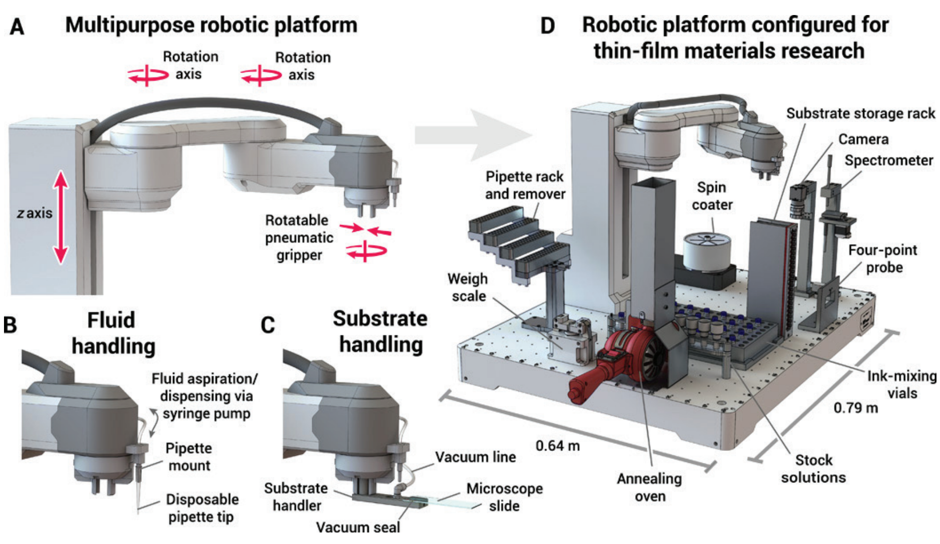

FIG. 1: THE ADA SELF-DRIVING LABORATORY (A) THE SELF-DRIVING LABORATORY IS BASED ON A MODULAR ROBOTIC PLATFORM THAT INTERACTS WITH OBJECTS USING A ROTATABLE PNEUMATIC GRIPPER ON A POLAR ROBOTIC ARM ACHIEVING 10-μm REPEATABILITY AND A MAXIMUM VELOCITY OF ~1 M/S. (B) FLUID HANDLING IS ACHIEVED USING DISPOSABLE PIPETTE TIPS THAT CAN BE PRESS-FIT ONTO AND REMOVED FROM THE ARM'S PIPETTE MOUNT BY THE ROBOT. PIPETTING WITH A MEAN ACCURACY OF 5 μl IS ACHIEVED USING A SYRINGE PUMP CONNECTED TO THE PIPETTE MOUNT. (C) SUBSTRATE HANDLING IS ACHIEVED USING A VACUUM SUBSTRATE HANDLER GRIPPED BY THE ROBOTIC ARM. (D) CONFIGURATION OF THE ROBOTIC PLATFORM FOR A SPECIFIC EXPERIMENTAL WORKFLOW IS ACHIEVED BY MOUNTING AN APPROPRIATE COLLECTION OF EXPERIMENTAL MODULES ON THE ROBOT; HERE, THE ADA PLATFORM IS SHOWN EQUIPPED FOR THE SYNTHESIS AND CHARACTERIZATION OF THIN-FILM MATERIALS (REPRINTED FROM MACLEOD ET AL., *SCIENCE ADVANCES*, 13 MAY 2020: VOL. 6, NO. 20, EAAZ8867, DOI: 10.1126/SCIADV.AAZ8867, COPYRIGHT © 2020 THE AUTHORS, SOME RIGHTS RESERVED; EXCLUSIVE LICENSEE AAAS. DISTRIBUTED UNDER A CREATIVE COMMONS ATTRIBUTION NONCOMMERCIAL LICENSE 4.0 (CC BY-NC)).

Recognizing the value of advanced materials discovery, Canada is investing heavily in this technology. Experts at Natural Resources Canada's CanmetMATERIALs research centre in Hamilton have been advancing two MAPs: E-MAP (designing new catalyst materials for clean hydrogen production and CO2 conversion) and TEG-MAP (designing new thermoelectric material for the conversion of waste heat to electricity), and have a been developing a third (3DP-MAP, focusing on the formulation and process development for 3D-printing of metals). The National Research Council of Canada and Natural Resources Canada are building a $60M expansion of the NRC Mississauga site, known currently as the Centre for Accelerated Materials Discovery and Innovation (CAMDI). The new facilities, expected to be constructed by summer 2023, will support collaborative deployment of MAPs. More recently, U of T has announced a new acceleration consortium which applies artificial intelligence to the discovery of advanced materials using self-driving labs. Overall, it is an exciting period for advanced materials, as these new development platforms promise to deliver innovations which used to take decades and hundreds of millions of dollars, in as little as one year and $1M. — *Technical Editor, Prof. Ryan Willing*

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University of Toronto Dr. Patrick Lee

Multiphase nanostructured lightweight and hybrid polymer foams and composite materials

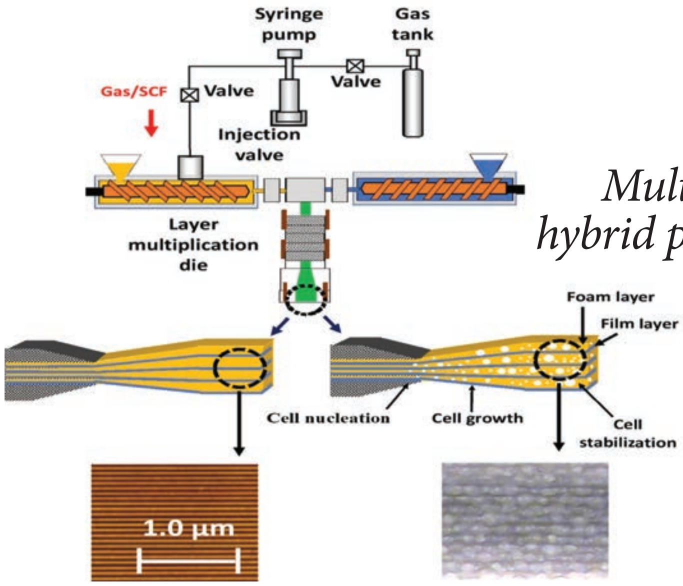


FIG. 1: ADVANCED MNL FILM AND FOAM MANUFACTURING PROCESSES FOR ACHIEVING HIGH-QUALITY MULTIPHASE POLYMER COMPOSITES.

Multimaterial polymeric composites and foams have become common in the automotive, aerospace, biomedical, healthcare, and food and electronics packaging industries. Due to their poor performance-to-weight ratios and insufficient control of gas transmission properties, however, there remain potentially productive applications for which they have not been widely adopted, such as high-performance foams and composites, and high-barrier packaging films. Dr. Lee's proposed research program will address these performance issues by developing new micro-/nano-structuring technologies that can engineer hierarchical multimaterial designs for the fabrication of nano-structured composite foams, fibres, and films by combining the synergistic effects of three processes (i.e., coextrusion, nano-fibrillation, and foaming). The outcome of this research program will be a comprehensive understanding of constrained microstructure evolutions, interphase compatibility, and embedded nanofibres on the final morphologies and properties, which will enable the creation of optimized nano-structured composites and foams.

Dr. PATRICK LEE, PhD, MCSME

Dr. Lee is an Assistant Professor in the Department of Mechanical & Industrial Engineering (MIE) at the University of Toronto. He received his PhD from U of T in 2006. Dr. Lee began his professional career at The Dow Chemical Company in 2008. He then joined the Department of Mechanical Engineering at The University of Vermont as an Assistant Professor in 2014. He joined MIE on July 1st 2018. Dr. Lee's research focus on polymer foam processing and characterization, and processing-structure-property relationships of nano-composites. Dr. Lee received the CSME G.H. Duggan Medal in 2020.

His research program is focused on understanding the process-structure-property relations of multiphase nano-structured lightweight and smart hybrid polymer foams and composite materials, which have a variety of applications in the automotive, aerospace, biomedical, energy storage, electronic device, food/electronics packaging, and the pandemic and healthcare industries. Dr. Lee's research vision includes the fabrication and processing of lightweight and smart polymers and composite systems in batch, extrusion, injection molding, bead, and compounding foam processes, the characterization of these system properties, the correlation of micro- and nano-morphological variations with macro-polymer/composite properties, and multiphysics analytical and numerical modeling of these material systems.

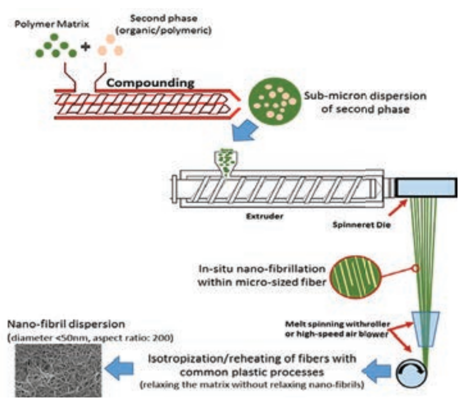


FIG. 2: ADVANCED IN SITU NANO-FIBRILLATION MANUFACTURING PROCESS FOR ACHIEVING HIGH-QUALITY POLYMER COMPOSITES.

Dr. Lee has established a world-class research program and laboratory entitled the Multifunctional Composites Manufacturing Laboratory (MCML) in the Department of Mechanical & Industrial Engineering at the University of Toronto, with focuses on developing a fundamental understanding of the process-structure-property relations of multiphase nano-structured materials through high pressure/temperature testing methods, engineering high-performance advanced composite structures using micro-/nano-structuring achieved through multiscale design, and attracting outstanding students to the lab to advance the goals of the research program. Since 2014 (U of Vermont, USA from 2014-2018 and U of Toronto from 2018 to present), he has supervised or co-supervised 7 postdoctoral scholars, 33 graduate students, and 36 undergraduates through his research program. His research group has authored and co-authored 59 research journal papers, over 100 refereed conference papers/abstracts, and 19 filed or issued patent applications.

His research group has been engaged in a number of projects that have led to the successful completion of many short-term goals and significant progress in the long-term objectives of the research program. Some of these project ideas stemmed from his postdoctoral and industrial research, but have since led to exciting new research directions for the MCML and brand-new collaborative opportunities domestically and internationally. The main research themes and projects in his group include: (i) micro-/nano-layered (MNL) film and foam technology (Fig.1); (ii) smart micro-/nano-fibre manufacturing technology (Fig.2); (iii) lightweight foam composites for various applications; (iv) new characterization methods and tools for multiphase composites and foams; and (v) microstructure evolution studies under controlled stress and a high-pressure gas/supercritical critical fluid.

For more information, visit the group at patricklee.mie.utoronto.ca.

IMAGES COURTESY OF THE RESEARCHER

University of Alberta
Dr. Dan Romanyk

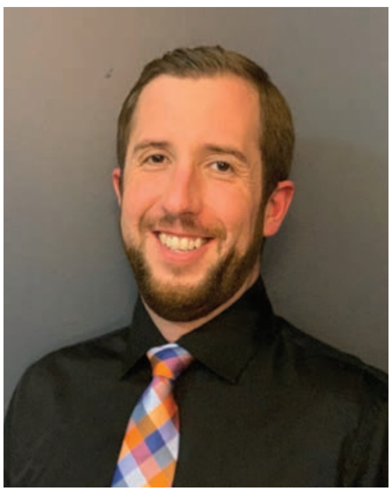
A new approach to understanding how our skull grows

Within the craniofacial environment, there are numerous conditions and clinical interventions that can greatly affect a person's day-to-day life. Such scenarios can range from the premature fusion of cranial sutures that prevents proper skull growth and requires invasive surgical procedures, or severe tooth misalignments necessitating orthodontic treatment through clear aligners or braces. Dr. Romanyk and his team are primarily interested in the mechanical characterization of biomaterials within the craniofacial environment, and particularly how biological tissues adapt when exposed to mechanical stimuli occurring in daily life (e.g. intracranial pressure) or as a result external appliances (e.g. orthodontic treatment). The knowledge gained from this work is then used to inform clinical interventions imposing external loading on tissues to improve results through a fundamental understanding of how tissues will respond.

During his PhD, Dr. Romanyk focused on establishing nonlinear viscoelastic material models of cranial suture tissue (soft connective tissue joining skull bones) under mechanical loading. Cranial suture tissue is unique in that when it is exposed to mechanical stimuli, it facilitates the remodeling and growth of surrounding bone tissue – a process critical to the growth of skulls. As such, having a true understanding of their mechanical behavior is vital when linking such results to biological adaptations (e.g. structural changes, cellular activity). Upon establishing advanced material models of suture tissue, they were then integrated into 3D full-skull simulations to better investigate the impact that orthodontic clinical interventions have on the transient behavior of suture tissue. This work was the first to integrate a nonlinear viscoelastic model of suture tissue into simulations of orthodontic treatment and provide insight as to how clinical protocols may be implemented without inducing failure of the tissue (see for example: *International Journal of Mechanical Sciences*, 2013;85:179-186 and *Scientific Reports*, 2019;9:8476).

Dr. Romanyk's team now utilizes developed expertise surrounding the mechanical modeling of suture structures to integrate with advanced imaging and bone labelling techniques towards truly understanding the link between mechanics and biological adaptations. Through utilizing high resolution X-ray computed tomography and dynamic bone labelling techniques, they are able to link the stress/strain distribution seen at suture sites with the subsequent bone formation and structural adaptations resulting from a range of mechanical stimuli (*Figure 1*). This work has involved international multidisciplinary collaborations with a range of investigators in fields of advanced imaging, biological sciences, and craniofacial surgery.

Moving forward, this work will be vital to understanding and predicting growth in the craniofacial environment, and how clinical interventions may be tailored to improving the patient-specific response. While current work has focused on studying suture site response during normal growth, future work will consider how externally applied stimuli will influence suture mechanics and the corresponding adaptations (e.g. craniosynostosis procedures or orthodontic widening of the upper jaw). Dr. Romanyk's team has the end goal of improving treatment planning for invasive surgeries (e.g. correcting premature fusion of skull bones) and the design and development of external craniofacial appliances (e.g. orthodontic expanders) through innovative foundational links between suture mechanics and the resulting biological adaptations.



PORTRAIT BY S. HERON / RESEARCH IMAGE COURTESY OF THE RESEARCHER

Dr. DAN ROMANYK, PhD

Dr. Romanyk is an Assistant Professor in the Department of Mechanical Engineering with an adjunct appointment in the School of Dentistry at the University of Alberta. He also completed his PhD and postdoctoral fellowship at the University of Alberta. Dr. Romanyk's primary areas of research surround the mechanical characterization of natural and synthetic biomaterials in the craniofacial environment, and studying the biomechanics of orthodontic treatment.

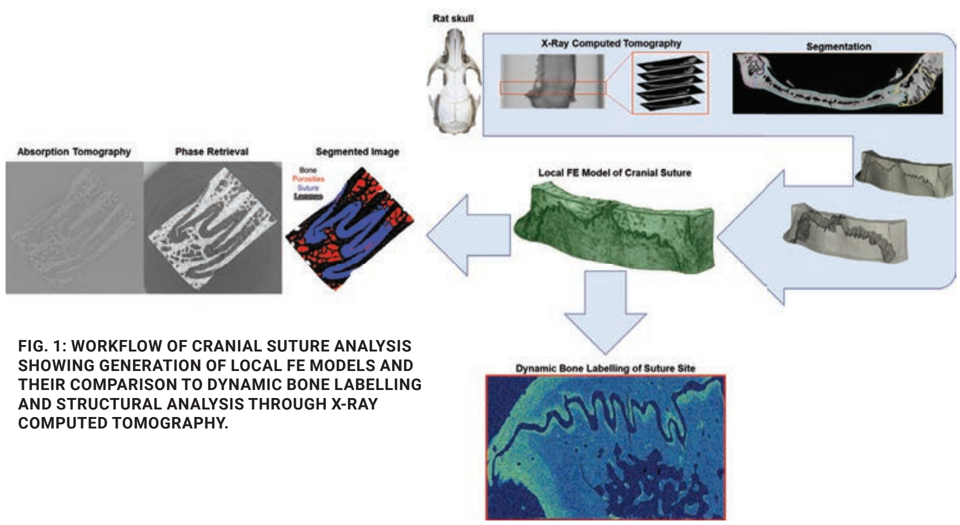


FIG. 1: WORKFLOW OF CRANIAL SUTURE ANALYSIS SHOWING GENERATION OF LOCAL FE MODELS AND THEIR COMPARISON TO DYNAMIC BONE LABELLING AND STRUCTURAL ANALYSIS THROUGH X-RAY COMPUTED TOMOGRAPHY.

IN MEMORIAM

Dr. Pearl Sullivan
(1961- 2020)

Pearl Sullivan, the University of Waterloo's former dean of engineering and the first woman to hold the position, died on November 28, 2020, after a 12-year battle with cancer. Just the fifth woman across Canada to head a school of engineering, she was a dynamic force for Waterloo Engineering and the entire University.

Under her leadership from July 2012 to December 2019, the Faculty reimagined engineering education and research with revolutionary spaces and transformative programs to ensure Waterloo remains a leader in engineering well into the future. A champion of the Faculty's work in disruptive technologies such as artificial intelligence, advanced manufacturing, nanotechnology, robotics, and wireless communications, she expanded the potential for industry collaboration and government support in key research areas.

Passionate about supporting students, she was dedicated to ensuring they had a full understanding of engineering principles as well as the tools and facilities they needed to succeed. In 2015, she launched the Faculty's Educating the Engineer of the Future Campaign and worked tirelessly to achieve its ambitious goals of building a new engineering building on the UW campus, Engineering 7 (E7), and providing students with enhanced experiences to help them achieve their aspirations. In addition to lecture halls, study areas, and special spaces for project work by students in growing undergraduate programs, E7, which opened in October 2018, includes the two-floor Engineering Ideas Clinic™ for hands-on design challenges and activities to help teach theoretical concepts.

Mary Wells, Waterloo Engineering's current dean, said Sullivan was a beloved dean, department chair, and faculty member. "She was a force of nature, always fearlessly working to advance Waterloo Engineering and opportunities for our students and faculty members," said Wells. "As a compassionate and caring leader, Pearl could rally her team to the causes that would matter most."

Feridun Hamdullahpur, president and vice-chancellor of the University of Waterloo, said he was devastated to hear of Sullivan's passing. "There is no doubt that Pearl left an indelible mark on the Faculty of Engineering and the University of Waterloo, but most importantly, on her students, friends, and colleagues," said Hamdullahpur. ''She exemplified how one can combine vision, determination, resilience, and hard work and deliver it in the most caring and passionate way. That's how Pearl did everything; she put her brilliant mind and kind heart into it."

Born in Kuala Lumpur, Malaysia, Sullivan studied both in Singapore and Canada. She received her BASc with distinction and MASc degrees in metallurgical engineering from the Technical University of Nova Scotia. After earning her doctoral degree in materials engineering from the University of British Columbia, she started her academic career at Nanyang Technological University, Singapore, in 1991. She returned to Canada in 1994 to join the mechanical engineering department at the University of New Brunswick, where she was twice honoured with the UNB Faculty Merit Award for Excellence.

In 2004, Sullivan came to the University of Waterloo as a mechanical engineering professor and served as chair of the mechanical and mechatronics engineering department from 2006 until January 2012. In 2009, she was recognized for her accomplishments with the University's Outstanding Performance Award. Sullivan was inducted into the Canadian Academy of Engineering as a Fellow last year.

In a 2019 interview, Sullivan said as dean she was interested in learning about the issues and achievements of multiple portfolios, including teaching and research, undergraduate and graduate studies, international and outreach engagements, and the entire university's workings. "I particularly enjoy developing strategy and advancement/fundraising projects and executing major strategic initiatives," she said. "But I must say, spontaneous meet-ups with our students, especially in their design and classroom activities, along the hallways and in the elevators are the most fun." When asked what advice she'd give herself as a first-year engineering student, Sullivan responded by saying, "You worked very hard to get into Waterloo Engineering, and you will work even harder to get out of Waterloo Engineering. But every bit of your sweat will be absolutely worthwhile."

Pearl devoted her life to the education of young minds and the care of her beloved family — husband Tom, a Waterloo civil and environmental engineering project manager, her son Michael (Emma), and daughters Veronica and Christina.

She will be remembered for her love of family, students, and colleagues along with her boundless energy, enjoyment of running, dancing, and fun music (especially K-pop), belief in the importance of healthy food, and her well-known disdain for doughnuts, but keen ability to have a second helping of dessert. — *Excerpted from an article by Carol Truemner*

CSME STUDENT & PROFESSIONAL AFFAIRS REPORT

THE CSME STUDENT & PROFESSIONAL AFFAIRS committees facilitate the CSME Student Chapters and new Chapters to organize events, networking and outreach activities. In a pivot to engage more membership during these online times, the CSME Professional Affairs and Student Affairs committees organized several online webinars with distinguished guests and hosted many participants.

On May 18th, our CSME webinar guest speaker will be Prof. **Alejandro Adem**, President of NSERC. The session will be moderated by Dr. **Faizul Mohee**. We are looking forward to hosting Prof. Adem for this exciting event.

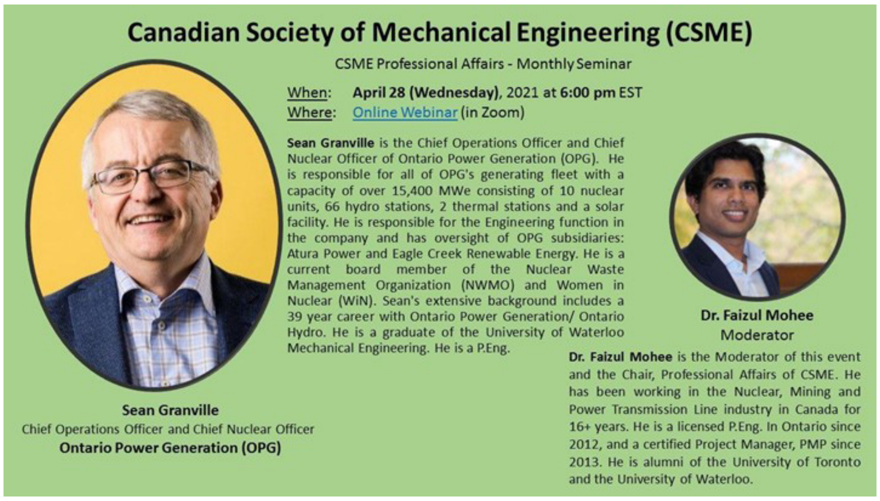
With Canada's Small Modular Reactor Action Plan and the exciting projects in the nuclear industry that are on-going, several webinars this quarter were centered on nuclear energy experts and energy specialists.

On April 28th, our CSME webinar guest speaker was **Sean Granville**, the Chief Operating Officer and the Chief Nuclear Officer of Ontario Power Generation (OPG). The session was moderated by Dr. Mohee. The attendees learned about the Nuclear industry in Canada and about Ontario Power Generation, Atura Power, and Eagle Creek Renewable Energy LLC. Engineers and Engineering students from almost all provinces of Canada, such as from Ontario (Toronto, Ottawa, Mississauga, London, Kingston), Quebec, Alberta, British Columbia, and Newfoundland, attended the event. In total, 64 CSME members attended this event.

Our January 26th, CSME webinar guest speakers included **Diane Cameron**, Director of the Nuclear Energy Division at Natural Resources Canada (Ressources naturelles Canada) (NRCAN), **Robin Manley**, Vice-President of New Nuclear Development at Ontario Power Generation, and **Andy Hayward**, Chief Nuclear Engineer at Point Lepreau Nuclear Generating Station and Director of Advanced Reactor Development at NB Power (Énergie NB). We learned a lot about the Nuclear and Small Modular Reactor (SMR) future plans and incoming SMR technologies in Canada including that Canada is a world leader in SMR. A total of 161 registered for this event, and 120 participants attended at the same peak time for this event. CSME members attended from almost all provinces of Canada attended, e.g. from Ontario (Toronto, Ottawa, Mississauga, Brampton, Ajax, Hamilton), Alberta, British Columbia and New Brunswick

On November 4th, 2020, our CSME webinar guest Speakers at this CSME event were: **Philippe Dauphin**, Director General, NRCAN, **Derek Wilson**, Vice President, NWMO, and Chair of CSME Student Affairs, Dr. M. Freire-Gormaly, Assistant Professor, York University. The session was moderated by Dr. Mohee. We learned a lot about the Nuclear Waste Management Organization, the energy and materials research at Natural Resources Canada (Ressources naturelles Canada), and on-going research on COVID-19 aerosol transmission at York University at this event. A total of 82 CSME members registered for this event, and 64 attended. CSME members from almost all provinces of Canada attended, including attendees from Quebec, New Brunswick, Nunavut, Yukon, Northwest Territoried.

WEBINAR GUEST SPEAKER: PROF. ALEJANDRO ADEM, PRESIDENT OF NSERC (HELD MAY 18), MODERATED BY DR. MOHEE.



APRIL 28 WEBINAR: SEAN GRANVILLE, THE CHIEF OPERATING OFFICER AND THE CHIEF NUCLEAR OFFICER OF ONTARIO POWER GENERATION (OPG), MODERATED BY DR. MOHEE; PRESENTATION PHOTOS, LOWER LEFT AND RIGHT.

JAN. 26 WEBINAR PANEL

The CSME Edmonton Chapter held several webinar events including an "APEGA: Ask An Expert" event on February 17, 2021 where **Jason Kalapurakal**, P.Eng., CSSGB and **Enayat Aminzadah**, APEGA's international qualifications officer discussed the entire process towards gaining a professional engineering license in Alberta. On December 8, 2020, they held a virtual networking and resume review with industry experts. Over 35 CSME members attended and provided feedback to the participants about the best approaches to improving their resumes for the next step in their careers. The CSME Chittagong University of Engineering Technology (CUET) Student chapter organized several events, including a NextScholar event to encourage new scholars from Bangladesh. NextScholar is a platform to encourage undergraduate engineering students to explore research by providing a platform for submission of research articles for presentation at an upcoming CSME CUET event. Overall, NextScholar aims at enabling students to take a leap forward towards their dream of being a scholar!

Please join as a CSME member, it is FREE for students (csme-scgm.ca/application). The Engineering Careers site (www.engineeringcareers.ca) also provides an opportunity to plan for your career. We are also looking forward to a CSME internship program for students to participate in industry.

Thank you to all the student chapter executives, volunteers and faculty mentors for your hard work! If you're interested in leading and founding a CSME student chapter at your campus, let us know. We also invite students to contribute a story to the CSME report. Contact us at marina.freire-gormaly@lassonde.yorku.ca or faizul.mohee@utoronto.ca or the CSME directly, we will walk you through the process. We are also looking to expand the CSME Student Affairs and Young Professionals Committee. If you are interested in helping lead activities locally or at the national level, please reach out.

Do you have a great idea, story or proposal to improve the CSME student programming? Feel free to share your ideas with us!

DR. MARINA FREIRE-GORMALY, PhD, EIT, LEED GA
Chair of CSME Student Affairs

Marina is an Assistant Professor at York University in the Department of Mechanical Engineering. She completed her PhD at the University of Toronto in the Department of Mechanical and Industrial Engineering. Marina's research team is investigating how COVID-19 transmits in air, and how to make energy and water systems more reliable and sustainable. Her research and teaching spans energy systems, nuclear, computational modelling and sustainability.

DR. FAIZUL M. MOHEE, PhD, P.Eng., PMP
Chair of CSME Professional Affairs

Faizul is the Director of Research at TMBNExtrados Inc. in Toronto. He completed his PhD at the University of Waterloo on mechanical anchors for composite materials. He also did a masters at the University of Toronto. He has taught a Machine Learning, Artificial Intelligence and Big Data for Manufacturing course at York University. He also taught the Materials Science course at U of T MIE. He previously worked at Hatch, WSP and projects for OPG, Bruce Power, Terrestrial Energy, Baffinland, Stornoway, SaskPower and Emera. Faizul works in research and development for the energy, mining and nuclear industries. He has been working in the Nuclear, Mining and Power Transmission Line industry in Canada for 16+ years. He is a licensed P.Eng. In Ontario since 2012, and a certified Project Manager, PMP since 2013. Faizul is passionate about research, teaching and student engagement to build smart and sustainable infrastructure that is resilient and adaptive to climate change.

Call for Nominations – 2022 EIC Awards

The Engineering Institute of Canada (EIC) is pleased to announce that it is currently accepting nominations for its 2022 senior awards and EIC fellowship inductees. The deadline for nominations is midnight, 15 November 2021 for awards to be remitted at the EIC Gala in April 2022.

The senior awards of the EIC are the highest distinctions made by the Institute and are awarded to deserving members of its technical societies:

- SIR JOHN KENNEDY MEDAL for outstanding services rendered to the engineering profession, or of noteworthy contributions to the science of engineering, or to the benefit of the Institute.
- JULIAN C. SMITH MEDAL for achievement in the development of Canada.
- K.Y. LO MEDAL for significant engineering contributions at the international level.
- JOHN B. STIRLING MEDAL for leadership and distinguished service at the national level within the Institute and/or its Constituent Societies.
- CANADIAN PACIFIC RAILWAY ENGINEERING MEDAL for many years of leadership and service by members of the Societies within the Institute at the regional, branch and section levels.
- EIC FELLOWS are inducted for excellence in engineering and services to the profession and to society.

Nomination rules and form can be found on EIC's website (eic-ici.ca/honours_awards/nomination).

About the EIC

Founded by Royal Charter in Montreal in 1887 as the Canadian Society of Civil Engineers with the mandate to disseminate technical information and experience, the society was renamed by Parliament in April 1918 as the Engineering Institute of Canada. In its first century, the EIC functioned as a learned society with members from various engineering disciplines. It is now a federation of fourteen technical societies representing the main engineering disciplines and whose mandates remain the dissemination of technical knowledge and experience and the maintenance of high standards for engineering practice in Canada.

Contact: Guy Gosselin, EIC Executive Director
ggosselin.eic@gmail.com / www.eic-ici.ca

The Canadian Society for Mechanical Engineering
A constituent society of the Engineering Institute of Canada

La Société Canadienne de génie mécanique
Une société constituante de l'Institut canadien des ingénieurs

NEWS COMMUNIQUÉ

Office of the President May 2021

The Canadian Society for Mechanical Engineering (CSME), founded in 1970, is pleased to announce the winning recipients of its regular 2021 awards. These awards may be bestowed annually to members of the society for their outstanding contributions to specific areas of mechanical engineering in Canada.

Robert W. Angus Medal

For "outstanding contributions to mechanical engineering practice in Canada, including industrial innovation, technology commercialization and creativity"

Zheng Hong (George) Zhu, PhD, FCSME
Professor, York University, ON

I.W. Smith Award

For "outstanding achievement in creative mechanical engineering within 10 years of PhD degree"

Pouya Rezai, PhD, MCSME
Associate Professor, York University, ON

Fellow of the CSME

For "excellence in mechanical engineering and significant contributions to the progress of the profession"

Daolun Chen, PhD, (new) **FCSME**
Professor, Ryerson University, ON

Call for Nominations – 2022 CSME Technical Awards

Nominations of CSME peers are currently solicited for three of the society's six technical awards, specifically for outstanding contributions to the fields of Fluid Mechanics, Solid Mechanics and Manufacturing. Members cannot nominate themselves; they must be nominated by CSME Fellows. The deadline for these submissions is **30 September 2021** (csme-scgm.ca/awards). Please consider mentioning worthy recipients to a peer Fellow.

Mina Hoorfar, PhD, FCSME
La présidente/President 2021

PO Box 40140, Ottawa ON K1V 0W8
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Dr. Zheng Hong (George) Zhu

Dr. Zhu is a Professor, Tier I York Research Chair and inaugural Academic Director of Research Commons in the Office of Vice-President Research and Innovation at York University. He contributes to mechanical engineering with strong leadership in management, excellent research achievement, and education for renaissance engineers. Dr. Zhu led the Research Commons' efforts to provide research support to scholars across the York University. He has conducted innovative research in astrodynamics and aerospace by combining fundamental engineering principles with industry application and made significant impact in sustainable use of outer space for humanity and sustainable green aviation. He published over 300 papers in peer reviewed journals and conference proceedings, attracted over $17M external research grants, and trained over 100 HQP.

Dr. Zhu is a College Member of Royal Society of Canada and a Fellow of: Canadian Academy of Engineering, Engineering Institute of Canada, Canadian Society for Mechanical Engineering, and American Society of Mechanical Engineers. He is also an Associate Fellow of the American Institute of Aeronautics and Astronautics and the Academician of International Academy of Astronautics. In 2020, he was recognized as a Top Two Percent Researcher worldwide by the Stanford's standardized citation indicators.

Dr. Pouya Rezai

Dr. Pouya Rezai is an associate professor in mechanical engineering at the Lassonde School of Engineering at York University and a professional engineer in the province of Ontario. He is the founding mechanical engineering graduate program director at the school. His research interest is in multiphase flows within microfluidic and Lab-on-Chip (LoC) devices. It aims to understand the interactions between biological nano- and micro-particles and fluids in biomimetic microsystems, for health-and-safety applications like pathogen and disease biomarker detection in air, water, food, and/or human body fluids (point-of-care and point-of-need bio-detection).

Dr. Rezai has published over 100 refereed journal and conference papers, 7 book chapters, 2 issued patents, and given 25 invited talks. He is a recipient of the Early Researcher Award from the provincial government of Ontario, a member of McMaster Engineering's Top 150 Alumni, and recipient of the Early Researcher Lassonde Innovation Award. He is the editor of the Canadian Society of Mechanical Engineering bulletin, an editorial board member of Nanotechnology for Environmental Engineering journal, a topic editor for Biosensors, and a guest editor for Micromachines.

Dr. Daolun Chen

Dr. Daolun Chen is a Fellow of the Canadian Academy of Engineering (FCAE), Fellow of Canadian Institute of Mining, Metallurgy and Petroleum (FCIM), and Fellow of the Institute of Materials, Minerals and Mining (FIMMM), is a Professor in the Department of Mechanical and Industrial Engineering, Ryerson University. He is a world-leading researcher in the mechanical behavior of materials, and has made outstanding contributions to improving the safety and durability of structural materials for the automotive and aerospace applications.

Dr. Chen has published 424 refereed journal (339) and conference (85) papers, plus 201 non- refereed conference papers/research reports, with 12,000+ citations and an *h*-index of 57. His pioneering work on nanocomposites leads to a well-known method that bears his name, and is twice identified by the Council of Canadian Academies to be one of the top 1% most highly cited papers in his field worldwide. He is a recipient of G.H. Duggan Medal, Canadian Metal Physics Award, Premier's Research Excellence Award, MetSoc Award for Research Excellence, MetSoc Distinguished Materials Scientist Award. Dr. Chen is currently serving on the editorial boards of 28 highly-regarded journals.

PROFESSOR CRISTINA AMON NAMED TO THE ORDER OF CANADA

University of Toronto Professor Cristina Amon has been named a Member of the Order of Canada. Amon is Alumni Distinguished Professor in Bioengineering and served as Dean of the Faculty of Applied Science & Engineering from 2006 to 2019. During that time, she established the Faculty as a world leader in multidisciplinary engineering research and education while making incredible strides in advancing gender equity, diversity and inclusion. She was recognized for her contributions to the advancement of the field of engineering and to research and innovation across Canada. For more information visit: news.engineering.utoronto.ca/professor-cristina-amon-appointed-to-the-order-of-canada.

PROFESSOR HODA ELMARAGHY NAMED TO THE ORDER OF CANADA

Windsor University Distinguished University Professor Hoda ElMaraghy has been named a Member of the Order of Canada. ElMaraghy obtained her BSc from Cairo University, then moved to Canada, where she received her Master of Applied Science and PhD degrees from McMaster University, making her the first woman to obtain a PhD in mechanical engineering. A world leader in manufacturing systems, ElMaraghy's work earned her a Tier 1 Canada Research Chair and first woman dean of Engineering in Canada. Her work has also been recognized with honorary doctorates from Chalmers University in Sweden and Aalborg University in Denmark. Her vast contributions to modern manufacturing systems' paradigms, flexibility, and changeability have changed how they are currently designed and operated. For more information visit: www.gg.ca/en/activities/2020/governor-general-announces-114-new-appointments-order-canada.

PROFESSOR SUSAN MCCAHAN INDUCTED INTO THE CANADIAN ENGINEERING EDUCATION ASSOCIATION

University of Toronto Professor Susan McCahan has been inducted as one of 21 inaugural Fellows of the Canadian Engineering Education Association (CEEA-ACEG). The honour recognizes noteworthy service to engineering education, engineering leadership, or engineering design education. In addition to her position in U of Department of Mechanical & Industrial Engineering, McCahan serves as Vice-Provost, Academic Programs and Vice-Provost, Innovations in Undergraduate Education. For more information visit: www.mie.utoronto.ca/mie-professor-susan-mccahan-one-of-four-u-of-t-engineering-professors-inducted-as-fellows-of-the-canadian-engineering-education-association.

PROFESSOR AIMY BAZYLAK ELECTED TO THE ROYAL SOCIETY OF CANADA'S COLLEGE OF NEW SCHOLARS, ARTISTS AND SCIENTISTS

University of Toronto Professor Aimy Bazylak has been elected to the Royal Society of Canada's College of New Scholars, Artists and Scientists. Bazylak, who holds the Canada Research Chair in Thermofluidics for Clean Energy, is working to advance fuel cells, electrolyzers and batteries for the production of clean power and energy storage without greenhouse gas emissions. She is an international leader in understanding the multiphase and microscale transport processes involved with polymer electrolyte membrane fuel cells and electrolyzers. Bazylak and her team have partnered with automotive and energy companies such as Nissan, Volkswagen and Hydrogenics Corp. For more information visit: news.engineering.utoronto.ca/professor-aimy-bazylak-elected-to-the-royal-society-of-canadas-college-of-new-scholars-artists-and-scientists.

PHOTO: PROFESSOR HODA ELMARAGHY / ORDER OF ONTARIO

TECHNICAL COMMITTEE REPORTS

Advanced Energy Systems

- Held a committee meeting, including the introduction of new Committee members and election of a vice-chair (Dr. Xianke Lin, Ontario Tech University).
- Supported the CSME International Congress 2021 (UPEI), by organizing the Symposium on Advanced Energy Systems.
- Supported the CSME *Transactions* published through the Canadian Science Publishing (CSP).
- Discussed with the CSME Heat Transfer Technical Committee for the planning of the joint CSME Heat Transfer and Energy Systems Seminar Series (*details to be announced soon*).

– Dr. Xili Duan

Biomechanics and Biomedical Engineering

The BBETC (csme-scgm.ca/content/biomechanics-and-biomedical-engineering) is going to organize a Symposium on Biomechanics and Biomedical Systems at the 2021 CSME Congress (UPEI). There will be 21 presentations on the most recent research of the CSME members active within the field of biomechanics and biomedical engineering. This TC also contributes to the review process of submissions to *Transactions* of the CSME.

Since November 2021, Dr. Hossein Rouhani, University of Alberta, has been the chair, and Dr. Thomas Jenkyn, Western University, has been the vice-chair of this TC. Thanks to the contributions and support of the former chair, Dr. Ali Ahmadi, University of PEI, this technical committee has started with several initiatives, including recruitment of new members and committee meetings for collaborative training and teaching programs in the fields of biomechanics and biomedical engineering across Canada.

— Dr. Hossein Rouhani

Computational Mechanics

- The interests of this TC include development of new algorithms and non-standard applications of existing algorithms. Routine use of software packages for various simulations falls outside its interests.
- The TC prepared symposia on “Computational Heat and Fluid Flows” as well as “Artificial Intelligence in Computational Mechanics” for the 2021 CSME Congress.

– Maciej Floryan

Environmental Engineering

- The EETC scope is to promote research and teaching in Environmental Engineering in Canada, and its mandate is to be the interface between the provincial and national governmental organizations and the technical and academic community; to be the contact point with the international technical and academic societies working in the domain; to be the contact point with the American and EU official organizations with relation to Environmental initiatives.
- The activities of the EETC have been reduced this past year due to COVID-19 crisis.
- EETC contributed 5 papers in Environmental and Wind Engineering for the CSME Congress (UPEI). Also, Horia Hangan agreed to a keynote presentation. The papers are:
- Hydrogen Generation Through Excess, Curtailed, and Potential Energy from the Major Ontario Grid System (ID 7, Abstract)
- A Sluice Gate Control Model to Maintain the Desired Downstream Depth by Controlling the Gate’s Opening (ID 115, Paper)
- Developing More Accurate Models of Tornados (ID 133, Abstract)
- Land Cover Classification Using Multitemporal Vegetation Indices and Performance Evaluation of Sentinel-2A And Landsat-8 Using Machine Learning Algorithms (ID 141, Abstract)
- Fundamental and Parametric Considerations for Numerical Rain Simulation in a Wind Tunnel (ID 192, Paper)
- Discussions between the chair and the vice-chair are taking place to re-orient/broaden the focus of the EETC in order to attract new members and to align with national interests for Canada.
- New members have been invited to adhere to the EETC this year.

– Dr. Horia Hangan

Engineering Design and Analysis

- Acted as associate editor for TCSME.
- Member of ICTAM and IUTAM GA, contributed to the activities of these committees: Symposium on "the Advanced Design and Analysis of Multifunctional Materials and Structures", CSME Congress 2021.
- Scientific Committee for ICED21, the 23nd International Conference on Engineering Design, August 16-20 2021, Gothenburg, Sweden.
- Keynote Address on “OBE-based Engineering Accreditation and Engineering Design”, The Society for Design and Process Science (SDPS) Annual Conference, November 18-20 2020.

– Dr. Kamran Behdinan

Fluid Mechanics Engineering

- 2021 CSME Congress co-organizing and chairing the Fluid Mechanics Symposium;
- Planning for a TC meeting at the 2021 Congress

– Dr. Martin Agelin-Chaab

Heat Transfer

- The HTTC had one meeting. Dr. Sébastien Poncet from Université de Sherbrooke has agreed to serve as the vice-chair of the HTTC.
- HTTC continues to support the *Transactions* of the CSME.
- HTTC has been working with the organization committee of the CSME 2021 Congress to organize the heat transfer symposium.
- HTTC is also working with the Advanced Energy Systems Committee to initiate the CSME Heat Transfer and Energy Systems Seminar Series, which will start soon.

– Dr. Sunny Li

Machines and Mechanisms

- Reviewed papers for *Transactions* of the CSME.
- Recruited a committee co-chair: Dr. Juan Carretero, Professor and Chair of the Mechanical Engineering Department at the University of New Brunswick.
- Organised the Machines and Mechanisms symposium at the 2021 CSME Congress with Drs. Taufiq Rahman and Juan Carretero.

– Dr. Eric Lanteigne

Manufacturing

1. Membership: Jana Abou Ziki (Ontario Tech University); Hamid Akbarzadeh (McGill University); Sayyed Ali Hosseini (Ontario Tech University); Ahmad Barari (Ontario Tech University); Daolun Chen (Ryerson University); Zengtao Chen (University of Alberta); Aleksander Czekanski (York University), TC Chair; Lucas Hof (ETS); Matt Khoshdarregi (University of Manitoba); Tsz Ho Kwok (Concordia University); Qingjin Peng (University of Manitoba); Carolyn Ren (University of Waterloo); Fengfeng Xi (Ryerson University).
2. Meetings: Annual meeting is scheduled to take place at UPEI 2021.
3. TCSME: Review of several research papers was led by TC Manufacturing chair.
4. The activities of Manufacturing TC: Reviewing submitted papers to 2021 CSME Congress; Supporting the 2021 Congress by developing Advanced Manufacturing symposiums; Initiated selection of vice-chair(s) (2021-2022).
5. Next steps: Contribute to organization of manufacturing symposium at CSME 2021; Select TC vice-chair; Update TC website.

– Dr. Alex Czekanski

Materials Technology

- An online symposium in Materials Engineering co-organized with UPEI at the 2021 CSME Congress. Major efforts have been made to distribute the call-for-papers to relevant parties including CSME members, university faculties, research institutions and industry.
- Continue to serve as an Associate Editor for *Transactions* of CSME and to handle (assign reviewers, review and make recommendations) a great number of manuscript submissions in Materials area.
- Give an “IAAM Medal Lecture” in Advanced Materials Lecture Series organized by International Association of Advanced Materials (IAAM).

– Dr. Frank Cheng

Microtechnology and Nanotechnology

- Recruited a new member (Dr. Savoji from U Montreal)
- Invited a keynote speaker (Dr. Derek Rosenberg from McGill) to give a talk at the Microtechnology and Nanotechnology Symposium at the (cancelled) 2020 CSME Congress at UPEI.
- The TC reviewed 10 abstracts for the Microtechnology and Nanotechnology Symposium at 2021 CSME Congress at University of Prince Edward Island.
- Future activities: Microtechnology and Nanotechnology Symposium at 2021 CSME Congress (UPEI).
- Organize monthly research e-seminars with speakers from the TC.

– Dr. Mohsen Akbari

Transportation Systems

- Organizing a Symposium at CSME 2021 Congress: Advanced Technologies for Road and Rail Vehicles; reviewed 9 papers / 8 papers accepted
- Acted as TCSME associate editor

– Dr. Yuping He

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