SILICONES

SUSTAINABILITY WORKSHOP

DECEMBER 7 & 8,
2023

Grand Hyatt Hotel
1000 H Street, NW,
Washington, DC

DRAFT PROGRAM

GSC
GLOBAL SILICONES COUNCIL

Silicones Europe
A sector group of Cefic

American Chemistry Council

SEHSC
Silicones Environmental, Health, and Safety Center

SIAJ
Silicone Industry Association of Japan

Workshop Day 1 Thursday, December 7, 2023

8:00 am

Registration (continental breakfast)

8:30 am

Preliminary Session
Opening Remarks

- Workshop Goals
- Workshop Deliverables
- Attendees Expectations

Karluss Thomas, *Global Silicones Council (GSC)*

Mike Brook, *McMaster University*

8:45 am

Session I
Silicones Chemistry - *Safety to Human Health and the Environment*

Abirami Skrikanth, Moderator
Tracy Guerrero, Rapporteur

- Environmental Impacts
  - Fate
  - Degradation
- Safety Assessments and Regulatory Challenges

Kathy Plotzke, *Dow*
Understanding the persistence and ultimate fate of organosilicon materials in environmental media

Alex Rinehart, *Shinetsu*
Global regulatory review of siloxanes

9:45 am

Session II
Silicone Sustainability Applications

Paul Zelisko, Moderator
Betsy Beckwith, Rapporteur

- Carbon Neutrality
- Energy Efficiency

Ana Carolina Felix, *Dow*
Responsible sourced and lower carbon silicones enabling sustainable applications

Lisa Perricane, *Wacker*
Sustainabalance Strategy at Wacker Silicones

10:45 am

Break - *Poster Presentations*

11:00 am

Session III
Silicones Lifecycle

Anne Skov, Moderator
Alex Rinehart, Rapporteur

- Lifecycle Considerations
- Metrics

Shuai Liang and Nicolas Drolet, *Saint Gobain*
Perspectives on the sustainability of silicone tubing used in life science applications

Vishal Asher, *Dow*
How to use the life cycle assessments for a holistic sustainability evaluation of silicones

Ashlin Sathyan, *Dupont*
Liveo™ Healthcare Sustainable Silicones

Sharon Dubrow, *American Chemistry Council*
Portfolio Sustainability Assessment Framework

12:30 pm

Lunch

Sponsored by Gelest

Gelest

1:30 pm

Session IV
Opportunities for Improvements in Silicones Sustainability

Mike Brook, Moderator
Ashlin Sathyan, Rapporteur

- Product Design / Development
- Process Technology
- Case Studies

Anne Skov, *Glysious*
Diluting silicone elastomers with glycerol and achieving improved mechanical properties

Paul Zelisko, *Brock University*
Silicone synthesis/degradation by biocatalysis

Vincent Monteil, *University of Lyon*
Chemical recycling of silicones

Abirami Srikanth, *Momentive*
Innovation case studies towards a sustainable world using principles of 4 Rs

3:00 pm

Break - *Poster Presentations*

3:30 pm

Session V
Wrap-Up

Mike Brook
Betsy Beckwith

- Day 1 Discussion/Summary
    - Expectations Review
- Day 2 Expectations

4:30 pm

Adjournment

5:00 pm - 6:30

Networking Reception

Sponsored by Saint Gobain

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Silicones Europe

American Chemistry Council

SEHSC Silicones Environmental, Health, and Safety Center

SIAJ

Workshop Day 2 **Friday, December 8, 2023**

8:00 am — **Breakfast**

8:30 am — **Welcome / Day 2 Overview**

Karluss Thomas, *GSC*

8:45 am — **Session VI**
Evolution in Silicones Sustainability

Shuai Liang, Moderator
Tracy Guerrero, Rapporteur

- Silicones at the End of Life
  - Circularity

Yang Chen, *EnRoute Interfaces*
Diluting the carbon footprint of silicone elastomers

Joe Furgal, *Bowling Green State University*
Explorations of the silicone lifecycle loop with chemical and photochemical depolymerization and direct recycling processes

Mike Brook, *McMaster University*
Compostable Silicone Elastomers and other end of life stories

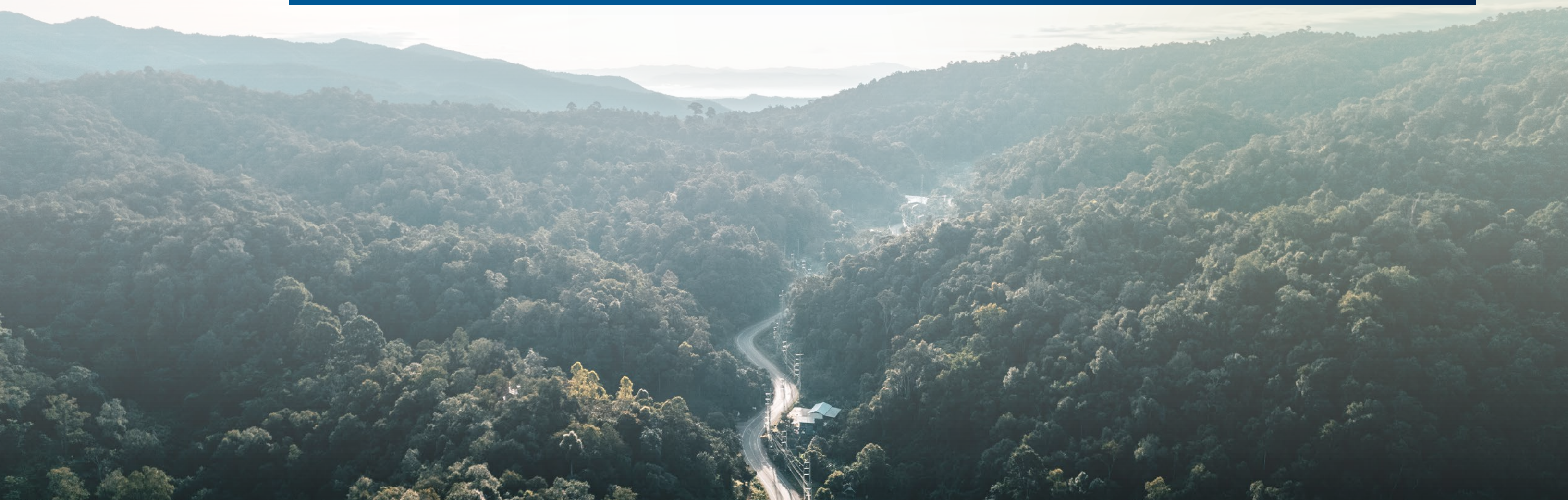
10:30 am — **Break**

10:45 am — **Session VII**
Summary of Key Lessons Learned, Next Steps

Abirami Srikanth/Paul Zelisko, Moderator
Betsy Beckwith, Rapporteur

- Development of Workshop Proceedings summary
- Next Steps

12:00 pm — **Adjournment**



Abstracts/ Speakers

Speakers List

Global Regulatory Review of Siloxanes

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Alexandra Rinehart

Shin-Etsu Silicones of America, Inc.

GSC advocates that countries use a risk-based weight-of-evidence (WoE) approach which considers exposure to evaluate the safety of silicone materials. GSC and a host of independent scientists and experts have confirmed that research and testing demonstrate the safety of silicones in their diverse and important applications. Regulatory determinations should be accurate and based upon all data and accepted risk assessment principles.

This presentation will provide a global regulatory overview of silicones, emphasizing that Europe remains the only region that has implemented product use restrictions for the common building used to manufacture silicone polymers – cyclosiloxanes and linear siloxanes.

The very different evaluations of silicone materials conducted by the regulatory authorities in Canada and Australia will be highlighted noting that these authorities concluded that the silicone building blocks can be used safely in appropriate applications without harming human health or the environment.

It will also be noted that regulators failing to consider all the available scientific evidence threaten to undermine the very innovation needed to meet key global sustainability goals.

Alexandra Rinehart

Product Stewardship and Regulatory Manager

Alexandra Rinehart is the Product Stewardship and Regulatory Manager at Shin-Etsu Silicones of America, Inc. supporting the Americas. She has earned her degree in Chemical Engineering from the University of Cincinnati, and is responsible for national and international regulatory compliance and advocacy within Shin-Etsu. With over 10 years working in silicone regulations, she serves as the current Chair of the Regulatory and Public Affairs committee as part of the Silicones Environmental Health and Safety Center (SEHSC) domestically and is also a member of the Global Silicones Council (GSC) supporting international silicone advocacy.

Speakers List

Diluting Silicone Elastomers with Glycerol and Achieving Improved Mechanical Properties

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Liyun Yu,[1,2] Jonas Brems Kristensen,[1,2] Stina Bjerg Nielsen,[1] **Anne Ladegaard Skov**[1,2*]

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[2] Danish Polymer Centre, Department of Chemical and Biochemical Engineering, Technical University of Denmark, Søltofts Plads 227, Kgs. Lyngby, Denmark 2800

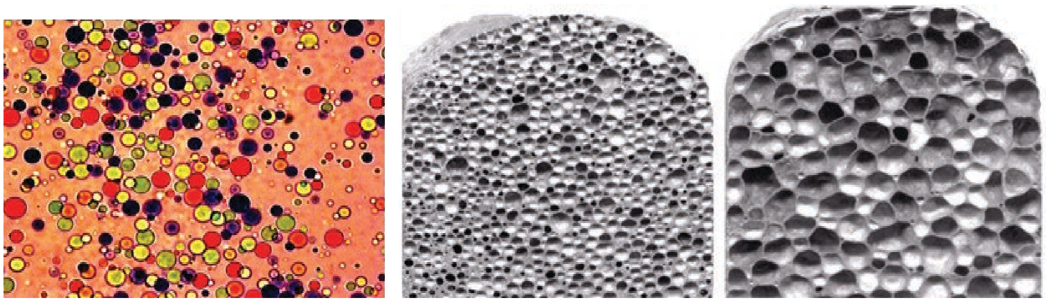

Figure 1. An example of an emulsion with multiple actives (left) and various structures of final elastomers (right).

The exploitation of fillers to reduce the environmental impact of silicone elastomers and adhesives always seem to introduce either rigidity or reduced performance of the silicone products. Counterintuitively, glycerol can be introduced into silicone and results in interesting properties of the resulting silicone elastomers and adhesives, with significantly improved moisture handling properties as the main advantage, and simultaneously not altering the mechanical and adhesive properties. Furthermore, introducing glycerol in significant amounts can reduce the environmental impact of up to 40% of the silicone product.

The recently developed silicone-based composite consisting of a silicone matrix with discrete compartments of liquids has been shown to hold great potential in various applications and promises to become a platform for creating multiple functional smart materials. It is prepared by a patented glycerol-in-PDMS emulsion, which is very stable for a broad range of concentrations. The glycerol allows for the incorporation of drugs and actives and can therefore be used for active wound care adhesives or vehicles for skin therapeutics.

Anne Skov

Professor, Technical University of Denmark

Anne Ladegaard Skov is a professor specializing in silicone elastomers at the Danish Polymer Centre, Department of Chemical and Biochemical Engineering, Technical University of Denmark (DTU). She held a Carlsberg research fellowship at Cambridge University, UK, before taking up a position as assistant professor at DTU. In 2015, she became leader of the Danish Polymer Centre, and in 2017, she was promoted to professor. In 2023, she has been appointed as member of the Danish Academy of Technical Sciences (ATV). She has received multiple prizes for her work on elastomers, such as Grundfosprisen, Elastyrenprisen and the Statoil Award. Functionalisation and formulation of silicone elastomers with focus on silicone elastomers used and optimised for dielectric elastomers and more recently for flexible electronics and drug delivery are the core of her research. She has published 177 publications and holds multiple patents on elastomers that are currently developed commercially by international and national companies.

References

[1] Mazurek, P.; Hvilsted, S.; Skov, A.L. Polymer 2016, 87, 1.
[2] Mazurek, P.; Brook, M.A.; Skov, A.L. Langmuir 2018, 34, 11559.
[3] Mazurek, P.; Ekbrant, B.E.F.; Madsen, F.B.; Yu, L.; Skov, A.L. Eur. Polym. J. 2019, 113, 107

Speakers List

Liveo™ Healthcare Sustainable Silicones

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Ashlin Sathyan, Lisa Anderson, Sabine Springael, Siri Kore, Michael Sauder

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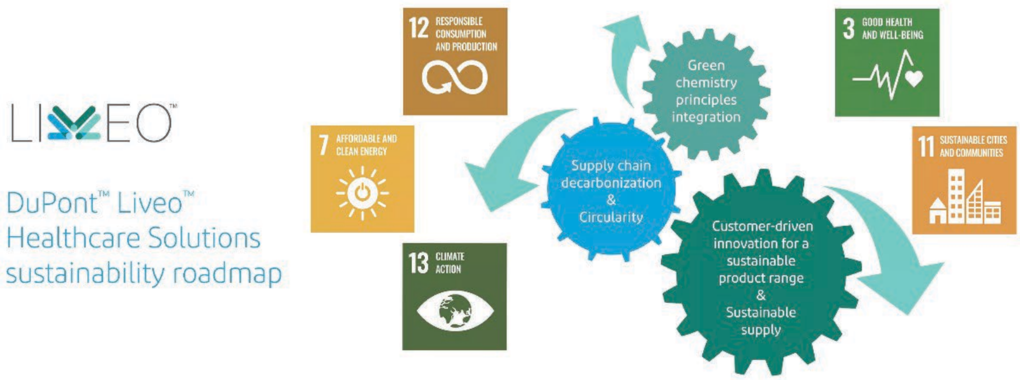

Figure 1. DuPont LiveoTM Healthcare Solutions sustainability roadmap.

DuPont's purpose is to empower the world with essential innovations to thrive. DuPont's sustainability objectives are to "Innovate Safe and Sustainable by Design", "Act for the Climate", and "Enable a Circular Economy". The sustainability of the silicones supply chain is vital for success in the healthcare industry. Inspired by the United Nations Sustainable Development Goals (UN SDGs) – which shape our product portfolio, our operations strategy, and our commitment to our people and communities, the Liveo™ sustainability strategy is grounded in our purpose to create essential healthcare innovations that enable patients to thrive. Our sustainability roadmap includes projects and actions targeting customer-driven innovations for a sustainable product range, decarbonization of our operations, and integration of green chemistry principles. Success stories to be shared will include DuPont Liveo™ launch of low cyclics products to support Safer by Design and Green Chemistry principles, ongoing effort to support renewable energy, life cycle analysis studies, and a partnership with silicone recycler ECO USA to divert scrap silicones from landfill and incineration. Achieving sustainability objectives and maintaining regulatory compliance along the siloxane supply chain cannot be achieved without an enhanced partnership between siloxane suppliers and downstream users. Collaboration and transparent communication are essential for the success of everyone.

Ashlin Sathyan

R&D Senior Scientist, Liveo™ Healthcare Silicones, DuPont.

Ashlin Sathyan is a Senior Scientist within the DuPont LiveoTM Healthcare R&D Team, situated in Midland, Michigan. In her role, Ashlin is responsible for identifying, evaluating, and cultivating innovative scientific concepts and technologies to tackle a variety of healthcare silicone-related challenges.

Her primary responsibilities include product/formulation development and silicone-organic hybrid polymer synthetic activities to develop products capable of delivering various medicinal applications.

She earned her Ph.D. in Polymer Science and Engineering from the University of Massachusetts Amherst in 2021, where she conducted research under the guidance of Prof. Todd Emrick. Prior to pursuing her Ph.D., Ashlin accomplished both a Bachelor's and a Master's degree in Chemical Sciences at the Indian Institute of Science Education and Research in Kolkata, India.

Speakers List

Explorations of the silicone lifecycle loop with chemical and photochemical depolymerization and direct recycling processes

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Joseph C. Furgal[1], Kalani Edirisinghe,[1] Herenia Espitia Armenta,[1] Ethan T. Chandler,[1] Cory B. Sims,[1] and Buddhima Rupasinghe[1]

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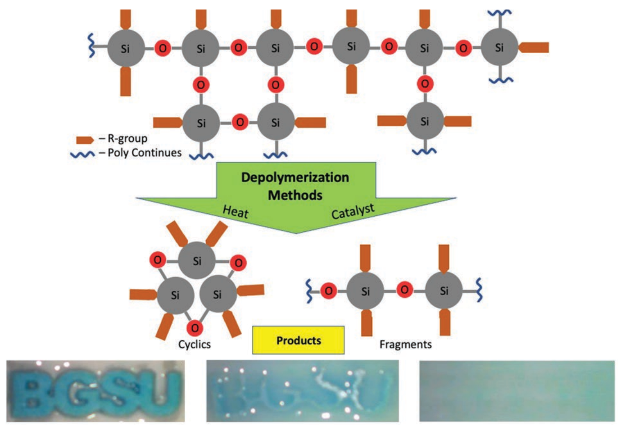

Figure 2. Catalytic silicone depolymerization methods

Joseph Furgal

Associate Professor, Bowling Green State University

Joseph C. Furgal received his B.S. in Chemistry from the University of Detroit Mercy, while conducting undergraduate research with M. Mio and a Snyder summer research fellowship at the University of Illinois Urbana-Champaign under the direction of J. Moore. He earned his PhD. in Materials Chemistry under the direction of Professors R. M. Laine and T. Goodson III on silsesquioxane based materials for energy/photonic applications at the University of Michigan, Ann Arbor. He then went on to a postdoctoral research position in Chemical Engineering at the University of Michigan under the direction of T. F. Scott, looking at sequence defined peptoid oligomers and their self-assembly. Joseph is currently an Associate Professor in the Department of Chemistry and Center for Photochemical Sciences at Bowling Green State University in Bowling Green, Ohio, where he was the 2022 BGSU Outstanding Early Career Investigator. His current work focuses on using hybrid (silsesquioxane and siloxane) based materials for the development and fundamental chemical understanding of photo-active architectures in the areas of switches, triggers, separations, sensors, self-healing, and environmental remediation; as well as new methods to catalytically effect molecular transformation in silicon-based systems. Our research has been funded by the US National Science Foundation, US National Park Service, US National Institutes of Health, Johnson and Johnson Vision Care Inc., Angstrom Technologies, and Bullen Ultrasonics.

https://furgaljc.wixsite.com/materialsworkshop

References

[1] B. Rupasinghe, J. C. Furgal, ACS Appl. Polym. Mater. 2021, 3, 1828–1839.
[2] B. Rupasinghe, J. C. Furgal, Polym. Int. 2022, 71, 521–531.
[3] H. Espitia Armenta, K. Edirisinghe, J. C. Furgal, Manuscript in Preparation

Transparent and thermoplastic silicone materials based on room-temperature diels-alder reactions

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Paria Azadi Namin,[1] Phoebe Booth,[1,2] **Julio Treviño Silva,**[1] Laura J. Voigt,[1] Paul M. Zelisko*[1]

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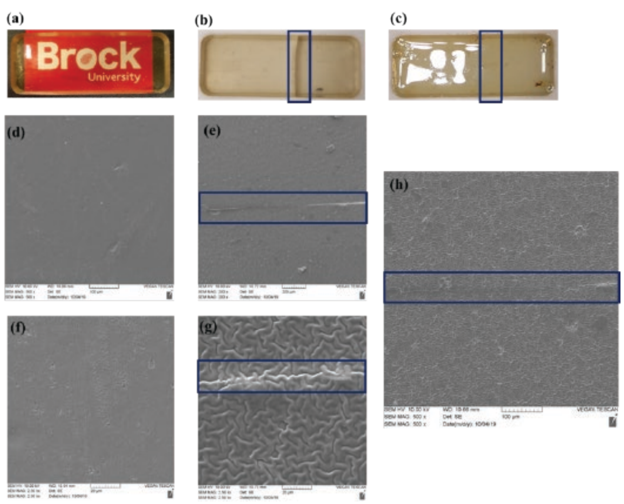

Figure 1. Microscopy images of healed, and remouldable silicones cured at room temperature

Chemoenzymatic approaches have been utilized to synthesize silicon-containing structured materials. Inspired by the self-healing properties of certain biological tissues and by the types of bonds found in nature, we are studying silicone systems that have the capacity to self-heal at relatively low temperatures and/or to generate robust silicone-based materials cross-linked by biologically-derived bonds. The exploration of a library of diene and dienophile combinations yielded materials that were initially cured in 5 h at room temperature and that could be repaired in <5 min with a relatively low-temperature regimen (heat to 80 ˚C and cool to room temperature to cure). All of the synthesized materials were thermoplastic and could be remolded while effectively retaining the bulk properties of the parent material (e.g., translucency, tensile strength, hardness, etc.). The healed “scars” of the materials were quite robust, with subsequent catastrophic failure during elongation of repaired materials occurring outside of these locations. To the best of our knowledge, this is the first and only reported case of a cross-linked silicone material based on the Diels–Alder reaction, where curing of the silicone material occurs at room temperature.

Julio Treviño Silva
Student

Julio Trevino, a driven international scholar hailing from Mexico, commenced his Ph.D. at Brock University in 2021 under the mentorship of Dr. Paul Zelisko. Julio's research focuses on advancing the understanding of synthetic procedures for obtaining fluorosilicone polymers, and their subsequent applications as surface coatings.

References
Azadi Namin, P; Booth, P; Trevino Silva, J; Voigt, LJ, Zelisko, PM. Macromolecules, **2023**, 56, 2038-2051.

Speakers List

Understanding the Persistence and Ultimate Fate of Organosilicon Materials in Environmental Media

Kathleen Plotzke

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The Dow Chemical Company

To understand the persistence and ultimate environmental fate of organosilicon materials it is critical to know all pathways (biological and non-biological) of degradation from parent to ultimate degradation products in air, soil, water and biota. To facilitate this understanding, one must first understand the movement and partitioning of the organosilicon materials to the various environmental compartments during their life cycle.

This presentation will describe how silicones enter the environment and how research illustrates that silicones or their degradation products do not build up in the air, water, soil or sediment. Understanding of how silicones degrade in the environment will be provided and their positive sustainability profile will be highlighted, noting that silicones empower sustainability while degrading back to natural substances in the environment.

Kathleen Plotzke

Chief Health & Environmental Scientist

Dr. Kathleen P. Plotzke is the Chief Health and Environmental Scientist for Consumer Solutions at The Dow Chemical Company. She represents Consumer Solutions in various industry boards (Silicone and Chemical) and scientific panels and provides technical leadership of global regulatory issues for Consumer Solutions and the Silicone Industry. Her areas of scientific interest include distribution, fate and effects of chemicals in the body and the environment.

Dr. Plotzke joined Dow Corning in 1992 to lead the Pharmacokinetics and Metabolism Group. After 7 years in this role she then became the Manager of Toxicology. In 2001 Dr. Plotzke was named Health and Environmental Science (HES) Director. Dr. Plotzke assumed the Chief Health and Environmental Scientist role in 2006 in addition to maintaining her HES Director role. She prospered in both of those roles and in 2013 she again held dual responsibility assuming the role of Director of Regulatory Issue Management for Dow Corning as well as maintaining her Chief Health and Environmental Scientist role.

Dr. Plotzke received her doctorate in Pharmacology from the University of Michigan Medical School and a B.S. degree in Chemistry from Saginaw Valley State University.

Speakers List

Synthesis of thymine-crosslinked silicone polymers: a bioinspired approach

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Laura J. Voigt,[1] Katie Tucker,[1,2] and Paul Zelisko,[1*]

[1] **Department of Chemistry and Centre for Biotechnology, Brock University, 1812 Sir Isaac Brock Way, St. Catharines, Ontario L2S 3A1**
[2] **Department of Chemistry, Cardiff University, Cardiff, United Kingdom**

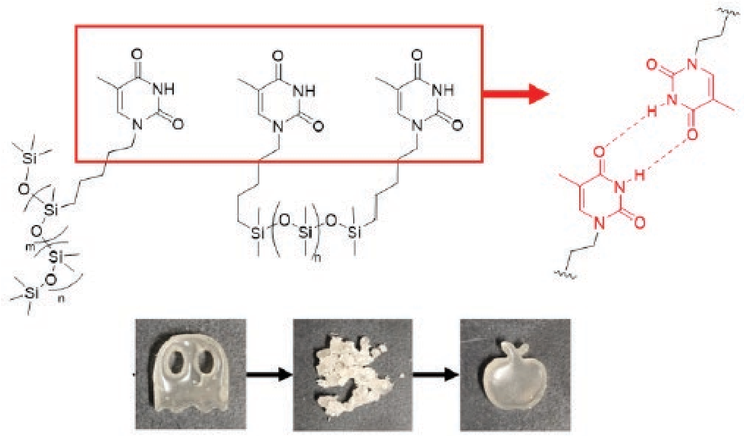

Figure 1. DNA-inspired self-healing and recyclable silicone materials

Hydrogen bonding has been employed as a crosslinking method in a variety of different polymers. Hydrogen bonding is a relatively strong, highly directional, and specific non-covalent interaction present in many biological systems, such as the interactions that hold DNA together, or those that assist in protein folding. These bonds can also be reversible under certain conditions, resulting in polymers with interesting characteristics, such as self-healing and recyclable properties.

The focus of this work is the functionalization of silicone polymers with the molecule thymine and the use of its hydrogen-bonding capability to create a bio-inspired cross-linked material. As one of the four nucleotide bases found in DNA, thymine has the capability to hydrogen bond due to its donor-acceptor character. We have observed hydrogen bonding in our thymine-containing silicone polymers, when thymine decorates the backbone of the polymer. We have created a library of silicone polymers with increasing amounts of thymine (3-4% thymine, 4-6%, 7-9%, 15-18%, 25-30%, and 50-55%) and at a variety of molecular weights. The reversibility of the hydrogen bonds has made the resulting elastomers recyclable. The elastomers can be torn up, deposited in a mold, and placed in an oven at 110oC. This heat is enough to cause the hydrogen bonds that are holding the polymer chains together to break, but these same bonds can reform upon cooling. The synthesis of these materials and their physical properties will be discussed.

Laura J. Voigt
Student

Laura Voigt is currently a PhD candidate at Brock University. Her research involves the development of recyclable silicone polymer systems using DNA bases as crosslinkers.

References

Voigt, LJ; Tucker, K; Zelisko, PM. Biomacromolecules, **2023**, 24, 3463-3471.

Speakers List

SustainaBalance® Strategy at Wacker

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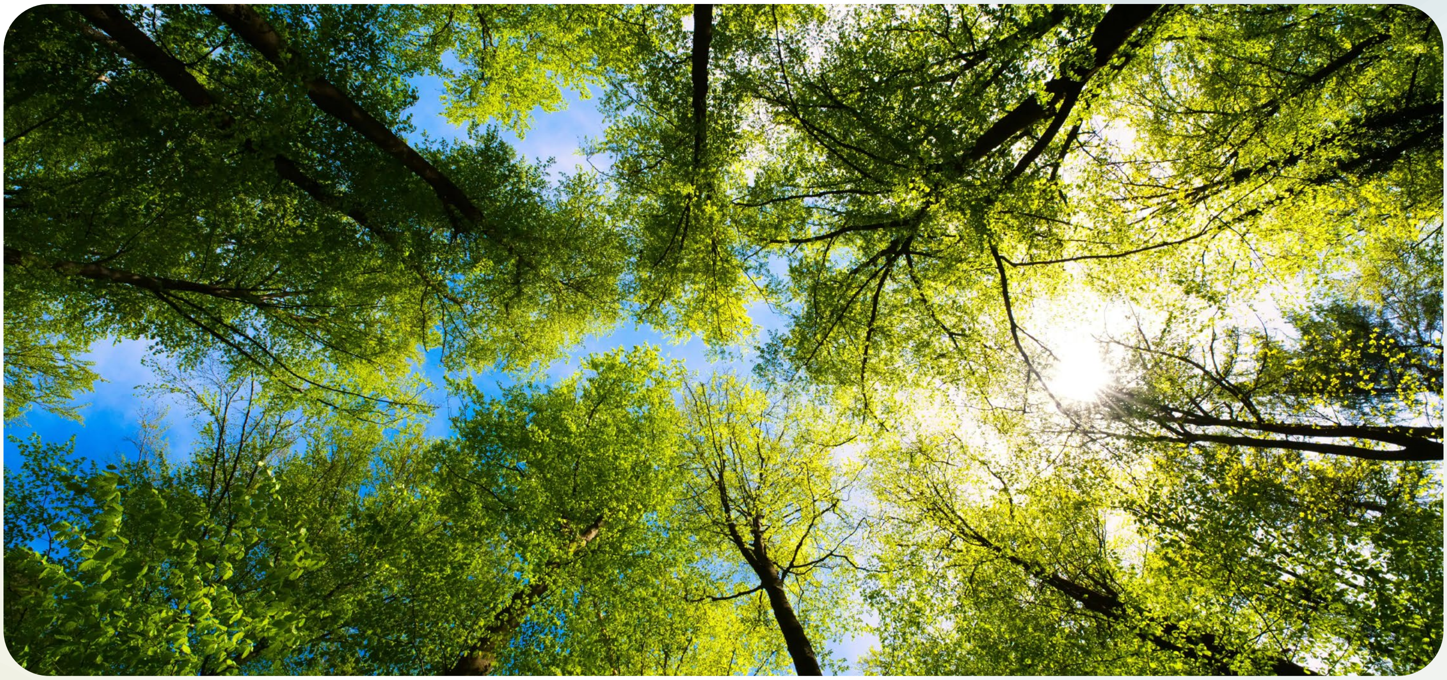
Lisa Perricane

Wacker Chemical Corporation



Wacker Chemical Corporation has developed a SustainaBalance® strategy which comprises three principles designed to promote the balance between ecological, social, and economic factors. By 2045, Wacker plans to achieve net-zero due to their expanding portfolio of sustainable products and decarbonized production.

This presentation will describe the three pillars of Wacker's SustainaBalance® strategy. The strategy rests on the following pillars: increasing values, reducing our footprint, and mutual cooperation and collaboration. Descriptions of what Wacker is doing to reduce our footprint in terms of CO_2 reduction, water, and energy reduction will be shared.

Lisa Perricane

Director, Regulatory Affairs and Product Safety

Dr. Lisa Perricane is the Director of Regulatory Affairs and Product Safety at Wacker supporting the North and Central Americas regions. She has earned her BS degree in biology, a Master's in Business Administration , and PhD degree in Public Policy and Administration and is responsible for US, Canadian, and Mexican regulatory compliance and advocacy within Wacker. With over 20 years of chemical regulatory and science policy advocacy experience, she serves as the current Chair of the Executive Committee Regulatory of the Silicones Environmental Health and Safety Center (SEHSC) domestically and is also a member of the Global Silicones Council (GSC) and serves as Vice-Chair of the GSC Global Public Affairs Strategy Team (GPAST) supporting international silicone advocacy.

Speakers List

Compostable Silicone Elastomers and Other End of Life Stories

mabrook@mcmaster.ca

Michael A. Brook,[1*] Erin Donahue-Boyle,[1] Kaitlyn E.C. Silverthorne,[1] Robert Bui[1] and Scarlet Zheng[1]

[1] **Chemistry and Chemical Biology, McMaster University, 1280 Main St., W., Hamilton ON Canada L8S 4M1.**

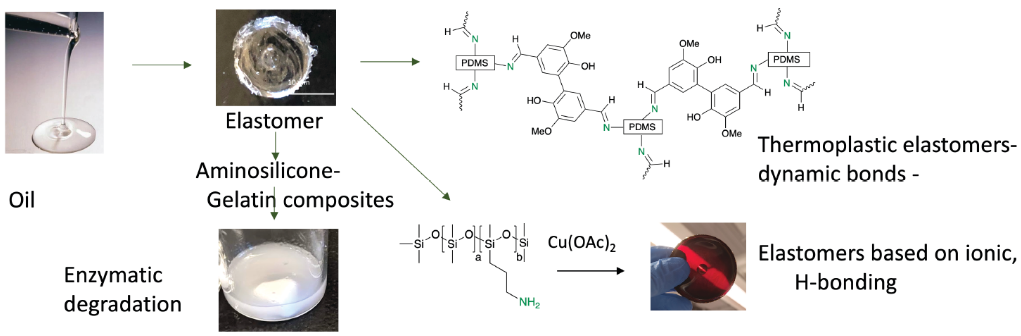


Figure. Silicone elastomers can be rendered functional, thermoplastic, and degradable on demand by incorporating organic motifs.

One of the attractive features of silicones is their resistance to oxidation; electrical current; voltage; water; heat... This is not so good when considering life cycle and circularity, as it means they are difficult to break down. We are focussing on developing silicones that have the ability to be reused (same application), repurposed (lower value application); recycled via conversion to monomers; and natural degradability in the environment, all of which should increase the sustainability of silicones, particularly elastomers. Three strategies to achieve this end will be described: i) dynamic bonds that promote self-healing, ii) ionic and hydrogen bonds that lead to thermoplastic elastomers, and iii) elastomers with biological weak links that degrade under environmental conditions.

Simple organic chemistry, applied to existing commercial silicones, opens the way to enhanced sustainability. A form of vanilla can crosslink aminopropylsilicones to give strong elastomers that, because of dynamic bonds, self-adhere, flow with heat and completely depolymerize in the presence of small amines; we are exploring the biodegradability of these elastomers. Aminosilicones undergo direct crosslinking with by ligand binding to copper ions. Presumably, the copper will leach out slowly. To degrade the elastomer, just add a better ligand. Aminosilicones can also be crosslinked with (toxic) formaldehyde. When gelatin is present, cross-coupling occurs to give silicone gelatin hydrogels containing up to 80wt% gelatin, but feel like silicones. The enzyme bromelain digests the protein leaving the silicone behind in oil form.

Mike Brook

Professor, McMaster University

Mike Brook is Distinguished University Professor, Professor of Chemistry and Chemical Biology and Faculty of Science Chair in Sustainable Silicone Polymers at McMaster University, Hamilton Canada. In 2023 he won the Chemical Institute of Canada Green Chemistry Award, and in 2016 the F. S. Kipping Award in Silicon Chemistry from the American Chemical Society. His current research is focussed on increasing the sustainability of silicone elastomers.

References
Brook, M. A., Chem. Commun. **2023**, DOI 10.1039/D3CC03531J.

Speakers List

Thermoplastic, Redox Recyclable Silicone-Lipoamide Elastomers

Muhammad Ebad Noman,[1*] Sijia Zheng,[2] Haiyan Xue[2] and Michael A. Brook,[1]

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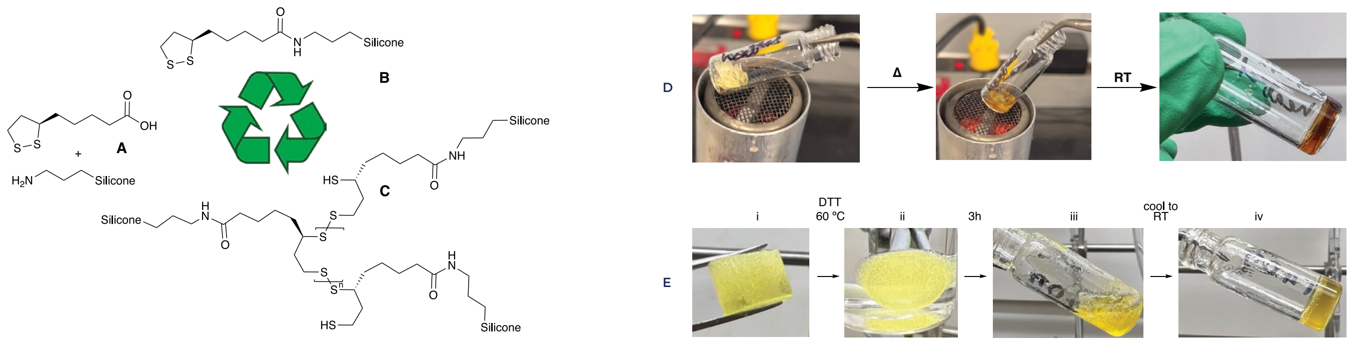

Figure. The sustainable loop of LPA-based silicone elastomers. Displaying, (A) The chemical structure of LPA and amino-silicone undergoing amide formation to produce (B) LPA-silicone, which undergoes ROP due to the presence of electronegative amines/amides, (C) LPA-silicone polymers with disulfide, (D) displays thermoplastic ability of the elastomers and (E) depolymerization through thiol exchange using DTT (a thiol-reducing agent).

Silicone elastomers, renowned for their exceptional properties, have historically been thermosets. Their high stability during use compromises the ability to repurpose or degrade them at the end of life. Hence, our group focuses on producing silicone materials that have the ability to be reused, repurposed; recycled through monomer conversion; and natural degradation in the environment, these efforts collectively aim to enhance the sustainability of silicones, especially elastomers.

In this study, we present an approach to repurposable and readily degradable silicone elastomers based on the incorporation of α-lipoic acid (LPA), a naturally occurring dithiolane. Unlike traditional methods for ring-opening polymerization (ROP) of LPA by use of heat, the amine used to form silicone amides also catalyzes ROP to give elastomers whose physical properties, as expected, are closely tied to crosslink density; both telechelic and pendent aminopropylsilicones serve as starting materials. The materials produced are thermoplastic elastomers whose properties remain essentially unchanged after several heating cycles. Reduction of the disulfide linkages in the elastomer using dithiothreitol (DTT) converts the elastomer to oils that contain DTT residues. These oils crosslink under air, but not nitrogen, to give new elastomers with slightly higher mechanical properties that are ascribed to the presence of vicinal diols. This process leads to elastomers that are more sustainable than traditional silicone thermosets because of the many attributes that facilitate reuse, repurposing, and recycling.

Muhammad Ebad Noman
Student

Muhammad Ebad Noman is a graduate student in Brook's lab at McMaster University, Hamilton Canada. He completed his BSc in Chemistry Honours at Ryerson University (Toronto Metropolitan University) in 2022 working at an organic synthesis lab for undergraduate thesis. In that time, he won Chemistry Research Award in the department of Chemistry and Chemical Biology (2022) and Undergraduate Award by ACS Division of Organic Chemistry (2022).Now he is focused on synthesizing sustainable polymers by incorporating natural products in silicones.

References

Muhammad Ebad Noman, Michael A. Brook*. Thermoplastic, Redox Recyclable Lipoic Acid-Silicone Elastomers, Green Chemistry, submitted.

Speakers List

Perspectives on the Sustainability of Silicone Tubing used in Life Science Applications

Nicolas Drolet[1] and **Shuai Liang**[1]

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shuai.liang@saint-gobain.com

1 Saint-Gobain Research North America, Northboro, MA, US 01824

Saint-Gobain Life Sciences is engaged in the production of various plastic-based products that cater to the diverse needs of the Biopharma, Medical, and adjacent markets. Notably, silicone stands out as a widely preferred material due to its exceptional properties and relative ease of processing. As an example, significant quantities of silicones need to be produced annually to manufacture single-use tubing to support the bioprocessing industry.

In alignment with Saint-Gobain's ambitious objective of attaining carbon neutrality by 2050, the Life Sciences division has undertaken a comprehensive life cycle analysis (LCA) of our silicone tubing products. During this presentation, we will delve into the insights derived from these findings and share our perspectives on potential avenues to enhance the sustainability of our silicone-based products. Furthermore, we will expound upon two distinct technological approaches currently underway within our Research and Development endeavors aimed at realizing carbon neutrality and fostering a circular economy.

Nicolas Drolet

R&D Manager, Saint Gobain

Nicolas Drolet is currently the R&D Manager of the Bioprocess Solutions team in Saint-Gobain Life Sciences located at the Saint-Gobain Research North America Center in Northboro, MA. Nicolas Drolet completed his Ph.D. Degree in Polymer Sciences in 2005 under the supervision of Professor Mario Leclerc at Université Laval, Québec, Canada.

Shuai Liang

Team Leader, Saint Gobain

Shuai Liang is a Team Leader for Silicone Competency Team at Saint-Gobain Research North America. His team is primarily focusing on silicone raw material validation and silicone new product development such as LSR, HCR, and RTV in automobile, aerospace, construction, and life science industries. Shuai studied polymer chemistry in his PhD program and then started concentrating on silicone research from his postdoc training in Prof. Brook group at McMaster University. Currently his research interests are advanced functional silicone elastomers such as thermally or electrically conductive silicone, ceramifiable silicone, silicone foam, silicone adhesive and sealant, and silicone tubing. He published a dozen of scientific paper and US patents so far.

Speakers List

Bioinspired silicone synthesis and degradation

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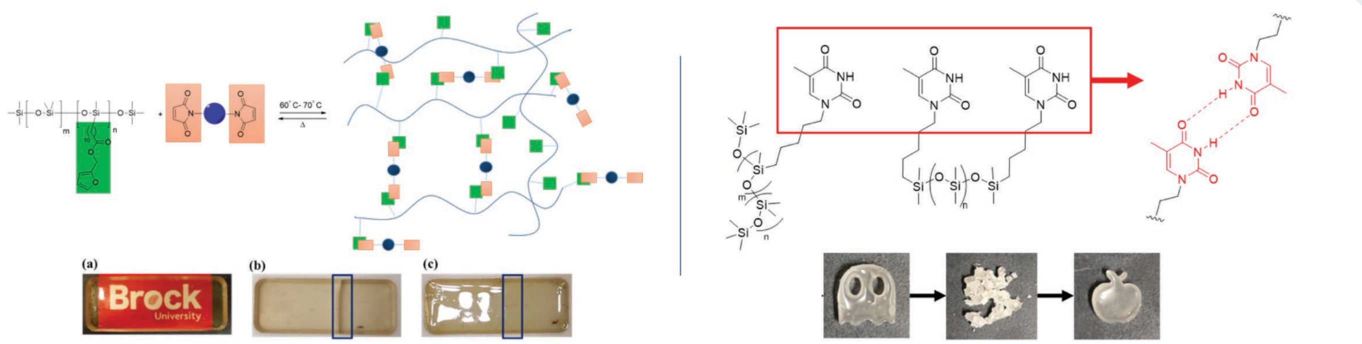

Figure. Bioinspired routes to healable and remoldable silicone materials.

Room temperature vulcanization (RTV) typically employs a tin catalyst, and addition cure systems generally use catalysts based on platinum to generate solid silicone-based materials. Although quite effective at cross-linking silicones, both metals in these catalysts must be mined and are non-renewable; tin is also extremely neurotoxic. These metal-based systems are extremely effective at catalyzing the formation of cross-links in silicones, however, the toxic nature of tin and the scarcity and cost of platinum necessitate the need to develop modalities for forming cross-links in silicones that are more cost effective and environmentally benign. Another detriment of silicone materials cross-linked using RTV or addition cure methodologies is that the resulting materials are typically thermoset and cannot be readily healed, remolded, or recycled at the end of their useful lifetime.

This presentation will discuss our philosophy behind, and our recent efforts to synthesize more sustainable silicone materials using a bioinspired approach. Our team is undertaking two principal strategies to address silicone sustainability. The first is the use of biocatalysis/biotechnology to mitigate the use of metal-based catalysts in silicone chemistry. Our strategy has been to utilize and develop biocatalysts that can effectively operate in organic solvents or hydrophobic silicones. The second approach is to apply chemoenzymatic strategies to produce silicone materials using dynamic bonds (e.g., reversible covalent bonds and hydrogen bonding interactions), such as the Diels-Alder reaction or the hydrogen bonds between DNA bases, to develop thermoplastic materials that can be cured at room temperature and remolded/recycled with a minimal input of energy.

Paul M. Zelisko

Associate Professor, Brock University

Paul Zelisko is an Associate Professor of organosilicon chemistry in the Department of Chemistry and Centre for Biotechnology at Brock University in Hamilton, Ontario, Canada, and is currently the Department Chair. He is an expert in the application of biocatalysis and biotechnology to silicone chemistry. His current research interests are focused on the application of biocatalysis and other bioinspired approaches to develop more sustainable methodologies in silicone chemistry.

References

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Chemical Recycling of Silicones

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The exceptional mechanical and thermal properties of silicones as well as their low toxicity make them the materials of choice for numerous applications. The raw material is quartz (crystalline silica) from which pure silicon metal is obtained via metallurgy to then form chlorosilanes that can be hydrolyzed/polymerized into silicones.
In a circular economy context, the chemical recycling of silicones to recover the monomers essential for their industrial synthesis is particularly relevant. It saves about 70% of the energy needed to manufacture virgin material by avoiding the metallurgy step from native quartz. This leads to a minimal carbon footprint from the chemical recycling of silicones.
We have recently develop two original catalytic recycling processes for depolymerizing silicones. The first one uses a ligand-potassium silanolate complex in a very effective catalytic process allowing chemical recycling of silicones into cyclic monomers from many substrates including silicone wastes.[1] The process, which requires only a small amount of catalyst (typically 0.1 mol% or a few mass ppm), operates over a wide temperature range (60˚C-170˚C) to efficiently produce the mixture of cyclosiloxanes (D3/D4/D5, efficiency up to 99%).
The second developed chemical recycling process of silicones goes further upstream in the silicone production chain allowing for the depolymerization of a tremendous variety of silicone substrates (oils, gums, resins and even cross-linked elastomers and actual silicone wastes) into chlorosilane monomers.[2] It requires a metalloid source of chlorine and a small amount of a metallic catalyst and operates at low temperature (< 60˚C).

Vincent Monteil
Research Director, University of Lyon

Vincent Monteil obtained his Ph.D. from the University of Lyon in 2002 under the supervision of R. Spitz and C. Boisson where he worked on catalytic copolymerization of ethylene and butadiene. He subsequently moved to the group of S. Mecking (University of Freiburg then Constance) as a postdoctoral researcher working on catalytic polymerizations in water. In 2005, he returned to Lyon as a CNRS Research Associate in the C2P2 Laboratory that became CP2M (Catalysis, Polymerization, Processes and Materials) in 2021. He became CNRS Research Director in 2017. Since 2021 he is director of the Polymerization Catalysis Materials (PCM) team of CP2M Laboratory and of the Lyon Polymer Science Engineering consortium (LPSE, 3 academic laboratories, 16 industrial companies). His research interests deal with the use of catalysis in polymer and materials synthesis (mainly polyolefins and silicones) and in their chemical recycling in a circular economy context. He is Junior Distinguished Member of French Chemical Society (SCF) since 2017 and received the Young Researcher Prize of Catalysis Division of SCF in 2014 and the bronze medal of CNRS in 2011.

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[2] N. D. Vu, A. Boulegue-Mondiere, N. Durand, J. Raynaud, V. Monteil, 2023, Under Review.

Speakers List

Converting Tire Waste to Valuable Reinforcing Fillers: “Diluting” The Silicone Carbon Footprint and Cost

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This simple process leads to a pathway to reduce both the carbon footprint and cost of silicone materials.

The energy used to make materials is normally lost at end of life, when they become waste. The ability to reuse these materials, particular for energy-intensive materials like silicones, permits one to significantly increase their sustainability. A key strategy to reduce carbon emissions requires effective processes to transform waste from one process into valuable raw materials for the same or different processes. Tires are arguably the worst example of single use synthetic polymers in linear economies. At the end of life, most automobile tires still have ~85% of their original mass. Current recycling waste tires include converting to very low value materials which requires intensive energy use, burned as fuel which is another source of carbon emission, and converting to rubber crumbs used as asphalt fillers that is actually another type of landfilled.

We have reported that complete devulcanization of the tire rubber is possible using a very simple organic process that reduces RS-SR’ crosslinks using HSi-containing.1 The process can also be used to reduce only the external surfaces of inexpensive tire crumb rubber from used tires, that is, by ‘doing less chemistry.’ The siliconized crumb could be directly used as a powerful reinforcing agent for silicone foams cured using the Piers–Rubinsztajn reaction2, or RTV silicone elastomers. Samples loaded with ~50wt% elastomer showed comparable tensile strength but far lower cost than the parent silicone elastomers; the carbon footprint of the organic rubber is reduced through this reuse. A further benefit: the produced composite is readily recycled to silicone oil and siliconized crumb.

Yang Chen
President, EnRoute Interfaces, Inc

Yang Chen is President of EnRoute Interfaces Inc. at Hamilton, Ontario, Canada, a company dedicated to improve the sustainability particularly of silicone polymers. His current research is focused on recovering and increasing the values of various waste streams, including used automobile tires for use as feedstock in sustainable silicone-based elastomers and foams.

References

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