CERAMIC TECH CHAT

Episode 52

Title – “Shaping the future with geopolymers: Trudy Kriven”

INTRO

McDonald: “I’m Lisa McDonald, and this is Ceramic Tech Chat.

Stone Age, Bronze Age, Iron Age—we often categorize periods in history based on pivotal developments in materials usage and design. Since the 1950s, researchers often say we’ve been living in the Age of Plastics. But the recent push to produce and consume materials more sustainably means a new materials age is up for grabs—and some ACerS members have strong feelings about what this age should be.”

Kriven: “You know, in that movie ‘The Graduate,’ one of the men folk took him into another room and said, ‘Has one word: plastics.’ Well, now I’m telling you, ‘Hey, there’s one word: geopolymers, inorganic plastics.”

McDonald: “That’s Trudy Kriven, the Donald Biggar Willett Professor of materials science and engineering at the University of Illinois Urbana-Champaign. Trudy is an internationally recognized expert in the areas of phase transformations in inorganic compounds and their applications in structural ceramic composites, geopolymers, and low-temperature synthesis of oxide ceramic powders.

In today’s episode, Trudy shares how her passion for research led her on a globetrotting adventure from Australia to Illinois and how she now focuses that passion on advancing the development of geopolymers to support more sustainable living.”

(music)

SECTION 1

McDonald: “Even before your research journey began, how is it that you came to be interested in science, materials science?”

Kriven: “Well, I guess I was interested in science, partially I was just interested in how things work. You know, when there’s a thunderstorm, it’s pretty scary. And then if you understand what’s going on, it’s not so scary. And, I don’t know, I think my father and mother were very intelligent, and I probably got a few of those in my genes.

And so, I went to a Catholic girls’ school. It was pretty strict. It was known for discipline and hard work. And so, got good enough grades to get into the university. And I did end up a degree in physical and inorganic chemistry and biochemistry. I originally [was] trying to become a high school teacher of science. But then that was in the ’60s, you know, people put a man on the moon. And our university decided they’d encourage students to go to grad school. And so, I just kept on studying and ended up doing a Ph.D. in physical and inorganic chemistry, or solid-state chemistry, at the University of Adelaide in South Australia.

So, I finished my Ph.D. in 1976. Then, I was a bit on the shy side, totally hopeless with fellas, getting nowhere fast, especially after a strict Catholic upbringing with the nuns, you know. So, I cast my fate to the wind, and the wind blew to a post-doc in Canada, London, Ontario. And also, I was born in Austria, but I grew up in Australia when I was three years old. And so, I sort of was thinking, ‘Yeah, I’ll sort of try to head on back to Austria like that fish in the ocean that heads on back into the river where it was born.’

But I landed in London, Ontario, in chemical physics, and it was pretty cold there. And they had statues of ice out in the fields, and they stayed cold all winter long. You know, it was really cold there, and that was a bit of a shock to the system for an Australian who was always on the beach on the weekends with the family.

Meanwhile, I got a letter, finally came in the mail from Berkeley, California. And I said, ‘Where the hell’s Berkeley? It doesn’t matter. If it’s warmer, I’ll go there instead.’ And I went to the Department of Materials Science and Engineering, and I was involved in ceramics. In my Ph.D., I did a lot of X-ray diffraction and electron microscopy. So, they wanted me to do electron microscopy of ceramics. And I sort of realized this wasn’t really solid-state chemistry. But then I also realized they didn’t know much about solid-state chemistry and physics, and I was sort of a bit overtrained for the job.

But then I had a departmental picnic. And we all went out, and we played like baseball. And apparently, I was a good player. I mean, I used to play five years of judo, two years of Taekwondo. So, I was sort of pretty sporty and athletic. Also, one year of Olympic swimming. So, when we played baseball, I really whacked the ball and ran like crazy.

And some of the professors said, ‘Hey, who’s that girl with all that energy?’ Unfortunately, one of the professors died suddenly from cancer, and they needed somebody quick fast to teach a course. And then they said, ‘Who’s that girl with all that energy?’ And they said, ‘Oh, that’s the new post-doc of professor Pask at Berkeley.’ So, I got called in the office, and they said, ‘Hey, we need someone to teach phase diagrams of ceramics.’ And I said, ‘Ah, I’ve never had phase diagrams. What the hell are phase diagrams anyway?’ And they said, ‘Well, you got six weeks to learn.’ And I ended up teaching it even though I never had it before.

It was a second-year course, undergraduate in materials science. So, I ended up studying all day and then all night till about midnight and then give the lecture at 8 o’clock in the morning. So, I lectured on something I only read the day before. And so that’s how I learned ceramics, by teaching it.

And then there was this new professor came, professor Tony Evans, Anthony Glynn Evans, and he came to Berkeley. And at the time, the hot topic was transformation toughening of ceramics, like partially stabilized zirconia or zirconia-toughened alumina. And I happened to do part of my Ph.D. in Australia on theoretical martensitic calculations of zirconia. So, he asked me to join his group. So, after two years, I switched to professor Evans' group, and I did electron microscopy of zirconia. So, that was my third year.

And then meanwhile, this was getting to be a world, sort of, swell of interest in transformation toughening of ceramics because zirconia-toughened alumina is now used for hip replacements and teeth replacements and balls for ball milling and tundra dishes for pouring molten steel into. But I sort of concentrated on the underlying science and mechanism of it, and the crystallography and watching it.

And so, there was a bit of a move of scientists to Germany to the Max Planck Institute in Stuttgart. And so my boss said, 'I'm going to send you on the Berkeley payroll, and you go and work in Germany on the high-voltage electron microscope.' And so I worked there on the electron microscope, the 1-million-volt electron microscope, before Berkeley got its 1-million-volt electron microscope.

And there I managed to elucidate the mechanism of transformation toughening, watching strain fields before transformation, and they were tensile strain fields due to thermal expansion mismatch and then compressive strains field after transformation. So, they let me stay there three and three-quarter years till I managed to get the results.

And so, at Max Planck Stuttgart, the head of the materials science department at Illinois, well he also came to Stuttgart, and we had lunch together. So, he got to know me and my work, and he said, 'Hey, what are you doing after you finish at Stuttgart? What about coming to Illinois?' By that time, I'd done eight years post-docing. You know, fellas usually do two years or three years post-docing, but I was just so interested in research, I didn't really care about getting a job, starting a family, and all that. I was hopeless with fellas anyway, you know, so bit of a lost cause there.

So, I finished in Germany, and I got back to Berkeley. But meanwhile, the University of Illinois sort of made me an offer, and they waited for six months till I finished. And then I felt morally obliged to go to Illinois, wherever Illinois was.

And after I landed in Illinois, I finally got married to my husband, who went to school with my brother. He went to an all boys' Catholic school, I went to an all girls' Catholic school, and never the twain should meet. But [my] brother finally introduced me to him, and after 16 years, he finally asked me out in my eight years of post-docing. I came back to Australia, and we got married, and then he came to Illinois. He's already had a Ph.D. in pure mathematics, but he came to Illinois, and he did another Ph.D. in theoretical and applied mechanics. And we had four children in five years. First baby [at] 37 and three-quarters, fourth baby at 42.

And then MIT [Massachusetts Institute of Technology] asked me, 'Hey, you want to come visit MIT and talk about an interview?' But Boston's such a big city, you know? Crikey, have you seen the traffic in Boston? You got to pick the kids up from kindergarten, you got to take them to music lessons, you got to take them to sports. How am I ever going to do that for four kids? And I thought, 'Ah, you know, a small town like Urbana-Champaign is not bad. It only takes you 10 minutes from one end of town to the other.' And so I sort of said, 'Thanks very much, but I think I'll stay here in Urbana-Champaign.'

So, I got this position at Urbana-Champaign, and I realized that I've got a synchrotron up at Argonne National Lab. I switched gears to in-situ, high-temperature synchrotron up to 2,000°C in air and did high-temperature synchrotron experiments. Also, I realized that ceramics still is the Wild West of chemistry and physics and mechanics. There's a lot of good chemistry, physics, science, and mechanics left to be discovered in ceramics. And I've been here now 40 years as of last February, and that's proven to be true."

McDonald: "That was just fantastic. From you briefly learned about ceramics maybe in your Ph.D. and didn't realize it. It was sports later, physical activity, that actually brought you to ceramics fully. But having all that background in the solid-state chemistry, how that applies to the ceramic materials, showing that post-docs can be fulfilling even for extended periods. Like you said, a lot of people do it for shorter periods, but after eight years, fate had its way, found you the perfect partner in your husband. And you ended up in the nice small town of Urbana-Champaign, which hopefully is not quite as cold as Canada."

Kriven: "No, no, it's not, especially nowadays."

(music)

SECTION 2

McDonald: "So, in this big Wild West of ceramics, like you said, there's so many questions to still be answered, so many areas to explore. And I know for you, one of the Wild West questions that has really sparked your curiosity and interest is geopolymers. So, would you be able to tell us what are geopolymers?"

Kriven: "It's an inorganic plastic. So, the organic polymers contain carbon tetrahedra with carbon in the middle and hydrogen and carbon, hydrogen, oxygen, nitrogen, all those variations, and it's all that organic chemistry. But geopolymers, it's an inorganic polymer made out of silicate tetrahedra and aluminate tetrahedra. And silicon is +4 oxidation, and aluminum is +3 oxidation. So, if you have a tetrahedron of O–H dangling off the end, then it means $AlOH_4^-$. So, you need a +1 charge-balancing cation. And so, that's why you've got sodium hydroxide or potassium hydroxide or cesium hydroxide. And you make a paste under high shear, and it sets at room temperature. Could be viewed as a glass, like a 3D glass, but it was never fired.

Actually, the history of geopolymers is, it was discovered in the Soviet Union in the Cold War. Nobody talked to anybody about anything. But Victor Glukhovsky in '57, they talked about it. And they built two buildings in Moscow: one out of cements, and one out of geopolymers.

They called them "soil cements," but geopolymers are not cements. In cements, it's layered silicates or aluminate, occasional tetrahedra with lime in between. And it's 2D layers, that's it. But geopolymers are 3D bonded, no calcium is in there. And it's not crystalline, it's amorphous. It's nanoporous, nanoparticulate.

So, the two buildings in Moscow. The one out of cement, it had freeze/thaw, freeze/thaw in Moscow winters, and it sort of got worn down a bit. But the one out of the soil cement didn't get worn down with the freeze/thaw [because] there wasn't that much water in it.

And there's this fella called Joseph Davidovits in France who gave it the name 'geopolymer.' And Joseph has now written one big book about geopolymers, which keeps getting bigger and bigger. And once a year, he gives this bootcamp, geopolymer bootcamp, with his son Ralph and a brother Michael. He's got a lot of men folk in his family. And his brother actually makes geopolymer exhaust parts for all the Formula 1 racing cars in Paris. When the exhaust comes out, the plastic body of the cars can't take the heat. So he has carbon fiber embedded in geopolymer as the exhaust part. So all the cars seem to have those now.

So, I've been working on this field for 25 years. I was at a conference in Scotland on the Isle of Mull. It was the mullite conference. And mullite is a workhorse refractory ceramic. There I met this fella from New Zealand, Ken MacKenzie. We got talking. He was working at Oxford in the materials science department. And he played the church organ like I played the church organ. And he earned his own living by playing the church organ at Oxford and also doing research: he was an expert in NMR, nuclear magnetic resonance. And he ended up writing a book about nuclear magnetic resonance.

So, we got talking, and he kept telling me about geopolymers this and geopolymers that. And the next week was another conference in UC Santa Barbara. And naturally Ken MacKenzie was there, and he continued on where he left off, geopolymers this and geopolymers that. Finally, I broke down, I said, 'What the hell are geopolymers?' We talked some more, and then I realized, 'Hey, these guys don't really know what the materials science of it is.'

And then, I had been getting funding from the Air Force Office of Scientific Research. I lived through various program managers, and I think that was the third or fourth program manager retired or moved up, then a new program manager came, and they said, 'Hello, I'm the new program manager. What's new in ceramics?' And I said, 'Funny you should ask. Geopolymers!' And she said, 'What the hell are geopolymers?' So, we went out for a drink that evening, and I told her about it. And when she got back to Washington, D.C., she said, 'Our new areas of research are going to be data management and geopolymers.'

So I said, 'Ah, funny you should mention that. I can give you a proposal about it.' So, she funded a proposal for five years on geopolymers.

But she also said, 'Seems like the Australians have been doing a bit of work on that, and you speak the same language. Why don't you talk to some of these fellas here? Jannie van Deventer is the dean of engineering at Melvin Uni, and also Doug Comrie.' So, she put me in touch with a couple of people already working in geopolymers. And then I said, 'Yeah, these guys still don't know much about the materials science of geopolymers.' And so, I broke down and started doing electron microscopy of geopolymers and looking at it like a solid-state chemist and crystallographer. And then, I worked on it, and the Air Force was happy to keep funding me. And so we were doing the research, and now, 25 years later, I've published a hundred papers on it, with another 30 in the works.

Also, I was active in The American Ceramic Society. So, I was asked to become the chairman of the Engineering Ceramics Division. They used to have their meetings at Cocoa Beach, and then it switched to Daytona Beach when it got too big. And so, as chairman I thought, 'Oh, we ought to introduce some more sessions. Why don't we have a session on geopolymers?' And I started it, and our work featured, but then the Australians and the Europeans got involved, it was being studied by the Europeans as well.

I've been holding these symposia for 22 years now. So far, we've got 100 journal papers published and 20 conference proceedings books on it, all through The American Ceramic Society."

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BREAK

McDonald: "The American Ceramic Society's Engineering Ceramics Division focuses on stimulating interest in the development and utilization of technologies based on ceramic materials. This Division organizes the annual International Conference and Expo on Advanced Ceramics and Composites in Daytona Beach, Florida. Learn more about this Division at www.ceramics.org/ecd."

SECTION 3

McDonald: "So cool to hear that there was a long time the materials science behind geopolymers wasn't that well understood, but now over the decades it's become well understood, we're starting to see some of these benefits in application. The fire resistance, like you said, it was used in houses, now it's being used in Formula 1 racing cars. The freeze/thaw resistance, it can be used to replace cement in concrete to make concrete structures a lot more resistant to those temperature changes. Of course, a lot of these applications we were able to realize because we took that basic understanding and the knowledge and were able to translate it into product development. But I know there can be some challenges in taking that basic academic research and using it to create things that are ready for the marketplace.

I do know that you have come up with one way to help straddle like that academic research and its commercial applications. You founded a company called Keanetech, LLC in 2004 to kind of help with this technology transition from this academic research and how it can be used in application. Can you tell me some about like how you started this company and how it works?"

Kriven: "Ah, yeah, sure. I started it in 2004. I was approached by GE Corporate Research. And GE said, 'Hey, we're interested' in one of my other patents, how to make ceramic powders with low energy and with various complex compositions. That's another talk, if you want it. So, GE Corporate Research said, 'We'd like you to make some materials for us by your steric entrapment method, and here's $125,000. Get on with it.' So, I went out and I put a deposit on a lab, and I furnished the lab, you know, with a fume hood and sinks and things. And we made the material that GE wanted us to make. And it was a DOE [Department of Energy] grant to GE. And so, I finished the job, and I gave them the ceramic powder and they said, 'Thank you very much, and you can keep the fume hood and the lab.' And I said, 'Ah, thank you very much.'

So, I built that lab in response to GE. And then the function of Keanetech is technology transition. The new technologies that we invent here on campus, we can transition them and scale them up and help if there's a company interested.

So, for the last 15 years, I've been getting money for my research from the Army Corp of Engineers and there's ERDC, Engineering Research Development Corp, in Vicksburg, and then they're related to CERL, Construction Engineering Research Lab, which is here in town in Champaign. And they funded our research, and they let me have a lot of academic freedom. So, we've developed some other high-tech technologies.

But the lower tech application that we're working on now is valorization of mine tailings to convert them into a geopolymer construction material that's just as strong as a cementitious construction material. So, right now we're developing a protocol procedure, what would you do with a mine tailing to see what it needs to convert it to a cementitious substrate.

Meanwhile, I've got this Ph.D. student from Pakistan. In Pakistan, the water is underground and it's doped with arsenic. So, everybody drinks arsenic in the water, and the little children sometimes grow up all crippled with arsenic. And they said, 'Please, can you figure out how to get the arsenic out of the water?'

So, we worked with the student for one year. And the government paid him for six months, but then I paid for another six months. And we developed a porous geopolymer that froths up, and then we decorated it with graphene oxide. And then we put arsenic in the water and exposed it to the porous geopolymer, and the graphene oxide sequestered the arsenic and let pure water through. So we had 500 parts per billion of arsenic, and just putting this porous geopolymer in the bottom of a beaker, it went down to 16 parts per billion of arsenic. So it cleaned up the arsenic out of the water.

So, now the next step is to get the arsenic off, wash it in acid, and then you reuse the filter. So, we could start now [with] heavy metals, mercury. In South America, people used to do gold mining. They'd let the mercury out, and it would pollute the countryside. All the vegetation died, all the rivers died. Now we could put porous geopolymers filter across a river and collect the arsenic or mercury."

McDonald: "It's so interesting to hear how these geopolymers are helping to solve the solution of mine waste from multiple perspectives. From cleaning it up out of the water sources, but then also helping to convert these mine tailings into building materials."

Kriven: "Yes, yes. And this year, we're starting our first symposium on CO_2 sequestration. And the way we're going to do it is with porous geopolymers decorated with zeolites. And you can use geopolymers to make nano zeolites by the bucket. So, we're going to decorate them [with zeolites], and we're going to put them on the rooftops and sequester CO_2.

The other thing the Army wants is to sequester PFAS out of the water and out of the soil. So, we're going to do that with the activated carbon decorating the porous walls.

So, geopolymers are a scaffolding that holds up the sequestering agent of the day for the poison of the day. So, it could have a lot of potential applications. Now it's up to you guys to figure out how to put it into practice."

(music)

CONCLUSION

McDonald: "Many material innovations will play a role in achieving a more environmentally friendly industrial and consumer economy. But as we learned today, geopolymers show great promise to help advance these efforts on multiple fronts.

I'm Lisa McDonald, and this is Ceramic Tech Chat."

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"Visit our website at ceramics.org for this episode's show notes and to learn more about Trudy Kriven and her research on geopolymers. Ceramic Tech Chat is produced by Lisa McDonald and copyrighted by The American Ceramic Society.

Until next time, I'm Lisa McDonald, and thank you for joining us."