CERAMIC TECH CHAT

Episode 01

Title – "Aircraft Ceramics at NASA and University: Beth Opila (E01)"

INTRO

De Guire: "What would you do if someone offered you $500 to major in a certain field when you went to college? That was the choice University of Virginia materials science professor Beth Opila faced when she was preparing to attend the University of Illinois at Urbana-Champaign for her undergraduate studies."

Opila: "So anyway, I'm a high school senior, and I've applied to University of Illinois in engineering. And I get this mail from the Department of Ceramic Engineering with a glossy handout and pictures of like cool glasses and things like that, and they also offered $500. I signed up for ceramic engineering. And so my thinking was, 'Well, this looks cool, and freshmen take all the same classes, so I'll just take the $500 and go.'"

De Guire: "Once she got to university, though, Beth quickly discovered that more than just the $500 excited her about ceramic engineering."

Opila: "I'm taking my chemistry lab, and I'm taking a ceramic engineering lab. I'm doing terrible in the chemistry lab. We're doing unknowns and titrating, and one little drop is supposed to fall in and you get your magic pH or whatever, but I let in like 20 drops, and I'm getting like zeroes on all my unknowns, it's like getting a D on chem lab. Then I go to my ceramic engineering lab and go into this room with these trashcans full of raw materials, and we get a scoop and we put it in a bag, and it's like, 'This is so much better than titrating.'"

De Guire: "Beth made an important discovery that year in her ceramic engineering lab—getting a 'right answer' is not the primary goal of ceramics research. New things are being learned about ceramic materials every day, and the willingness to investigate the 'why' when things do not go as planned and the curiosity to figure out how to apply those findings to applications is a driving force for many ceramic scientists and engineers.

But just who are these people pursuing careers in ceramics, a field that many people think simply refers to pottery, tiles, and toilets?"

(music)

SECTION 1

De Guire: "Traditional ceramics are what many people think of when they hear the word ceramics. Traditional ceramics are made from three basic components—clay, silica, and feldspar—and these can be found in many homes in the form of mugs, dishes, and pots.

Advanced ceramics, on the other hand, include materials such as oxides, nitrides, carbides, and borides and are found throughout our modern-day lives, from cell phones and laptops to cars and airplanes to dental crowns and hip replacements.

Beth Opila researches advanced ceramics in her lab at the University of Virginia, particularly those used in high-temperature systems, like aircraft engines. But Beth's research began much earlier when she worked on ultrahigh-temperature ceramics at NASA in Cleveland, Ohio.

Opila: "When I got hired at NASA, I got hired for a specific program. So of course the first 'A' in NASA is aeronautics, which people forget about that, so I was hired for an aeronautics program where we were working in collaboration with GE Aviation and Pratt & Whitney on a new engine concept that was supposed to go in like a high-speed civil transport, like a replacement for the Concord.

In order to be better than the Concord, which used so much fuel, they wanted a more efficient engine. And there were other issues, like the sonic boom and things like that, but we were working on the engine from the point of view of making it more efficient.

And so they wanted to run it hotter, and they were going to use silicon carbide-based ceramic composites. And so I show up at NASA and they said this engine concept was going to have two chambers, one where there was a fuel lean, comparing the fuel and air ratio; and the other chamber was going to be fuel rich, so more fuel than air for the actual combustion reaction."

De Guire: "So a reducing atmosphere on one side and an oxidizing atmosphere on the other side."

Opila: "Right. So, they gave me the oxidizing environment because they thought it was easier, and they gave this fuel rich, this reducing atmosphere, to another engineer.

When you burn fuel, of course you get CO_2 and water vapor, and so I spent a lot of time looking at interactions with water vapor at these really high temperatures. And I discovered through a lot of painstaking experiments that… actually, they thought it was going to be, you know, fine in this environment. It would oxidize, and the oxide would grow thicker, and the reaction would slow down, and that'd be fine. And so I was just kind of figuring out how fast that happened.

But what I discovered was that the oxide was actually vaporizing in the water vapor and the reaction rates were much, much faster. And it took me a long time to convince people that this was actually happening. And so they said, ‘Oh, we need a coating.’ And so because of my work, there’s the whole field of environmental barrier coatings. And, for example, at this conference [ICACC 2020] there was like two, at least, days on environmental barrier coatings, and so I’m very proud that I was the origins of that technology. Of course, I wish silicon carbide didn’t have that problem, but it does, so anyway, I feel like I’ve had an impact in enabling the use of silicon carbide in engines because we realized that we did need this coating.”

De Guire: “Right. And so are environmental barrier coatings actually used now in engines?”

Opila: “They are! Yeah, yeah, so silicon carbide composites entered service in civilian engines in 2016, in LEAP engines that GE makes in consortium with Safran, I believe, in France. So EBCs are flying.

So that was at NASA, it was always like, are you working on a project and are you getting it flying. So, yes.”

De Guire: “How many months or maybe years into this research were you when you started to realize that what everyone thought would happen is in fact not what was happening?”

Opila: “Well, let’s see. I think I started in ‘91, and my paper was published in ‘97, so somewhere in between there, maybe like ‘95-ish? So probably like four years. I remember I had all my silicon carbide samples and I was just like ‘I am so confused.’ So I took them all and spread them all out on a table and grouped them in little groups and said, ‘These ones are like losing weight, why is that? They should be gaining weight,’ and it was like a big puzzle that I had to solve. So maybe four years into the puzzle and kind of getting what’s going on.”

De Guire: “Is that kind of typical for research, that it takes a long time to collect enough data to start to see what’s happening?”

Opila: “I find it’s very typical, at least for the subarea that I work in, is you’ll do experiments and… you know, usually I’m working with materials that want to be used for a long time so you have to do long experiments, like, a week is kind of a short experiment. And I find that like maybe every three years I’m able to make a, as an individual researcher, an individual researcher can make a contribution in this kind of subdiscipline about every three years. You know, get enough experiments done, figure out what’s going on.”

De Guire: “So, as you work with graduate students, how do you advise them as far as… like, we don’t really live in a patient world right now, so how do you help them sort of see that it takes time?”

Opila: “That’s a good question. I’m not sure I address that when they start. I mean, when they’re new in the group and they have some experiments, I want them to be comfortable with knowing everything about whatever equipment they’re using. So usually I have them repeat what the last person in the field has done. It's like you want to understand everything.

So we work with a lot of furnaces, so you want to understand, do you really know what temperature it is, do you really know what's reacting with what in there, are you comfortable with how the gas is flowing, you know, all that stuff. So the first year is kind of just getting into that comfort zone.

And then I tell them that they should expect that, but… I guess we have conversations about how different research areas work and, you know, like some people, students in other groups, may be publishing things in a year, and they'll be like on a paper with ten or fifteen other people. And I say, 'You know, you really own this project, and so you're gonna be the one putting in a lot of work to it and it may not be this big, giant co-author paper.'"

(music)

SECTION 2

De Guire: "Looking back on research discoveries can help you appreciate how things you learned in school are actually critical to figuring out what is going on. For Beth, her work on ultrahigh-temperature ceramics gave her a much deeper appreciation for the thermodynamics classes she took in school."

Opila: "So, I mean, I've taken three thermodynamics classes in my life, and in materials I took the undergraduate one, the master's degree one, my Ph.D. one, and I hated all three of the classes. I never understand like, 'What's with these reference states? I don't get it.'

So now I'm at NASA, and we're thinking about these high-temperature materials, and because we're thinking about these high temperatures, kinetics are pretty fast, and so thermodynamics is really important in what's going to happen. And I started using these tools of thermodynamics and it's like, 'You know? This stuff kind of works.' And so I really needed to understand these tricky bits about thermodynamics in order to be accurate, and so I started to appreciate reference states and all the things that had tormented me before.

I love to teach it because I want to convey to the students that you may hate this class, I'm going to try to make it real for you how we can use this stuff and why it's so cool."

De Guire: "And do you see the students responding a little bit better? Because you actually use it as a tool whereas many professors teach it as sort of, part of, not something they actually use but something everyone needs to know."

Opila: "Right. I think so. I also try to make it… you know, sometimes I feel like some of the more finer details you can sort of get, and then when you use it you can look into the book, but I want them to feel comfortable with the concepts. And so I think that's important and I think they get that.

Like I try to do little things that they'll remember. So when we first talk about solid solutions I have my M&M lecture where I bring in two colors of M&Ms and we talk about the blue M&Ms and the orange M&Ms and they've got their own molar volume and now we'll mix them and they could be attracted to each other or repulsed from each other and now they have partial molar volumes that are different. And so I try to explain it in a way that makes kind of visual sense. And then they can eat them and they can remember the taste too, so appeal to all those senses."

De Guire: "So I can't help but notice that blue M&Ms and orange M&Ms are the colors of the University of Illinois."

Opila: "And University of Virginia."

De Guire: "Oh, okay, excellent. So it's a holistic approach. Very good."

De Guire: "So, you know, yourself had some experiences in pretty different areas. Can you comment on how much it helps you as a researcher… eventually as a researcher, you kind of have to pick a lane and go down it and more or less stay with it; you know, you're asking some really deep questions. But to what extent do your other experiences in other areas sort of inform or help you in the particular area that you're really going to focus on?"

Opila: "I think any experience provides value, right? You've opened your mind up to some different things, you've got different ways you can look at questions. So, everything's been helpful.

And you mentioned you go very detailed down a certain path, but some people don't, right? They're able to recreate their research in a different field. I'm not really that person but I do like to borrow from different fields, like, I also tell my students, 'I haven't had an original idea in my life but what I have had is the ability to take two different ideas and put them together in a new way,' and I think that is really valuable. So if you have a lot of different experiences, you have more things to pick and choose from to combine in unique ways."

De Guire: "That's an interesting point, that it's not that you have to have the original idea. It's sort of that you have to see how you can tie two things together in a useful way. So that's an interesting insight."

Opila: "Yeah, it makes it fun, you keep your eye out. You could go, for example, at this conference [ICACC 2020], you could go to a presentation in a completely different field and just be keeping your eyes out, 'Is there something there that I can bring into my field that would be new and exciting?'"

De Guire: “Does any example come to mind easily that you could illustrate with?”

Opila: “Sure, I can talk about these ultrahigh-temperature ceramics. We want to see how they react at these super high temperatures and the kinds of furnaces that you can use in a lab environment in air or something where there’s a reactive gas, typically you can’t go hotter than 1,500°C. And so I’m always looking for ways to make things hotter in an easy way. I don’t really like complicated things in the lab, I like simple and easy.

And so actually John Halloran, who’s a professor emeritus at University of Michigan, had his students doing resistive heating of ultrahigh-temperature materials. So he put 100 amps through a thin cross section, and it heats up like a light bulb filament. And so I said, ‘This is really cool.’ They were doing it just on like a bench top in a lab and I said, ‘You know what? I wanna control the environment, so let’s take John Halloran’s idea here and put it in a chamber where we can control the gas.’ And so we actually built, my student built this chamber and you can put in different mixtures of gases.

And one of the cool things we did is we borrowed from another experiment where they oxidize in just regular oxygen and then they do a second exposure in an isotope of oxygen, O-18, so you now have your material reacted with two different kinds of oxygen. And then you can take it to a certain characterization equipment—time of flight, secondary ion mass spectrometry—and you can like image your material but you can sort out where the original oxygen was from this heavier oxygen and you can get a nice map to kind of guide you to understand the reaction.

So I combined this John Halloran’s resistive heating system with this idea of doing this two kinds of oxygen exposure into one experiment so we could do this at these ultrahigh temperatures. So that’s an example.”

De Guire: “Yeah, that’s really interesting. Thank you for that. I think it’s useful for people to kind of see how things tie together in an interdisciplinary way like that.”

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SECTION 3

De Guire: “What other experiences did you have early in your career that really kind of led you towards where you are now? Because when we entered the field, ceramics was still very much traditional, you know, triaxial whitewares and refractories, nothing like, it didn’t look like anything you are working on now. So what was that pathway?”

Opila: “Well, again I wasn’t sure and took the long path. I finished the bachelor’s degree and still have no idea what I want to do with my life. So, I’ll delay, I’ll go get a master’s degree. I went to Berkeley, and I got a master’s degree and learned some good things, learned to appreciate thermodynamics a little bit more. My research was pretty obscure. Surface diffusion in porous oxides.

But anyway, I still kind of didn't know what I wanted to do, so I said, 'Well, I'll go work for a while.' I was out in California, so I just worked in Silicon Valley for two years as a packaging engineer, so we're talking about ceramic packages that you put the silicon devices in and seal them and making sure they're reliable and all that stuff. And again, I learned some stuff, it was really the only time I worked in industry, so you learn about, you know, quality control and quality assurance and what's the difference and how you gotta keep the production going. I discovered I was starting to learn what I wanted and that wasn't it, because I never got to ask 'why.' It was just 'let's make this thing, let's make it work, if there's a problem, we'll fix it as fast as we can, we might not fully understand why it's fixed.' So then I went back to grad school and now I'm sure I want to get my Ph.D. and do research and ask that 'why' question."

De Guire: "What has surprised you about your career as its unfolded? You know, thinking back to the 18-year-old who entered a career because they offered her $500, it's actually been a pretty good ROI for you, but looking back, what would you say she would be surprised at where she is now?"

Opila: "There is no way, on earth, that I would ever be a professor. Why would I be this person who wants to work 70 hours a week who, like I said, I thought I didn't have ideas, but it turns out I do, and I love mentoring students, which I never would have thought that either."

De Guire: "Excellent. So it sounds like 18-year-old Beth Opila would be pretty happy, surprised but pretty happy with how it's turned out."

Opila: "I think she would have no clue, like 'How did that happen? I'm not doing that.'"

De Guire: "So, somewhere out there is an 18-year-old who just got her shiny brochure from a university probably offering her $5,000 instead of $500. But what would you say to a young person today considering options, career options, and thinking about materials science, particularly ceramic engineering? What kind of future would you offer to that young person?"

Opila: "Well, I mean, based on the way I've wandered around, I have a couple of responses. The first one is just don't be afraid to try anything, right? You'll get some value out of any experience. And you can change your mind, right? If you start a Ph.D. and you find out you hate it, just get your master's degree, right? Or you start your Ph.D. and then you get a job and say, 'You know what? I really want this job instead.' That's all great because you're just piling up new experiences.

And I guess the other one, I'm going back to that 'why' question, why would you want to do this? What do you value that can help inform choices of direction? Yeah, so, it could be money, it could be like me, you just like solving puzzles, you know, what turns you on? And just follow that."

De Guire: "What kind of global problems do you want to help solve?"

Opila: “Right.”

De Guire: “What kind of global problems would you say UHTCs, your research helps solve?”

Opila: “Oh, well, you know, so we have these engineering themes at University of Virginia, and one of them is for a more sustainable future. So anything that I’m working on is basically focused on increasing the efficiencies. So, this is where I feel like I’m contributing to the big pictures, like let’s do things in a more sustainable way. And if I can help make airplane engines more efficient, then that’s a great thing.”

De Guire: “I just have to ask, when you were doing your research at NASA and understanding how corrosion happens in an engine and that led to environmental barrier coatings, did you ever go through a phase of being afraid of flying? Because maybe knowing too much?”

Opila: “Well, there is that thing, I know what’s going on in an airplane engine, yeah, so, I don’t think I was afraid of flying ever, maybe I don’t want to sit right next to the engine. But I’m sure everyone has heard this but flying on a plane is so much safer than getting in your car. So, I’m not afraid. I understand what’s going on in there, and I realize there’s a lot of engineering behind this wonderful machine and they put a lot of safety factors in there.”

De Guire: “That’s a much better way to look at it. It’s more like that knowledge is positive. Rather than noticing every that could go wrong, it’s more like all the ways engineers and smart people have mitigated what could go wrong.”

(music)

CONCLUSION

De Guire: “For Beth, government and academic laboratories turned out to be the perfect fit for her career, as both environments gave her the flexibility to ask ‘why?’ and to dig deep into understanding what caused materials to behave the way they did.

I’m Eileen De Guire, and this is Ceramic Tech Chat.”

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