CERAMIC TECH CHAT

Episode 57

Title – "Microwave processing for future lunar colonies: Holly Shulman"

INTRO

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

In rare cases, novel materials and processes will debut with a bang, instantly transforming existing research paradigms. But more commonly, technologies will require incremental advancements to reach their revolutionary potential, which keen eyes may anticipate and then work to help support."

Shulman: "And so I always have looked at technologies that would be breakthrough technologies taken to the next step, where they're working, they're scaled up, they're controllable, and those things. So, I just kept my eye on microwave sintering as one of many, many technologies that were interesting."

McDonald: "That's Holly Shulman, research professor at Alfred University and founder, president, and chief technology officer of Bluestar Advanced Manufacturing. Holly specializes in developing microwave processing technologies, and she was recently named director of the new Space Materials Institute at Alfred University in part due to the potential applications of her research on the moon.

In today's episode, Holly will share how she became interested in microwave sintering, its benefits compared to conventional sintering processes, and how it could support the development of future lunar colonies."

(music)

SECTION 1

Shulman: "So, it started with mud pies in the backyard. My mother noticed it when I was four years old that I was quite serious about the whole thing. Unlike my sisters, I was making things and also noticing that you could dry it out in the sun and all these things. It was at a very young age, so I don't know that that was anybody thinking about science, but my mom got me pottery lessons as a little kid, and I always loved that, working with clay. So, really it started with caring and liking clay and working with clay physically, you know, with my hands.

And then heard about ceramic engineering while I was at university, Fairleigh Dickinson University in New Jersey, taking some engineering courses and liking calculus there. And taking a pottery class there, the professor was from Alfred University, he was a ceramic artist. And he said, 'Oh, if you like engineering and you like working with clay, why don't you go for ceramic engineering?' Which was so much better than electrical engineering. And so I came out to Alfred to check it out, and it was just an amazing place for both the ceramic art and for engineering, and so I transferred in."

McDonald: "That's wonderful. So, after then you came to Alfred, what was your pathway?"

Shulman: "So, I was a transfer student, I was an independent student. So, I had some funds coming from a college fund and then student loans. And I was 22 years old when I started here and transferred in and had been working full time before coming here. And, you know, it was a lot of stress, too, trying to keep things going, make things work, being independent. And it was my senior year that I did my B.S. thesis and just fell in love with research."

McDonald: "What was that research project that you were doing at that point?"

Shulman: "So, it was in electroceramics, and it was looking at doping barium titanate to be able to make a positive-temperature, coefficient-resistant material, and so that it was less sensitive to oxidation, I mean, to losing its ability to be used as a sensor."

McDonald: "So, after your undergraduate studies, where did you end up going, what did you end up doing?"

Shulman: "So, I took a job as a research engineer in Tucson, Arizona, for a company called Keramont. And then Keramont kind of split up, and I went with part of that company that became MER, Materials and Electrochemical Research, and I worked there. And then from there, I was a research engineer, and I went to Kennametal in Latrobe, Pennsylvania, and I worked for them. At the same time, they paid for my master's degree at the University of Pitt [Pittsburgh], so that was really good.

So, just well established as a research engineer, and then went to Switzerland and did my Ph.D. in the ceramics lab at the Swiss Federal Institute of Technology. So from there, I was able to, got my Ph.D. while working on an industrial project, and that was in electroceramics as well, even though I was working on structural ceramics at Kennametal and doing cutting tools and such. But all through was research, but it was always applied, it was always looking for developing materials for use in difficult environments."

McDonald: "I also know that you have your own company now. So, when did that evolve during your journey from, you know, you were in the United States, you went to Switzerland."

Shulman: "So, from Switzerland I went to New Zealand and worked in a Crown Research Institute, also doing ceramics research. So, I had my Ph.D., I kind of finished my Ph.D. when I was in New Zealand, I went back to do that in Switzerland with a two-year-old child in tow; it was quite an ordeal. And, so, in New Zealand, I worked on structural ceramic research and different things that were relevant to New Zealand, like cutting tools, shears, sheep shearing."

McDonald: “So, there’s ceramics in sheep shearing?”

Shulman: “Well, we were evaluating ceramics for all different products that were already being used in New Zealand or could be manufactured, but it all had to be New Zealand themed. So, you know, you look around and there was just a lot of sheep in New Zealand.

So, I was basically overseas for 10 years, and from New Zealand decided to relocate to the United States and wanted to start a company. And so this was 2000, and looked at different places in the U.S., and different ideas, and did one of those pros and cons lists. And Alfred was on it but didn’t win, Tucson, Arizona won, and then I came to Alfred anyway because I really like it here. So, I started up my company here in Alfred in 2000, I relocated here from New Zealand, and that was called Ceralink.

And so, the theme for Ceralink was energy-efficient processing for ceramics and glass because it’s highly energy intensive, those fields. It’s really a bottleneck in the process cost-wise, time-wise, energy-wise. And so, I had along the way run into some ideas for energy efficiency, and one of those was microwave processing. So, in 2000, I came here to Alfred with my then five-year-old son, and figured well, you know, I’ll give this a shot, and if it doesn’t work, I’ll just go get a job. It’s not the end of the world, right? I’ve got my Ph.D.

But I didn’t have any money or funding; it was totally bootstrapped. So it was fun, it was interesting, exciting. And one of the things I did is I wrote a proposal to NYSERDA [The New York State Energy Research and Development Authority], and they liked it well enough to fund me, something like $250,000. So, that was the kickoff of my company; that was enough to hire some people and get started.

And the concept was a microwave testing center in order to help industry—and this is why NYSERDA would like it—to help industry save energy by employing microwave [sintering] with their materials. So, we were doing feasibility testing that was underpinned by NYSERDA funding for New York state industry. And we worked with many different materials and many different industries here in New York.

And, you know, [we] had a lot of success in terms of developing good processes and then getting industry contracts and then leveraging other types of government funding, mostly federal, too, to help, you know, it was New York state industry, but then of course it grew beyond that. So, that was Ceralink.”

McDonald: “That’s really interesting, that you were able to have this idea, be able to get the funding for it, and then really get to see it grow and flourish.”

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SECTION 2

McDonald: “So, I know for a lot of our listeners, they might have heard of the term sintering, but what exactly is sintering of ceramics mean?”

Shulman: “Here’s the reality: There is no hard and fast definition for sintering in ceramics. Typically sintering is used to mean you’re taking powders and you’re forming an object that’s solid. And it also implies that to make that happen, that you have to heat it in order to force some sort of diffusion. But if you have liquid in there, which you very often can, so that liquid then assists with all the movement that might happen in that consolidation process.”

McDonald: “So, basically we’ve got some loose particles, loose powders, and we’re basically, through different types of methods, typically with heat in the traditional sense, you get them to condense together. And that’s one reason why the ceramics industry is kind of energy intensive, because a lot of the traditional sintering processes rely on lots of heat to make it happen?”

Shulman: “Exactly.”

McDonald: “So, how is microwave sintering more environmentally friendly than the traditional sintering process?”

Shulman: “It’s more efficient. So, what’s happening is instead of just driving heat from the surface inward in materials that are very slow to move heat. In those types of materials, if you can apply the energy volumetrically instead of just from the surface, then you’re able to absorb energy in larger volumes, right? And so you’re now efficiently deploying that energy. So, it’s the mode at which the material is able to take the energy in.

And the only reason you can’t heat very quickly, whether it’s electric elements or fossil fuel, because of the properties of the ceramics, you can thermal shock it, right? So, with microwave, you can heat it much faster. So, by heating it faster, you are using less total energy. So, you might need a radiant heat to get into a range at which it then absorbs really well. So, that combination of radiant plus microwave is extremely efficient.

Now, microwaves is not the most efficient way of creating a heat source. When you take electric elements, you are able to pretty efficiently convert from like out-the-wall to the radiant, alright? With microwaves, you’re losing some of that. So, maybe you’re at 60% efficient in terms of the source. But once you have that energy, the microwave energy, impinging on your product, your product is able to absorb it immediately and completely in the whole volume.”

McDonald: “That’s really well said. And I think it also really drives home the point that when looking at what is maybe the most efficient or environmentally friendly or fastest, all these key terms of manufacturing processes, there are so many steps throughout the process that need to be considered to really determine which one I guess is most efficient. Because it might be, like you said, more efficient at the very start, but once you get into the actually interacting with the material and causing it to undergo a change, it's more efficient at that point in the process."

Shulman: "Right. And that's why it's relevant to do manufacturability studies, so that you take into account everything. You know, the cost of the equipment, the upkeep, reliability, then the cost of the type of labor to run equipment. And when you put all of these things together, we did a lot of manufacturability studies of a lot of different product types, and there were like paybacks of a year to two years. And that's not including other things like looking at the ability to use microwaves to make better products. So, that's just looking for trying to make equivalent products.

There's also opportunities because you can use microwave to, for example, with nanoceramics. You've got a real problem as soon as you apply heat to it that you lose your nanostructure because of all that surface area driving force for the sintering. But you can use, it's like a flash sintering technique, you can use it with microwaves so that you cut the energy, you just cut the power, and you stop heating, and then you can freeze in really good structures.

McDonald: "That's really cool."

Shulman: "We did a project with Ferro, big producer of barium titanate. It's super important for those multilayer capacitors to have really fine particles. You need thin, thin layers, and to make a thin layer, you need six or seven particles deep. And these are tape cast—amazing technologies.

So, we worked with Ferro, and we did microwave processing and were able to get barium titanate out without any grain growth to the titania. It was the same size as the titanium starting input. And it was a really great project. And so, using mixed oxide, it was absolutely the finest you could possibly do, and you can't do it with traditional calcining because of all that heat; you can't control it like that.

But here's this; this is really interesting. The dielectric properties of barium titanate, it turns out that you have a self-limiting process because the barium titanate did not absorb as strongly as the titania. So, you can blast it with microwave, and the barium titanate was not absorbing particularly well compared to the titania. So, it would drive the process so that the titania was all converted, and the barium titanate that it was converted to, there was a drop in its ability to interact in the microwave. So, yeah, it's a beautiful process."

McDonald: "That's just beautiful because, like you said, with heat, you wouldn't be able to do such like, it would be impossible to do that with the heat process."

Shulman: "Right. And so, there's lot of different things that are just not doable conventionally with radiant heat and standard ways that can be done with microwaves."

McDonald: "So, when did people start experimenting with microwave sintering? When did this start becoming a research field?"

Shulman: "I saw it in the '80s. I was at The American Ceramic Society conference. It was probably Terry Tiegs out of Oakridge National Lab and playing around with microwave sintering. And my feeling was that it doesn't work, but they were able to get the tiniest little speck and analyze it. And that was very interesting because if it did work, if you could get it in control, then it would be really significant.

And then I ran into somebody in Australia when I was working in New Zealand. And I said, 'How about if I send you some samples and see what you can do?' So, I sent him my samples that I made in my lab in New Zealand of zirconia toughened alumina, and he sent me back those samples sintered with a finer grain size than was at all possible conventionally. So, I started saying, 'Well, it can work, and it works under these conditions. Can we make it work in different conditions?' And I started experimenting while I was in New Zealand. And then when I came back to America in 2000, I was like, 'Yeah, I'm going to see if I can't start a company for energy-efficient processing leveraging the value of microwave.' So, that's where I went."

(music)

BREAK

SECTION 3

McDonald: "For your research so far during the interview, it's really spanned the world, you know, all the way from Australia to the United States. And I'm really excited that your company now is thinking even broader. You're expanding beyond just the Earth to the moon now. That's a completely different environment and situation that we might be able to use microwave sintering in.

So, I guess can you tell us a little bit about the current state of space exploration? You know, like why are we even thinking about needing to use materials manufacturing processes on the moon? Why is that even something that's being considered right now?"

Shulman: "Well, there's an interest in using the moon as a launching position for outer space exploration. Once they found water, you know, water ice, and a lot of it, that's an important source for rocket fuel as well as for any sort of human habitation or that kind of processing. So, the gravity is less, there's no atmosphere there to fight against, so you can launch with much less fuel. And so, really Mars is a destination."

McDonald: "Well, it sounds like those are some really good reasons to use the moon as like a launching base for further exploration, like the lower gravity, like you said. But why don't we just, if we need to establish a base there to launch from, why don't we just bring the materials from Earth to the moon to make all of these space stations?"

Shulman: "Trying to get off of Earth beyond our atmosphere is extremely energy intensive. Someone from NASA once gave me the analogy, if you take a car and then you want to send it off into space, most of that car is all just going to be the energy input, and you just have one little nut, lug nut on the hubcap that is the payload. So, that's what it's all about, it's just trying to get enough stuff up there."

McDonald: "And since it's kind of hard to get stuff up there, it's nice if we can just use materials already on the moon then, right? And turn them into the products that we need."

Shulman: "Right, nice, right. That'd be nice. So, it's necessary if you want to build on the moon, it's necessary to use material that you find there. So, they call it ISRU, in situ resource utilization. And so, what's on the moon? Well, there's, you know, there's a lot of moon dust. There's moon dust, right? And rocks. And they call it regolith. So, regolith is basically broken rocks."

McDonald: "So, I know we talked about why microwave sintering is much more efficient than traditional heat-based sintering, and so I'm sure that's probably one reason why microwave sintering would be useful on the moon: It's just so much more efficient. Are there other benefits about using microwave sintering on the moon that make it so desirable of a process to use for manufacturing there?"

Shulman: "It's energy efficient, which is super important because that decreases the infrastructure that you need in order to make more infrastructure. So, other reasons is it's also, it's very versatile.

So, initially what needs to happen is some paving, right? So landing pads. And so, it starts out with dust mitigation. One of the major problems on the landings on the moon was dust getting into the mechanisms, even on the space suits and everywhere. So, first dust has to be controlled, and microwave offers a way to do that on a rover. You can actually attach a microwave horn and be able to raster back and forth in order to passivate that dust and make a landing pad and roads, too."

McDonald: "Would that be classified as a type of additive manufacturing? Using the microwave to make these pavers?"

Shulman: "That's absolutely can be used in additive manufacturing, and it can be done in different ways. You can do it by making a pass through and then putting powder on top, regolith on top, and then doing the next pass and building vertically that way.

But you can also do it by, the way that you can control a microwave, you can make it penetrate quite deeply and say, you know, more than a meter deep. So, you penetrate deeply, and if you can, you know, arrange and there's technology, develop the technology so that you're now sintering at a depth and not at the surface, and then razing that heat front, fire, you can 3D print sort of starting down without having to add powder, but you're three dimensionally building from a depth."

McDonald: "That really is versatile, then, this technique."

Shulman: "Right. You can also make bricks and tiles, which I like the idea of bricks and tiles."

McDonald: "It all comes back to those traditional ceramic forms, right? Bricks and tiles."

Shulman: "Right."

McDonald: "I guess one of the challenges is in theory, you know, this is great. We can take this regolith, we can turn it into the other products. But it also kind of hinges on do we know that this regolith material is going to respond well to microwave sintering. And of course, we can't necessarily just go to the moon to test it on regolith on the moon. So, how are we able to figure out here on Earth how well it's going to respond to the moon surface?"

Shulman: "So, they do have regolith simulants, and so we're working with those. We're doing microwave sintering of regolith simulants here."

McDonald: "So, how do create the regolith simulants? Do you find places on Earth that are similar to what we expect the moon to be? Or do you create simulants from scratch?"

Shulman: "So, it's a new thing to be making synthetic simulants. What has been done is geologists have looked for deposits that were a reasonable match to what would be on the moon. And so, they've been using mined materials, but now they're developing synthetic glass, which is done at Washington Mills.

And we here in my team at Alfred have developed some synthetic simulants that have the different materials that you need to have because it's really hard to find some of those in a mined position. It's very rare to have a high calcium material in aplasia clays. Like on Earth, we have a lot of sodium, and on the moon they do not."

McDonald: "That's really cool that you're able to make it yourself versus just having to rely on mining it because it'll be so much more accurate to the materials you'll be experiencing up there."

Shulman: "Yeah, absolutely. We've been struggling with some non-lunar material in simulants, when we go to vacuum microwave sintering and it's outgassing. And it shouldn't be there in the first place, so if we make simulants ourselves synthetically, we can get a much better behavior and understanding. So, we're working on that."

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CONCLUSION

McDonald: “As we prepare for a future traveling the stars, energy-efficient processing technologies will be a necessity for both those in space and those remaining as Earth’s stewards. Fortunately, thanks to innovations such as microwave sintering, we are on the right path to achieving this goal.

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 Holly Shulman and microwave processing. 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.”