CERAMIC TECH CHAT

Episode 61

Title – “Hypersonic research and fast-track education: Rod Trice”

INTRO

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

When things do not go right during your experiment, it can be frustrating to feel that what you learned about in the classroom is not working in real life. But being humbled by the lab is a key part of growing as a researcher, and it is one reason why hands-on experience is so important for students just starting on their scientific journey.”

Trice: “I think most folks in the audience will resonate with any sort of hands-on experience is just a great teacher, right? You know, I love reading books, but man, when you get your hands on something and start doing things, that’s just really when everything just sort of connects, so.”

McDonald: “That’s Rod Trice, professor of materials engineering at Purdue University in Indiana. Rod has been a professor at Purdue since 2000, and he and his students have played a role in the resurgence of hypersonics research in the past couple decades. He is now currently teaching a course on hypersonic materials as part of The American Ceramic Society’s government-funded hypersonic training program, which is coordinated in collaboration with the United States Advanced Ceramics Association.”

In today’s episode, Rod briefly overviews the history of hypersonic flight, describes current hypersonic vehicle design paradigms and materials, and shares his expectations for the future of this critical national defense sector.”

(music)

SECTION 1

Trice: “I did undergraduate at The University of Texas at Arlington, and I was fortunate enough to work with just a great mentor, Professor Roger Goolsby. He was an MSE [materials science engineer] working in a mechanical engineering department, and so he had this great mechanical test lab, and I was able to as literally a 20-year-old do all sorts of interesting mechanical testing. And I learned how to do like fatigue testing of silicon solder joints for TI [Texas Instruments]. I learned how to do fracture toughness testing of like titanium for a missile company. I mean, I did a lot of just great things, and it was just a fantastic experience for me.

But from there I did get a master's with him, and then I went into industry. So, I was there for six years in the low observable area, this was like the stealth area, it was a very hot topic in the '90s. But I knew I wanted to be a professor, and so at the age of 29, I started applying to grad schools, and I was lucky, and I do mean lucky enough, to get into the University of Michigan starting in the fall of 1995.

I was a non-typical grad student because of my age. I was, what? I guess roughly 8 years older. And so I always felt like I probably wasn't the most attractive grad student on paper. Honestly, it's kind of embarrassing to say, but like the internet and email was mostly new to me. I didn't have an email address. My first one was at, you know, rtrice@umich.edu, right? That was my very first email that I ever had.

And so, there were two faculty at the University of Michigan I was interested in, and thankfully the one who had support was Professor John Halloran. Hopefully some folks may remember the great John Halloran. I will forever be grateful to John because he gave me a chance to be a grad student and he took a risk with me. And so I, you know, I've always just had a real fondness for John.

But John was working on this DARPA-funded effort where they were using powder processing to make like CMC materials, ceramic matrix composite materials. It was called fibrous monoliths, that was the name of the actual technology that he had developed, and I worked on processing these materials. They were boron nitride, like a coating of boron nitride around like a silicon nitride fiber. But these were all powders, right? They weren't like classical fibers like we think about now. And so it really was a brilliant idea that John had. It was kind of a low-cost way to make CMC materials.

So, this was my introduction to ceramics, was working with John. I'd never really done much in the ceramics area up until that point. And I got to do what I still do today, which is ceramic processing, because there was really no one better than John at ceramic processing. I got to do mechanical testing, which I was familiar with just working on other material systems. And then I got to do TEM, which was to me like the thing I wanted to do when I went to grad school because it seemed like it had so much appeal. And it turns out TEM was actually a lot of fun. I had a great time, and it became very important for our research as we were trying to figure out how these materials failed at high temperature, so."

McDonald: "Can you explain what this TEM stands for and what its purpose is?"

Trice: "Yeah, so, TEM is just simply transmission electron microscope. And essentially what we do is we make our samples thin enough and make the electron beams powerful enough that we can actually move it through the sample. There's a lot of math involved in TEM, that probably wasn't my favorite part, but you can do some amazing imaging. You can really look at the grains, you can look at the grain boundaries, and in my particular case, I was able to see some glassy phases that were sort of collecting in specific areas of our composite that were really dominating the high-temperature properties.

So yeah, I learned a lot from John while I was there about advising students. I still use that at Purdue today as a faculty member. And what John was really good at was giving people like freedom to do, to fail, and to succeed, and just being really hands off. And so, I appreciated that John trusted me.

After I graduated, I needed to do a postdoc to be a faculty member. John sent out some emails and really helped me. Thankfully I got to work with another great in the field, which was Professor Kathy Faber, who was then at Northwestern University. I hope many of the folks know her, she was a super influential ceramist along with John.

And what was great about what Kathy was doing, it was different. It was in the ceramics area, of course, but it was different than what John was doing because Kathy was kind of getting into plasma spray coatings and the plasma spray technologies. And so, I got to learn this whole new field. It was still ceramics, of course, but I got to learn how to do that. And that's really helped me out a lot as a professor because I can kind of talk in the CMC area and I can also do research in the coatings area.

And so, I learned a lot from Kathy as well. She was a tremendous leader and really just a great listener. Honestly, one of the very best people I've ever worked with. And so, I always want to give a shout out to these folks that were influential in my career and helping me be successful.

But yeah, working with John and Kathy, I got to see maybe some of the most interesting things in the ceramic area for me. But what's interesting is like knowing about CMCs and ceramic coatings really helped me to make contributions in the hypersonics field, right? Because you're going to need these high-temperature composites and most likely you're going to need a coating for them. And so that was really, really beneficial to actually work with those folks.

And so, that's kind of where I am today, still doing some research in that area. And I'm guessing you'll probably ask me some questions around that later on."

McDonald: "Of course we are, we love hypersonics. That really is a hot topic right now. So, let's talk a little bit about like what is hypersonics? People probably have heard that term, but what does it mean?"

Trice: "Sure, great question. So, hypersonics is flight that is five times the speed of sound. That's usually the definition. So, we would call that Mach 5. Hypersonics was extensively studied in the '60s and '70s, but then I feel like the focus changed and became sort of an afterthought. There was really a focus on stealth, and I was supported by that when I worked in industry. And it was a lot of fun.

You know, stealth is, of course, evading a radar, and you gain advantage by sneaking up on people essentially. With hypersonics, it's not about sneaking up, it's just about being fast. And so, that's kind of what was happening in that day.

So, there has been tremendous investment in hypersonics the past 15 to 20 years. And this investment [is made] by almost any nation that's worried about their borders. So, I don't see it stopping any time soon."

McDonald: "So, you've talked about how in the '60s and '70s, it was all about the fast speed, then it kind of went to stealth. Was there a specific thing that caused us to kind of go back towards researching hypersonics in the recent decades?"

Trice: "Well, that's a great question. I suspect it's because other countries were developing some of this technology a little bit more rapidly than we were. That would probably be the most honest answer I can give. I think there was just concerns."

McDonald: "That makes sense. We love competition. Competition is the fruit of innovation a lot of times."

Trice: "Oh, absolutely it is."

(music)

SECTION 2

Trice: "So, a little bit about kind of like the past history of these aircraft. Things have been falling to Earth [at] hypersonic speeds for eons. But like the first manufactured object to reach hypersonic speeds was in 1949; it was in a sounding rocket. Sounding rockets were like research rockets that people used to gather information from high above the Earth. And so, these sounding rockets were put up into space 30 to 90 miles above the Earth. And then when they came back to Earth due to gravity, they would achieve remarkable speeds. I think this particular instance, it was Mach 6.7.

Yuri Gagarin was the first human to achieve hypersonic flight; this was in 1961. And once again, it was when this Russian cosmonaut was falling back to Earth or coming back to Earth. The great Alan Shepard was our U.S. version of Yuri Gagarin. He was a Navy pilot, he was working on Project Mercury, and he reached those sort of hypersonic speeds about a month later after Yuri did.

The first aircraft that wasn't just falling back to Earth but was actually flying was this X-15 aircraft. This is an experimental aircraft. It curiously was dropped from a B52 and then it was accelerated with a rocket horizontally to Mach 6.7. And this was way back in 1967, and William Knight was the pilot. Here's what's interesting about that. We're about 58 years later, and the X15, that particular flight, still holds the record for the highest speed for a crewed, meaning there was a person on board, powered, meaning that it was propelled, aircraft, right?

So, another famous pilot I should mention who flew the X-15 was, of course, Purdue alumni Neil Armstrong, and this was in 1962. He got to Mach 5.24 in his particular flight.

But it’s amazing that we do not put people in these hypersonic planes anymore. You’re going to see that they’re all unmanned or unpersoned.

Probably what I can do now, I can talk about a couple of the new modern aircraft, kind of the general design, if that’s okay.”

McDonald: “That sounds perfect.”

Trice: “Okay, great. So, yeah, there’s kind of looking after the X-15, there’s two basic aircraft that we’re seeing in our designs today. One is called a boost–glide aircraft. So, boost–glide systems are where the aircraft is typically launched very high into space. This is the ‘boost’ part of boost–glide. And then as it falls back to Earth, there’s typically some sort of a maneuver where the front end of that aircraft is lifted up and it’s going to sail horizontally with respect to the Earth’s surface. That’s the ‘glide’ phase. So, that’s our boost–glide aircraft.

And then in contrast to that, we have what we typically call scramjet vehicles. These are typically launched at lower elevations, they’re accelerated with a rocket to Mach 4, and then they fire this scramjet. This is a particular type of propulsion system, and that scramjet then takes that aircraft up to Mach 5 and faster speeds depending on the fuel.

And what’s significant about scramjets is that while there’s fuel on board of that plane, they actually gather oxygen from the air as the oxidizer for that fuel. And this is significantly different than a rocket. So, scramjet vehicles actually have to fly much closer to the Earth where the oxygen levels are at a higher concentration.

So, we got boost–glide systems and we got our scramjet vehicles. And so those are kind of the two basic vehicles that we see today. Once again, these are all unmanned aircraft that we see today.”

McDonald: “So, with the hypersonics moving at such fast speeds, I assume that there are some challenges with that. So, what are some of the challenges with developing vehicles that can move that fast?”

Trice: “Yeah, no, that’s a good question. At Mach 5 and faster, it is an incredibly harsh and unforgiving environment. Typically there’s like three key problems that people talk about. One of those is that region directly in front of the leading edges or the nose cone. In that region, the air is slowed down dramatically; it simply cannot get out of the way of the speeding aircraft.

And so what you form there is what’s called a stagnation region flow field. And so just picture it as kind of a thin, maybe a boundary layer there that’s several millimeters thick in front of your aircraft. And in that region, the gas is so compressed it has very high pressures associated with the gas because of its high compression, has a very high enthalpy, very high temperature. You can even have, and this is remarkable, disassociation of the gases there, like the O_2 can become atomic oxygen.

So, this environment is incredibly challenging for any materials that we're going to put on our aircraft. We can see temperatures in excess of 2,000°C easily in these areas depending on some geometry factors as well.

We also worry about what's called the high-speed boundary layer transition problem. And this is really easy to understand. Essentially you want the airflow over your aircraft to be laminar. And when I think of laminar flow, I think of a nice lazy river in a valley, right? You know, it's just making its course and it's very, very smooth. That's a great picture of laminar flow. The problem is that while we have laminar flow maybe over early parts of the aircraft, as it goes back on the aircraft, it begins to transition to a turbulent flow. Turbulent flow, that's your whitewater rapids, if that helps you to see it. The problem when we go from laminar to turbulent flow is that the amount of heat that comes into that aircraft has increased dramatically, maybe by 7 to 10 times. The problem for us as materials folks is that as we go to that turbulent flow, we just see a lot more damage done to our materials. So, this is one of the areas.

And then the third area is just something called shock–shock interactions. The idea here is that you've seen these pictures of bow shocks in front of a moving object before. The problem is that when we have real aircraft that have like, for example, swept wings that sort of transition into unswept wings, and I'm sort of picturing the space shuttle right now whenever I say that, that region where we go from unswept to swept, you can actually have competing bow shocks there. And in those regions, we can have really, really rapid deterioration of materials.

So, these are some of the big problems, but all of them come down to the fact that the materials are interacting with this really harsh and unforgiving environment. That's really what's driving this. So, it's a difficult problem. I look forward to seeing what happens over the next 20 or 30 years; that will be pretty cool to see."

McDonald: "Well, I definitely will, too, because, you know, already in just these few decades, we've made such leaps and bounds with the design, the technologies. And one of the reasons that we've been able to come so far is because of materials scientists like we have here at The American Ceramic Society. We can have the best designs in the world, but we need the materials to be able to realize those designs. And so, what are some of the materials that we see that are used in these designs that you've been talking about, with the scramjet and stuff?"

Trice: "So, if we think about the materials on these aircraft, I've kind of put them here in three categories. One area is just the structural ceramics. These are materials that are out in front on the leading edges. They're designed to carry loads. These are most likely going to be ceramic matrix composites, meaning that it's going to be a fiber-reinforced material. One of the most important, of course, is carbon–carbon, and many folks have heard of that today. Of course, this is a refractory composite. It can withstand temperatures up to 3,000°C. That's a remarkably high temperature. But, of course, it has an Achilles heel, and that's the fact that any oxygen will react violently with the carbon and will ultimately destroy that matrix. And this reaction occurs at temperatures as low as 500°C. So, any structural ceramic like carbon–carbon really is going to have to have some kind of a protective layer on it, and we'll talk about that.

Some of the other structural ceramics that are of interest include silicon carbide fiber in a silicon carbide matrix. We would call those SiC–SiC composites. What's great about these materials is that they do form a protective glassy layer on the surface as the silicon carbides oxidize to silica. So, that's fabulous. And then I think a new and upcoming material is going to be ceramic matrix composites, but we're going to make the matrix now out of an ultrahigh-temperature ceramic like ZrB_2 or hafnium diboride or some materials. So, an example might be a silicon carbide fiber reinforced ZrB_2 matrix material. And so, I think there's interest in doing work making UHT–CMC [ultrahigh-temperature–ceramic matrix composite] materials.

So, I think the second category of materials of interest are probably going to be window materials. All aircraft have to make some navigation decisions, and so your aircraft has to have the ability to receive information and then make some decision with it. In a non-hypersonic aircraft, that's pretty simple. A lot of the radomes that you see up front are actually made out of some kind of a glass composite. Of course, now we're talking about traveling at incredibly high speeds with a lot of friction in the air. And so, we need new materials, new window materials that will sit in front of these sensitive electronics that can not only transport the gigahertz frequencies but can also essentially be able to withstand these incredibly high-temperature environments.

And so, in the window material category, we're looking at windows for guidance. We think about things like silicon nitride, and silicon nitride is probably the baseline material used in these particular applications.

Okay, so we've talked about our structural materials, structural ceramics, we've also talked about window materials. I think the third category of materials is gonna be just coatings, right? We already mentioned that carbon–carbon is gonna need coatings, so we gotta make sure that we can develop coatings for those. And one of the central categories of these coatings are called ablative coatings. The X-15 that I mentioned earlier that flew to Mach 6.7 was actually covered with ablatives. Evidently it looked like a giant eraser because these ablatives, I think it took on kind of a pink hue whenever it was applied to it.

But what's interesting for me, Lisa, is that these ablatives are a polymer, right? It's a phenolic resin. You know, we think of polymers as being sort of not a high-temperature material, and they are certainly not. But when we put phenolic on our aircraft, it actually can protect that underlying structure. And so, there's a lot of research going on right now in these sort of coatings and making these great phenolic coatings.

And the way they work actually is also very interesting to me. These phenolic coatings, when they're sprayed on an aircraft, and as the aircraft heats up, they interact with them and they form like a porous char. And that conversion of the polymer to like a carbon char absorbs a lot of that flux that's coming into our system, so that's fantastic. But the second thing that happens is that there's always a pyrolyzing reaction going on below the char that produces gases. Those gases sort of filter up through the porous char, they get heated, and then they're just passed into the atmosphere. So, this particular ablative, you actually get a couple of very, very positive effects that come out of them that make them a very, very effective way to protect our aircraft from these intense heat fluxes."

McDonald: "I think that's a great overview, of how you can kind of separate and think about it in these three kind of ways and how they all work and integrate together to keep the vehicle safe during these very high speeds."

Trice: "Yeah, absolutely. And, you know, for the materials scientists and ceramists specifically, I mean, it's incredibly exciting to be working in these areas. There's never, never ever been a better time to be a high-temperature ceramist than today, in my opinion. And so, I've really enjoyed all of the research activities and the things that I've gotten to do in my particular research group at Purdue and then through another organization that I work with. It's been remarkably, a remarkably fun time. It's a great time to be alive."

(music)

BREAK

McDonald: "The ACerS–USACA Hypersonic Materials Training Program is a comprehensive approach targeting workforce development in this critical national defense sector. Consisting of both in-person and virtual courses, the recently granted two-year extension of government funding for this program will allow it to continue into 2026. Learn more about this program and how to get involved at www.ceramics.org/hypersonic-training-program."

SECTION 3

McDonald: "So, with your research at Purdue, you mentioned that you do some characterization, like using that TEM technique that we talked about. What are other ways that you go about working with, what types of experiments do you do with your students on hypersonic materials?"

Trice: "What we're known for in our group is ceramic processing and ceramic forming. As you know, most ceramics are formed by starting with powders, right? And then we take those powders and we do something with them to get them into some cool shape or some useful shape.

So, in our group, we do what I consider to be a lot of creative processes to be able to take powders and put them into useful shapes. We do things like slip casting and extrusion forming, injection molding, coextrusion, additive manufacturing, this is all with ceramic powders of interest, like a ZrB_2 powder or silicon nitride powder or something like that. So, that's kind of like the area that we work in. We definitely do characterization in our group because that's part of evaluating our processing method. But really what we sell ourselves at is just being world-class processors of ceramics within our group.

Right now, I have 10 grad students and five undergrads. They all support work in this hypersonics area. I work with some great faculty colleagues at Purdue. One of the ones that I've worked with the longest is Professor Jeff Youngblood. He's been a collaborator and really a close friend for about 20 years now, more than 20 years now. And also work with some folks in other departments, Professor Andres Arrieta in mechanical engineering. So, these are some of the folks I work with.

The other thing I wanted to mention is that I am very closely tied with Purdue, obviously, but in 2022, Purdue created this Purdue Applied Research Institute on campus through investments from JHTO [Joint Hypersonics Transition Office] in collaboration with Crane Naval Base and internal of Purdue investments. We've created this world-class facility where we can sort of scale up the things that we do at Purdue. And so I really am very blessed to have such great facilities surrounding me and then also great collaborators and great grad students as well."

McDonald: "It really sounds like Purdue is the perfect place for you to land to do your research on these materials."

Trice: "Man, it absolutely is."

McDonald: "And speaking of collaboration, it's been pretty exciting here at The American Ceramic Society because back last year, in January 2024, it was announced that The American Ceramic Society had received some grant money from the Department of Defense Cornerstone Consortium under the DOD Industrial Base Analysis and Sustainment Program to put together a hypersonic training program. So, ACerS has been working with the United States Advanced Ceramics Association on this program, which to date has involved a lot of virtual and in-person courses. And I know you've been one of our instructors through this program, so can you kind of talk about how you became involved with this initiative and what the classes are that you've been teaching?"

Trice: "I'd be happy to do that. Just going back a couple years, I developed a course on materials for hypersonics. Actually, during COVID [the COVID-19 pandemic], I developed a course right here in my basement where we're recording this, and it was probably the most stressful thing I've ever done because there was no book on it. And just going through and from literature and a few book chapters developing this course. But I just felt this strong need to really understand the problem. And probably most faculty will tell you, if they want to understand something, they probably just want to teach on it, and that's going to make us learn it for sure.

So, I developed this course on materials for hypersonics. It was pretty broad; it covered a lot of the areas. And I've taught this course at Purdue for many times now, and it's been developed into an online class at Purdue that's taught asynchronously. And so, the course was pretty mature now. What's interesting is that one of my students who took that first class was a guy named Cole Davis, and he's at the Naval Surface Warfare Center in Crane, Indiana. And so after he took my class, he took a job there, and he approached me about doing like a short course there. And I thought, 'Oh my gosh, what an amazing opportunity. Thank you, Cole.' And so I taught that course.

And then what's interesting is a few months later I ran into Eileen De Guire at MS&T, right? And she mentioned that they were, I guess that they had gotten some money and were looking to develop a course on hypersonics. And of course I volunteered my services, and this is really what started my teaching relationship with ACerS. And since then, I've worked with Amanda and Madilyn, of course, and they've been booking me these sort of different projects or different teaching assignments along the way, and I really appreciate that.

But I guess most recently they have won another sort of pot of money for workforce development, and they've asked me to continue to contribute that by offering a short course on this materials for hypersonic along with my notes that I've developed as well. And so yeah, I'm going to be doing that here, it looks like, I guess it's October 29 in Washington, D.C., and this is for the United States Advanced Ceramics Association. And so I'm going to be teaching roughly a 7-hour version of that course on that day, along with providing my notes just so folks have something to take home with them. So, I'm really excited about that.

And then I'm going to be doing some more stuff for ACerS, doing a virtual course in early January, a two-day, and then also a one-day course at CMS. CMS is the Composites, Materials, and Structures [meeting], and that particular meeting is in late January in New Orleans. So, I'm very excited about all of these things. I love the fact that I get to work with ACerS doing this, and that's really what probably brings me a tremendous amount of joy, so."

McDonald: "That is really fantastic that we've been able to work with you to help share all this vast knowledge that you have on hypersonic materials. And so, as you've said, this kind of was the beginning of your teaching relationship with ACerS, but I'm sure you've been involved with ACerS before this, that's how you ran into Eileen at MS&T. So, can you tell us a bit how you came to join The American Ceramic Society in the first place?"

Trice: "Oh yeah, absolutely. Yeah, it was 1995, actually, my first year in grad school. When I started with Professor John Halloran at the University of Michigan, that is when I signed up for the first time, and it was going to probably that spring meeting, or maybe, I think it was in Indianapolis or Cincinnati at the time. So, that was my first time.

I am a huge fan of ACerS, obviously. They are my only professional society. It's really where I commit a lot of my time, I mean, really all of my service time for an organization goes to ACerS, so.

I would say what ACerS has taught me, especially as a young scientist, was how to present technically. There's a learning curve, right? You don't just show up one day and give this perfect, flawless presentation. And so, through a lot of, you know, failures, or at least what's in your mind seems like failures at the time, I've been able to sort of tweak my style and just become a bit better at communicating science. And so I give ACerS a lot of credit for that.

Also, ACerS, it allowed me to be able to meet my like ceramics heroes. Because there are all these papers when you're young and you're in grad school and you're like, 'Oh my gosh, all these different folks, Tony Evans,' could go through other names as well. But you know, you just kind of want to meet them. And it's there at that organization or at those meetings where you get to see them, you know, riding down the escalator or something, be able to have a side chat with them, so.

So, I love ACerS, and will, you know, continue to work there. Right now, I'm on the board and will continue to just serve the organization and, you know, it's something that I'm really committed to. But yeah, I'm very, very happy. I've invested a lot of my time, parts of my life into the organization. So, it's a really special place.

McDonald: "And it's members like you that make us have such heart in our Society, you know? Like the passion of our members getting together, networking, is what brings it all alive and makes it such a great place to be."

Trice: "Absolutely. And once again, just the staff at ACerS, starting with Mark and on down, you know, just really enjoy these folks."

(music)

CONCLUSION

McDonald: "With the race to develop hypersonic vehicles continuing at full speed, we are fortunate to have researchers like Rod who can guide us in safely developing this critical technology.

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

(music)

"Visit our website at ceramics.org for this episode's show notes and to learn more about Rod Trice and the Hypersonic Materials Training Program. 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."