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ORAL HISTORY PROGRAM

Harry Bhadeshia: An Awe-Inspiring Steel Innovator

2021

PREFACE

The following oral history is the result of a recorded interview with Harry Bhadeshia conducted by Sudarsanam Suresh Babu on February 3rd, 2021. This interview is part of the AIME and Its Member Societies: AIST, SME, SPE, and TMS Oral History Project.

ABSTRACT

Knighted by the Queen of England for his research on steels and deploying highly advanced steels in real-life applications, Harry Bhadeshia has impacted the world with his contributions. A Professor of Metallurgy at the University of Cambridge, Bhadeshia was born in Nairobi, Kenya and emerged from the inspiration and support of his parents. At 16 years old, Bhadeshia began as a metallurgy laboratory technician at the British Oxygen Company, where he was encouraged to continue his education and eventually earned his PhD at the University of Cambridge. Bhadeshia studied the controversial topic of bainite transformation and presented a T-zero curve theory, which led to a breakthrough in the design of steel properties. An influential figure through his paper and book publications, Bhadeshia is an inspirational mentor to his PhD students, encouraging them to always dig deeper. Worldwide professional societies have recognized his achievements and Bhadeshia sparked the success of numerous welding journals after the creation of his own with support from the Institute of Materials. Bhadeshia is an active advocate seeking sustainable solutions for steel production and reducing CO_2 emissions. He has also contributed to neural network analysis of materials, among his five decades of steel research.

Readers are asked to bear in mind that they are reading a transcript of the spoken word, rather than written prose. The following transcript has been reviewed, edited, and approved by the narrator.

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PART 1

01:09 Parents' Sacrifice and Support of My Academic Pursuits– "I Owe So Much to My Parents"

Babu:

Today it is February 3rd, 2021. I have the privilege and honor of interviewing Professor Sir Harry Bhadeshia. This interview is being conducted and recorded via AIME's Zoom account because of the COVID-19 pandemic. Professor Bhadeshia, who goes by Harry, my PhD mentor, is the Tata Steel Professor of Metallurgy at the University of Cambridge and also a fellow of Darwin College. In 2015, Harry was knighted by the Queen of England for research on steels and for the deployment of advanced steels in real-life applications. My name is Sudarsanam Suresh Babu, and I go by Suresh. I am a Professor at the University of Tennessee Knoxville and also have a joint appointment with the US Department of Energy's Oak Ridge National Laboratory.

Harry, thank you for your willingness to help us capture your story this way. Let me start with my first long-distance drive from the University of Cambridge to London. I still remember this, in 1992, you took me to your parents' house on our way to the Institute of Materials. And, during the travel, you talked about their role in your life, career and early days of your academic pursuits. I have a text from your PhD thesis. So, let me read it out, and then we can start with that. So, the last sentence goes like this: "Finally, it seems to me that I owe so much to my parents, that to express my gratitude in words would surely lead me to exceed the 60,000-word quota, signed Harry Bhadeshia, September 1979." That actually touched me quite a lot. So, with that, let's go into some other questions, and I look forward to hearing from you. So, let's start with question one. Can you talk about your childhood, your parents, and how they supported and inspired you?

Bhadeshia:

First of all, Suresh, thank you so much for taking the time to do this. I know you're an extremely busy person, but thank you. So, my childhood, I was born in Nairobi in Kenya and one of four children to my parents, Narmada and Dharamshi. We were not particularly well off, but what was absolutely certain was that my parents placed great emphasis on studies and performing well in studies, and we'd be in trouble if we didn't do so. They did sacrifice quite a lot to ensure that all four children actually managed to get a reasonable education. I think that is a trait in many Indian parents. But, the fact that you have to go through quite a lot of hardship to pay for schooling, and so on, was particularly pronounced in our family because of four children and one person earning all the income.

Whereas, my mother was a fantastic home builder, in modern terminology. In the old days, we used to call it housewife, but it meant the same thing. Then, we had quite a lot of trauma when Kenya became independent from Britain; it used to be a colony of Britain. There was a two-year period where we were not allowed to take any jobs. So, we had to survive by selling things, effectively, until the British government actually allowed us to migrate to the UK. We were living on top of a shop in London before finding better accommodation, and, you know, things worked out at that time.

04:31 Migrating and Finding Work in the UK

Bhadeshia:

So, as soon as we came [to Britain], I started with a job at the British Oxygen Company, and it was in the metallurgical quality control laboratories. Do you know what my salary was?

Babu:

I don't know Harry; please let me know.

Bhadeshia:

It was eight British pounds per week.

Babu:

Wow.

Bhadeshia:

That includes all the costs of travel and so forth. Then, my parents managed to buy a house and because it's London, and it's very expensive, and that's their life savings, basically. The house itself cost just four thousand pounds in those days. But, 4,000 pounds meant a lot if you compare with the salary that I used to earn. So, they did extremely well and took a leap of faith in committing their entire life savings from selling everything back in Kenya to buying this house. My mother was the first one who got a job in Britain, and she used to make dresses. And, she worked incredibly hard, you know, because we had the mortgage to pay and a family to support and so on. And then, my father got a job as well. So without the vision of the parents and the sacrifices they made, I don't know what the future would have been. So, it is absolutely true that if I did express all that in my thesis, I would have exceeded the word quota.

06:23 Starting at British Oxygen Company at 16 and Their Support to Further My Studies

Babu:

Thank you, Harry, for sharing that. It actually touches me so many ways. We see the same thing with the parents having a big influence. I really thank you for sharing that, also. Going along that way, I see you went into the company, British Oxygen. So, did you need to commute a long distance, or how did you go there?

Bhadeshia:

I had to catch two buses, and the total journey took two hours, if the traffic was slowi. Then, the journey back home. But, you could read on the bus, and there were two particular books that I repeatedly read. One was about electricity, and the other one was about magnetism. People used to criticize me, "Why are you reading the same book again and again?" And the truth is I couldn't understand many things in those books.

Babu:

I completely understand. I still remember when I couldn't read the thermodynamics of bainitic transformation, I had to read many, many times. I still remember that paper I read. So, thank you, Harry. So, as we are moving along the story of going into the company, one of the things that caught my attention when I was listening to your video introduction you gave, when you become a fellow of Royal Society, you talked about a human resources person on how he encouraged you to study further. Can you describe the same to the audience here, please?

Bhadeshia:

I was only 16 years old when I took up the job as a technician in a metallurgy laboratory. The human resources person came to see me. He said to me, "Look, you really ought to be studying," which I would like to do, but there wasn't an opportunity. So, he arranged for me to have a day off. And, in those days, you could study with one day and an evening. So, you did that every week, and, eventually, if you pass the examinations, that would allow you to enter a university. At that time, the racial tensions were really high in London, with the National Front, and so on. This was a white person who came to see me and said, “Look, you have to be studying.” After I finished that, and the company sponsored me to go to do a degree. But, he was the one who got me the sponsorship to go and do a degree at the City of London Polytechnic. This really, I've said this before, but it really brings back your faith in humanity. There are people of all kinds who are nice. Whereas, we tend to focus on the other side of the spectrum.

09:29 Pursuing My PhD at the University of Cambridge – Literature Reviews and Libraries

Babu:

I can relate to that, Harry, that sometimes some random person as the kind one sets us in a different direction, and, in a way, helps us also. And so, coming along that, as you're going in to study in London, when did you choose to go to the University of Cambridge to pursue a study?

Bhadeshia:

My degree course was at the City of London Polytechnique and during the summer vacations, I would go back to the company, and they would pay me. The final examinations in Britain, where you actually get a degree, you have to have an external examiner from another place to check that everything is done fairly. The final examiner has a big job to look at the manuscripts to see whether the marking is fair, see, even before the examination, to check whether the papers themselves are good enough for the qualification. The person who was the external examiner happened to be a Professor Robert Honeycombe from Cambridge. And, he said to me that you must apply to go to Cambridge. So, after that, I looked at the application procedure, and, for me, it was confusing.

There were 34 colleges and departments, so I didn't apply. Then, one day, my tutor at the City of London Polytechnique said, “Have you applied?” When I explained, he got really furious with me. So, we sat together, and we made the application, and then I started with a PhD. So, the PhD was supposed to be about retained austinite. So, before I went there, I actually reviewed the literature. There's a very famous paper by Morris Cohen from MIT, actually completely on retained austinite. And, I copied it all out by hand, including the diagrams. It was a really nice experience to be able to read something from a person like Morris Cohen. People outside of the subject may not know who Morris Cohen is, but he was one of the fathers of the subject.

Babu:

Thank you. So, I'm going to follow up on that. So, as you went through the literature review, and it may kind of given you a glimpse about those days, how we went about doing literature review compared to the current days.

Bhadeshia:

There was no internet, but we were very fortunate because there are huge numbers of libraries in Cambridge. But, there was a particular library right next to our department. You just walked down, and you walked into the Scientific Periodicals Library. And then, you look through the card indices about where is this and where is that. And, the equivalent of Scopus was basically volumes and volumes of indices. So, you would look in each volume for the term retained austenite or bainite to find the location of papers, get the hard versions, read them, return them to the library. I don't know which system is better, because you do need time to read things; so now we can access millions of papers, but there's no way you can absorb all those papers.

Babu:

I still remember one interaction during my PhD is that the library was next door to the tea room. We used to have arguments, and then we go there and pick up the book and read it. So, we used to say that photocopying a paper is not good enough. We need to really dig deeper.

Bhadeshia:

The coffee room was fantastic, wasn't it?

13:37 PhD Thesis On Retained Austenite – The Adventure of Researching Controversial Bainite

Babu:

That's correct, very close to the coffee, tea place, also. So, having said that, I'm going to transition to your thesis. Many of the young researchers who are coming into the PhD courses, I like to kind of ask questions that lead to a conversation about your thesis. Like you talked about already, it's about theory and significance of retained austenite, but how did you stumble on this topic? And, then when you are going through that PhD, what were the challenges and tribulations? You kind of jumped out of that and then said, "Wow, I got it." So, can you kind of share those feelings with us?

Bhadeshia:

So, of course, you know, this is all in hindsight, so you look through rose-tinted glasses. But, there's no question; there's an awful lot of pain involved in doing a PhD thesis because you have to actually get some new knowledge, which is recognized as new knowledge. It is not just a repetition of what has been done in the past, but you have created new knowledge. That's the essence of a PhD. My task was assigned by Professor Honeycombe and David Edmonds, who was my immediate supervisor on retained austenite, but we had enormous freedom. So, I looked at the structures, and I saw there was a huge amount of confusion in the topic of bainite, which also leads to retained austenite when you have a certain amount of silicon in the steel.

Deliry in France had shown that, but the mechanism was in complete disarray. If you picked up a book, it would dismiss bainite by saying it's controversial. There is therefore a challenge, like those books on the bus. If you can understand the book in one go, it tends to be boring. What human beings like is a challenge. So, I went into the literature in great detail, and there was a lot of literature on bainite. I identified some difficulties, did some experiments. I would say that the key point was when the data agreed so well with the T-zero curve, which defines the point beyond which transformations cannot happen if they involve a composition change. The curve representing equilibrium, was far, far away from T-zero. So, the points all fell nicely close to the T-zero curve. And, that is where the adventures began because, obviously, as I said to you, it was a controversial subject. So, the opposition was building up quite intensely, not at first, but when we started publishing the work.

Babu:

Thank you, Harry. I still remember the MUCG-65 and then calculating T-zero and putting the lines in the retained austenite steel. That's amazing; it set the stage.

Bhadeshia:

So, do you know what MUCG stands for?

Babu:

No, Harry, please let me know.

Bhadeshia:

In order to calculate the T-zero curve, you need thermodynamics. MU is the Greek symbol for chemical potential, C is for carbon, and G for gamma. So, in the computer program, MUCG referred to the chemical potential of carbon in austenite.

Babu:

That is amazing. That's wonderful. So, that leads to one of the things, I still remember you were in the coffee time, we were all struggling about the T-zero concept. You used to write with a napkin and draw these T-zero curves and explain to us. That time I realized that, if I were to ever become a teacher, I need to become like Professor Bhadeshia.

17:45 The Bumpy Road to Becoming A Professor at the University of Cambridge

Babu:

So that takes us to the next topic. When did you decide that you wanted to be a professor at the University of Cambridge, and can you share your initial thoughts and trajectory as you went into that adventure?

Bhadeshia:

There was no thought of that sort, absolutely none. We had one professor in the entire department, and people who were Fellows of the Royal Society didn't have a professorship. So, you cannot imagine becoming a professor in the British sense. So, after my PhD, I became a Science Research Council Fellow for two years. I could, therefore, completely independently pursue research within Honeycombe's umbrella, but it was direct funding for me to do work for two years. I pursued many ideas on the same principles, phase transformations, and designs of alloys. And then, I applied for a position in the university, which was known as a Demonstrator. A Demonstrator is like a tenure track in the US; it's for five years. You do teaching, you build up your research group, but it wasn't like these days where you need massive amounts of funding to build up a team.

For example, you were funded by the Cambridge Commonwealth Trust, and so on. So, we could obtain sufficient funding to do interesting things. And, towards the end of the five-year period, you can either get upgraded to what's known as a lectureship or not, in which you leave. So, it's almost exactly like a tenure track. That position does not exist anymore. You go directly into a lectureship. Then you continue to do your research, and so on. Teaching, of course, is a key part. My first ever course was a complete disaster. It was on the crystallographic theories, and so forth. It was a graduate student course.

I had the most appalling reviews; and, I felt it myself, actually, that it was a disaster. So, the university sent me to a course to learn how to teach at the University of Surrey. Then, things went very well because that gave me the training to teach. Previous to that, I had no training at all. It was only on the basis of research that I was appointed. So, after the lectureship, if you continue to do good research, and you are a good citizen of the department, then you might be promoted to a reader, then, eventually, a professorship. So, it was never a planned career. And, there were uncertainties, major uncertainties, at each stage when the fellowship ended, and Demonstratorship was going to end, and so on.

21:08 The Gentlemen Who Influenced Me and Helped Me Develop My Ideas

Babu:

So, Harry, that leads to the next one. So, you have a great influence on a lot of people that pursue steel metallurgy, directly or through the web and other people. So, going back to as you [are] building up your career, who influenced your academic research career trajectory, and what was the first eureka moment, like as you are going through? So, can you share that, also?

Bhadeshia:

Robert Honeycombe and David Edmonds were, I think, very special people, scholars and gentlemen. I was developing ideas, which they did not agree with. David Edmonds was my immediate supervisor, and Robert Honeycombe had been the Head of the Department for something like 18 years, the single Professor in the Department. They told me once that, if you go down alleyways, you are likely to get mugged. But, give them all credit. They allowed me to continue when I talked about the T-zero curve and that the mechanism of transformation is not what Honeycombe had written in his book And yet, they allowed me to continue. That is the mark of a good university, really. I felt no threat at all.

Babu:

I still remember that Harry, about the pursuit of truth as a part of that training, which I received. And, it goes back to your teaching, also.

Bhadeshia:

Because I was deviating from the sort of things that were normally done in the steel group, I needed a great deal of theory, which I didn't have. So, the other person who influenced me enormously was Jack Christian from Oxford. He once spent an entire day with me. This is the world-famous Jack Christian, the leader in phase transformation theory. I wrote to him, and he wrote back, I went there, and he spent an entire day with me. Eventually, when I went on sabbatical to MIT, I spent the whole time reading his book from page one to the end, the classic *Theory of Transmissions in Metals and Alloys*. He, too, was a perfect gentleman; in spite of our huge difference in achievement, and yet he treated me just like anybody else.

Furthermore, he was so clever that I once made the mistake of not asking a question. We were writing something together, and he said to me, obviously, there will be solute drag effects because molybdenum diffuses slower than iron. So, I said to him, no, actually, it diffuses faster than iron. He thought for a moment and said, that's the solute effect of diffusion. And, I did not have any idea what that meant; I don't know that today. I should have asked. I felt at the time that it would be a stupid question, but I should have asked.

Babu:

I think that's a great way to lead into that you should have discussions, and that's the book by Jack Christian's. I still remember you recommended that I buy that book, actually. I did go and buy that for 75 pounds. One of my students took it. Now, he has it.

Bhadeshia:

Well, that's a good way. I have it here, actually. You can see how bedraggled [it is]. I still use it. And, of course, there are new editions, but I'm loyal to this one, you know?

Babu:

I still remember that one of the discussions we had in the coffee table is that there is a Christian's book in the library. I used to take it to my room, but I never read it. And, once you said, "Suresh, unless otherwise, you buy it, you will not read it." So, I remember that going to buy the book and reading it as you recommended. So, thank you, Harry; that is a great way to talk about your mentors and trajectory, also.

25:41 Five Decades of Steel Research – T-zero Curve Theory and Steel Design Properties

Babu:

It leads to your favorite topic that is steels. So, you have provided quite a lot of demonstrated passion for steel research. Can you talk about some of the innovations that came in your long research in steels, and in the last actually five decades or so? So, can you kind of take us through the journey?

Bhadeshia:

I think, obviously, the mechanism of the bainite transmission features a lot; because, I tell you why, not because it's simply an academic argument, but you can use the theory in order to design practical steels. Whereas, if you are just saying, this is happening by diffusion or by shear, and you stop there, then you're actually missing something. Because until you use the theory, you don't realize the pitfalls associated with theory. So, the T-zero concept, and Aaronson had a role in that because he tried to use it to disprove the displacive mechanism. But, the fact is that the T- zero curve allows you to calculate, in steels where the precipitation of cementite is retarded, how much transformation you should have, and the stability, both mechanical and thermal, of the austenite that remains. Now, how can you use this?

In my work with David Edmonds, he was my supervisor, we had a small breakthrough, which helped us use the theory to design properties. And, the breakthrough now seems very simple and is referred to casually in lots and lots of papers. But, it goes as follows: if you have a mixture of bainite plates and retained austenite, that should be an ideal composite, because you've got the strength from the ferrite and you've got the toughness from the austinite and TRIP effect and blah, blah. When we did the experiment, the toughness was awful. So, we looked and figured out that these blocks of austenite are responsible because the thermodynamics tells you the reaction will stop, no matter how long you hold at the transformation temperature. So, these blocks will not disappear. You've got to do something by calculation to reduce dramatically the size of the blocks.

Of course, the T-zero curve helps you to do that. So, without doing any further experiments, we designed two steels, which would maintain the strength levels but cut down the size of those austinite islands. Voila, lots of toughness at cryogenic temperatures plus strength. Eventually, that led to the design of the rail steel, which now is in the Chunnel Tunnel. In April, I received a message that it has done 1 billion metric tonnes of traffic without the need for grinding. Normal rails are ground to remove any fatigue damage. So, this has exceptional rolling-contact fatigue resistance as well. That is an application which is in service. And then, of course, we have the bulk nano-structured steel, and some rolling elements in bearings are made from the bulk nanostructure bainite. But, the essence is the same, it's a mixture of plates of bainite and austenite, and it's a very versatile structure, because you can change the scale by altering the temperature.

29:40 A 100 Year Experiment of Bainite at the Science Museum

Babu:

Thank you, Harry. And, also, you used to mention that one of your super-bainite wire is in the museum holding?

Bhadeshia:

Yes, that's a fun experiment that I did with Saurabh Chatterjee. We did some calculations to show there's no particular limit to the lowest temperature at which bainite can form. So, for example, in a particular alloy system, if you had one weight percent carbon, it would take a hundred years for bainite to form at room temperature. We made a sample, we polished it completely flat, sealed it up in an inert atmosphere in a quartz tube. We started that experiment in 2004. So, it will be completed in 2104. And, you will be able to see if there's transformation by the surface relief, but it should produce incredibly fine bainite plates. You have to tell your children about this story so that they can verify it, because I'm not likely to be around in 2104.

Babu:

That is a nice story, Harry. In fact, I would recommend to whoever is listening to this, like you can go and get some of the laser things, and then you can go look at the surface relief.

Bhadeshia:

It's stored in the science museum at room temperature, at 24 degrees centigrade.

31:16 Mentoring and Inspiring PhD Students to Pursue the Truth and Research

Bhadeshia:

Thank you, Harry. You talked about Saurabh, in that experiment and also other people who work with you. You are known for mentoring just under a hundred PhDs, and also not only mentoring PhD students, but you also inspire others to research. But, as a Professor, I always wondered what is your magic behind this infinite source of enthusiasm and trying to get other people motivated to pursue the truth and research?

I think the students have to take credit for that because I tell them that, when they go for the PhD examination, I will not be there. So, if they pass, they have to take the credit; after all, if they fail, I will not take the blame. So, the students have been very good, and the atmosphere in Cambridge is -- I'm going to cause controversy by saying it's the best in the world. We have such an environment there that you don't need to encourage people. They will be talking to people from so many different subjects, and they will be meeting people who have achieved an awful lot, and so on. So, you would have to work hard not to do a good PhD.

Babu:

I still remember that one of the favorite moments of mine is that you will call me and say, Suresh, let's talk about it, let's go to the metallography lab, and I will be moving from the annex. And then, I will see you like a crisscrossing across the stairways. And, I wonder how do you move so fast? Then, I said, “Well, it is displacing transformation.”

Bhadeshia:

I remember the experiment that you did of acicular ferrite under stress. That was the first-ever experiment where the basket-weave structure changed into an aligned structure. And, at first, you were keen to show it to me when Lars Erik Svensson visited. But, I said we'll talk about it later. But, when I saw it, you know, it was amazing.

Babu:

As you mentioned, that it takes a vision in that atmosphere to make the PhD students to pursue that. And, that leads to the next topic.

33:43 Embracing the Concise and Precise Writing Style of Oxford – Inspiration from Jack Christian

Babu:

Harry, we are transitioning into some other professional development and milestones along your career. You have written more than 500 papers, many books, and one of the things many of my students comment about, reading your papers and everything, is about how crisp it is. Then, when they read it, they can kind of internalize what you're writing. So, please share your passion for that. And, also, how do you go about disseminating the knowledge and also focusing on readers who read your papers?

Bhadeshia:

Thank you, Suresh. Don't forget that the 500 papers you talk about are over a period of something like 50 years in the subject. So, it's not actually a large quantity, in that respect. Of course, I had really good students and collaborators as well. I learned from Jack Christian. Oxford is the holder of the English language, and people who are educated in Oxford have wonderful styles of writing. So, if you read his book or any of his review articles, they are written concisely and precisely, with every sentence pregnant with meaning. Now that, of course, means you have to read it many, many times to completely get the gist of what is being said. But, as I said to you, a challenge is a good thing.

I tried to emulate that and didn't succeed very well, initially. Once I submitted a paper with lots of emphasis, that means underlined things. And, the reviewer said, "Look, if you underline too many times, then it loses the significance of being an emphasis." So, there was a learning process, and [I was] inspired very much by reading Christian's review articles and books. I think we were not under pressure at all to publish, the pressure that exists now. You published when you wanted to. I didn't publish any papers until 1979, after my PhD, effectively. Nowadays, there's incessant pressure to publish.

36:14 Authoring Books – Geometry of Crystals and Bainite In Steels

Bhadeshia:

The book is a different story. The first book was a short book, *Geometry of Crystals* on the course that went disastrously, I was telling you about: the teaching course. But, over a period of five years, I learned how to do it better. And, that's when I wrote that book, *Geometry of Crystals*. Eventually, I was able to make it completely freely available. The Institute of Materials published it, allowed me to simply put it on my website, which was great. Now, there are advantages to doing this because many people in the world do not have access to funds to buy books, and they can easily download it. If 1% of the people who download the stuff actually read it, that is amazing. Honeycombe was writing his book on steels, the first edition. And, David Edmonds was also supposed to be the author, but David Edmonds was a research fellow of the Royal Society. And, someone at the Royal Society made a comment that he shouldn't be writing books. So, Honeycombe wrote it by himself, and he gave me two chapters to look at before publication. One was on martensite, and the other was on bainite. I commented on the martensite one, but I said I don't want to comment on the bainite chapter because I don't agree with anything. He respected that, and he put me in the acknowledgment in that book. The subject [of bainite] was in turmoil. And, over a period of years, up to 1991, I started to compile a book on bainite, no limits to size, simply compiling. I mean, you were there when it was published, right? So, it isn't just about a mechanism, but it covers all aspects of the bainite transformation. And, when you do that, you can present a coherent story which fits.

Whereas, if you just write a paper on a particular topic, you may ignore a lot of the other evidence, which is common these days in publications. The idea was to produce a coherent book, which covers all aspects of bainite in a consistent manner where things fit. Of course, now it's in the third edition, and I've just received the Chinese translation of the third edition, which has been published this year. Again, I was able to make those freely available, the early edition, no problem. Then, it was taken over by Taylor and Francis. And, I said to them, "Look, if I don't take royalties, can I make it freely available after 30 months?" And, again, no problem. The book still keeps on selling, even though they are freely available. So, it's possible to make books open access without much pain, if you plan it ahead of time.

Babu:

So, I have many instances, many people work in the industry have read your paper and used to have discussions about how you have a lucid way of talking about reconstructive and displacive transformations. Even though it's not only bainite, but it also talks about the mechanisms. I used to think that, wow, it is amazing how people can relate to, when they're reading the papers and this general knowledge and phase transformation.

Bhadeshia:

And, of course, I gave a copy to Professor Honeycombe, and, after he looked at it, he said to me, "Look, we are planning a second edition of the steels book, and you have carte blanche to alter completely, the chapter on bainite and add any other chapters." So, we wrote the second edition together, and it's now in its fourth edition, the book on steels.

Babu:

Beautiful.

Bhadeshia:

So, that's what I mean by this concept of academic freedom doesn't mean that you get your salary, whatever you do, you know? But, it means that when you have a disagreement with someone who is superior to you, in a superior position, they don't actually do anything to stop you. They give you the freedom to dig your own hole, if you like.

41:02 Pioneering the Materials Algorithm Project – Putting Theses on the Web

Babu:

Thinking a little bit about the dissemination of knowledge and everything, I still remember when you started the materials algorithm project and then also putting some of your teaching and seminar videos on that. So, you were pioneering that area also, a lot of following. So, when you are developing that, so what was your thought process? Can you kind of give us some idea about it?

Bhadeshia:

Suresh, you'll remember that whenever a student left, we lost the material, whether it's a computer program or micrographs, et cetera. And, that should not happen, you know? If you want to find out what Darwin was doing on a particular day, you can find all of his notes. For a modern student, you will not be able to do that after they've left. That doesn't make sense. We should develop from what has been done in the past, and just looking at publications is not enough. You need to look at the data and everything else that goes into creating that. For one micrograph published, there might be a thousand more which are not published. So, 1997 was the breakthrough, when we all got access to the internet. And, that made it possible to put your materials on the web for anybody, anywhere in the world, any time of day or night to access. Before that, it would be like, like what we do with Darwin, that there will be several people researching his documents, discovering them, and so on.

Babu:

So, that's actually one of the things I would point out is that, the Cambridge University right now puts all theses electronically. But, you did that beforehand for all your PhD students, from number one PhD students. I still remember walking into your office; you used to have a scanner; you used to scan while you're reading and everything. In fact, you scan the whole thesis and then put it in the web also and including Prof. Roger Reed's big thesis.

Bhadeshia:

That's right. That's right.

Babu:

That's amazing.

PART 2

00:27 The Innovation Cycle – Neural Networks, Material Properties, and Design

Babu:

I want to go into a little bit of detail, about some of the things you've done. You have made brilliant contributions to steels, welding, crystallography, phase transformations, in general, and then the super bainite and also the neural network application of materials. And, this is actually kind of looking back from where we are right now. You are far ahead in the call to data science and engineering, also. So, you can pick any one of the topics and then kind of walk us through the innovation cycle. How do you stumble on, how do you pick up and take it to the next level? Because many times we don't, and many people don't understand.

Bhadeshia:

I'll take the example of the neural network. I was attending an American Welding Society meeting in Florida. DebRoy was there, together with all the usual people, and someone presented a talk on neural networks. I didn't understand it. Furthermore, conferences these days don't actually allow for real discussion, apart from meetings like the Gordon Conference. So, I came back to Cambridge, and I bought a book on the subject. I still couldn't understand it. So, I went to Darwin College for lunch, and I was mourning that conferences aren't what they used to be, and books are not what they used to be. Sitting right next to me was a young guy called David MacKay (https://en.wikipedia.org/wiki/David_J._C._MacKay), who turned out to be one of the world's leading experts on information theory. We hit it off and he helped me with neural networks, to really go deep into the subject. But, it's a totally different language that he would speak, because his level of mathematics was far above mine; but, it was all lubricated because we've watched many Bond movies and Jackie Chan movies and had dinners together.

We went to protest marches against the war, and so on. Over a period of something like 24 years, we worked together very well whenever time allowed. The first encounters were before our Department was connected to the internet. So, I would cycle over to the Cavendish with a disk, load it up, and then cycle back to the department, that sort of stuff. But, I tell you, the motivation from my point of view was that, whereas we could go quite far in calculating structure, the engineer is not frankly interested. They are interested in what properties the structure delivers. There wasn't a quantitative connection between these two because the complexity of the problem is enormous. You can't just take precipitation hardening theory, and so forth and so on. You can't even calculate an elementary tensile test, the full curve.

Neural networks are a breakthrough, in that sense, the more complex the problem, the better, really. And, it is remarkable that, when you combine these [methods], you can actually design new alloy systems in a short period of time. One example is the nickel-based alloy, which we designed for steam temperatures of 750 degrees centigrade, unheard of. But, of course, nickel is very expensive. So, this has to be a very cheap element. So, by combining thermodynamics, kinetics, neural networks, we came up with an alloy design without doing any experiments, and it worked the first time. That's not always the case. But, in this case, it worked the first time, and we call this alloy FT750DC. 750 for the steam temperature, FT is Dr. Frank Tancret, the postdoc who did the work, and DC for dirt cheap. We designed it so that it would be affordable.

Babu:

Amazing. So, that shows the innovation cycle of how you take a particular topic through collaboration, also.

04:48 Future Research – Digging Deeper and Understanding Where the Gap Exists

Babu:

So, that takes us to one of the areas, which I'd like to personally ask you a question. So, I still remember you wrote this classic paper called unresolved issues in bainite and also in phase transformations. I still remember. I still have it. What are some unresolved issues with reference to steels and iron which still exists? And, if you can give a marching order to a new generation who are walking into the steel, what would be the future researchers can tackle? What are the unresolved issues?

Bhadeshia:

This is one of those questions that is impossible to answer because, if I could predict the future, then I don't know what I would do, but it's not possible to do that. Steel is not a subject for the faint-hearted, because there is an enormous amount of good knowledge that exists in this area. So, you have to do that yourself. You have to identify a topic and go into it deeply before starting the research. Now, in the humanities subjects, PhD students actually have to propose a topic before they get funding. Scientists have become corrupted in that sense that, you or I would find the money for a PhD student. And, in getting that money, nine times out of ten, you would be fixed on the project. So, a student has to come and do that project. There is an element of creativity [that] is lost in that. I would encourage studentships in which the student has to actually produce a proposal before they're accepted, a detailed proposal based on critical thinking.

Babu:

I completely agree with you. And, in fact, so I take your message many times, I tell them to my students to dig deeper. So, for last Christmas, they gave me a shovel with a signature and everything.

Bhadeshia:

To dig deeper!

Babu:

I can show it right here. You can see that; so, there it is.

Bhadeshia:

Fantastic. I don't see any dirt on it.

Babu:

No, I haven't dug deeper yet. So, having said that, so, I think that is a clear message, too. It is more about digging deeper, and then understanding where the gap exists, and then devoting your life to make sure that you have a tangible impact on that gap. Then you build on it, like standing on the shoulders of the masters before us.

07:31 Industry, Academic, and International Collaborations

Babu:

So, one of the things which I will take it to the next one, we talked about books already. And also, there is one area I would like you to touch upon is that, when you did all those things, how did you take it to the world, working with the industries? And also, when you are going through that, how did you bridge the gap, a cultural gap, and also the different countries? So, share that aspect, also.

Bhadeshia:

So, initially, I didn't have any connections with industry. But, one day in the coffee room, there was a guy called Lars-Erik Svensson who had come to work with Paul Howell, who was in the electron microscopy team. But, Paul Howell went away to Penn State University. So, Lars-Erik started talking to me, and he said, "Look, would you like to work on welding, because after leaving Chalmers University, I'm going to go to ESAB." And, of course, foolishly, I said, how complicated can welding be? I accepted, and then we started working together, and that's how the entire work, sponsored partly by ESAB and by others on welding, started. And, of course, other people who worked on welding then got interested, for example, Parsons, the steam turbine generators, and so on, because they could see an advantage in doing some design philosophy in this and some predictions and calculations validated by experiments, and so on.

The industrial connection grew quite rapidly, and students also helped. People were coming from industry as PhD students. So, the first Japanese person we had in the group, you might remember, Manabu Takahashi. He came from Nippon Steel. And, all those connections grew quite rapidly, simply from a reputation, I suppose, of what was achieved by the other students. Then, we had some massive projects with Japan covering something like 50 man-years of work, sponsored by the Japan Research and Development Corporation, working on nickel-based superalloys and on steels, that went extremely well. But, of course, all of these things last for certain periods, and that lasted for approximately seven years. And, in terms of academic collaborations, I had a strong collaboration with MIT in the very early days with

Morris Cohen and Greg Olson.

We published a couple of papers together. I call those papers strange couplings because we were trying to see whether we can explain things with a combination of diffusion and displacement. I think it was worthwhile because I didn't think we could explain that. I remember talking to Christian about this and explaining why we were doing this, just to show that it doesn't make sense because the whole thing would collapse towards equilibrium. I had a collaboration with the Naval Research Laboratories and with Northwestern University, where Greg went, and, to a small extent, with Colorado School of Mines as well. So, those were the days in which I had a lot of US collaborations, almost none in Europe. And then, the European Union happened, and I had lots and lots of students from France, for example. It started with a random encounter with Roland Taillard, who is a Professor at Lille University. And, he said, "Look, French engineers have to do a project. Can we send them?"

We had a whole string of French engineers who then stayed on to do PhDs with me. So, that was the European connection. India, of course, from the very beginning, from the Cambridge Commonwealth Trust Scholarships and also some connections with Pakistan. Later on, in 2005, was a very big collaboration with POSTECH in South Korea where we started with a blank sheet. We had to create a Graduate Institute of Ferrous Technology: no building, no equipment, no people, plenty of money. So, within three years, we had a fantastic building with the blast furnace as its entrance; a glass blast furnace as its entrance: a giant anvil pattern, lots of students, and lots of equipment. And, I stayed there for ten years. The reason for leaving was, when I went there, I trained all of my students to play squash, and I would beat them, beat all of them. After ten years, I was getting beaten. I thought this is typical Korean. They take something and do it better, so I better leave now. So, I stopped in 2015, but we did a huge amount of work, actually.

13:15 Innovation Can Be Accomplished By Anyone – Inspiring New Advanced Materials Research

Babu:

So, Harry, that takes to the recent book you wrote, In that, you articulate that innovations in materials can be accessible to anyone. So, you're reducing that barrier to entry, I would call it activation energy. In fact, you're making it so easy for anyone to pick up material science research. You wrote this book with Professor DebRoy; can you, kind of, cap up the professional development with that book, please?

Bhadeshia:

Actually, this was completely DebRoy's idea. He had read a book called *Letters to a Young Chemist* in which somebody wrote a book, beautiful letters, explaining a particular problem which young people could help solve. The goal was to do that, in the context of everyday engineering materials. These days in science, there's too much noise. You know, if you look at graphing, there are about 1.1 million papers published and almost nothing achieved. So, the point is we make innovations which actually change the quality of life. When we talk about so-called ordinary materials, not the steels but silicon, for example, if you can change the process of making silicon, you would cut the scrap from single crystals by an enormous amount, diamonds, the artificial diamonds, and so. We chose topics, which would illustrate, basically, that looked at everyday engineering materials, which you use in large quantities, and everyone has them in their hand.

There is a lot of innovation associated with that. We included a couple of maverick chapters. For example, high entropy alloys, nothing applicable has been achieved, right? But, it is an interesting concept, and, if people can focus on scaling up and finding an application which can afford those alloys, then they would be extremely useful. That was the goal of that book, and it turns out, the hard copy is really nice. I know you've got the electronic copy, but you need to hold this in your hands.

Babu:

But, it's still not available for us to buy it.

Bhadeshia:

It says it's available.

Babu:

Okay. I would buy it. So, I have it on my iPad.

Bhadeshia:

Yes, I know you bought the electronic version.

16:02 Creating the "Science and Technology of Welding and Joining" Journal

Babu:

Harry, we are going into some of the membership societies which had relevance to your career. So, the question is, you have been a member of many professional societies. Can you share how the societies have played a very vital role in your career and also the dissemination of steel metallurgy to citizens of the world?

Bhadeshia:

Yeah. So, the Institute of Materials used to be called the Institute of Metals in London. I became a books editor for that, and it emphasized to me the importance of, actually, books. And, I was actually a member from the age of 16; that was the minimum age at which you could become a member. Actually, the people who interviewed me did not know that there was a minimum age. The aim of becoming a member was to get books at a 40% discount. Later on, I actually became the books editor and commissioned many books for the Institute of Materials. It was eventually taken over by Maney and then Taylor and Francis, still published by the Institute, but run by Taylor and Francis. In that sense, the IM was extremely important.

When on one night in Graz, Austria, DebRoy, Stan David, and myself were complaining about the American Welding Journal taking so long, three years to complete a paper review. We decided to create our own journal, and I approached the Institute of Materials, and immediately they agreed to publish "Science and Technology of Welding and Joining," which now is probably a quarter-century in publishing and the elite journal in the subject. And, it has brought forward the other welding journals because, if you follow the significance of the journals after we created the journal, they stimulated the others to do a better job. So, from the point of view of metallurgy and the well-being of the subject, the Institute has been very good in promoting that. And, I suppose that's the goal of AIME and TMS and all the rest of them. They are there to promote the subject more than anything else, in the interest of the members.

18:41 Member Society Nominations – The Royal Society and International Recognitions

Bhadeshia:

When I was a reader, Honeycombe approached me and said, "Look, I want to nominate you for the Fellowship of the Royal Society. And, it requires a number of people to do the nomination." But, he handled it all himself. It came out of the blue, as far as I was concerned. He nominated me, and I was elected a

Fellow before I became a Professor. That's like in the very old days, people were readers and still Fellows of the Royal Society. Nowadays, probably that would not be the case. Then, David West, who wrote the book on ternary phase diagrams, nominated me for the Royal Academy of Engineering. So, that's how those two came about. People at the Indian Institute of Science in Bangalore nominated me for the National Academy of Engineering in India, and so on. And, this particular badge that I'm wearing is an honorary member of the Iron and Steel Institute of Japan. Dr. Toshi Koseki from Tokyo University did the nomination. None of these I asked for, but they were kind enough to contact me and do the work associated with the nominations. So, when it comes to my turn to nominate people, I do it very quickly. I don't hesitate, but I do it very quickly. And, sometimes people are shocked. Writing references are important things to do for other people as well. And so, that's how membership of societies came about.

20:30 Mentor-Mentee Relationships – Networking with Societies, Letters, and Walks

Babu:

Thank you, Harry. So, actually, there is a follow-up question on this. One of the things I still remember is that when we went to the Institute of Materials, my first-ever meeting, and one of the things you did is that you grabbed me and introduced me to Mats Hillert (https://en.wikipedia.org/wiki/Mats_Hillert) and others. And, I still look up to that networking as a young student who has no idea about seeing the stalwarts of the phase transformations and everything.

So, how can the societies generally provide kind of this atmosphere for the students who are coming into the field from different backgrounds to excel in the steel and materials community? Right now, we have so many tools, but if you can have a magical way to look at it, how can we expand more of this?

Bhadeshia:

I think the students need to take the initiative. You will find, speaking from a student's point of view, you would find that people are actually interested in talking to you. My interaction with Jack Christian began by simply writing a letter. They [these giants of the subject] are not arrogant; people who are really, really good are not arrogant at all. They take you at face value, and they're quite happy to discuss things with you—obviously, the timing and so forth has to be arranged. But, what I would say is never write an email; write an actual physical letter.

Babu:

That is a good one!

Bhadeshia:

That makes a big difference because email sending is just too easy now. If you want to talk to a person who has actually done the theory associated with the publication, write to them. They will be delighted to actually share their knowledge.

Babu:

That is a very good kind of tip for most of the people who want to walk into that. And, that is the, I call it mentor-mentee relationship, and how that happens. That's great, Harry, thank you. And, I still remember that I did follow up one day with Mats after we were introduced; I still believe I was in Sweden. He walked with me all the way from the university to where I was staying, and that walk I still remember in my dreams, too.

Bhadeshia:

I think he lent you his swimming trunks, didn't he? Didn't you go swimming?

Babu:

No, no, I just walked, and we were walking.

Bhadeshia:

I thought you went swimming together.

Babu:

I just walked from the university to where I was staying. That walk was very good. I still remember one of the words he said that "Don't you ever give up working on steel metallurgy."

Bhadeshia:

Excellent. He, of course, is a superstar. You know, there is nowhere now that you do not find thermo-calc, for example.

Babu:

So, coming along that walking, and I still remember my walks with you from a Department of Metallurgy to Darwin College, curry dinners.

23:38 My Wonderful Daughters and Grandchildren

Babu:

So, that takes us to a little bit of mentoring side of it, also, and also being a parent. So, you are very close to your daughters, and can you share some of your thoughts as a dad?

Bhadeshia:

Yes, obviously not a very good dad, but, in spite of that, they have turned out to be really super human beings and very kind, generous, and just delightful characters. Obviously, they're not young now; well, I mustn't say that. They are not old now. I have grandchildren as well: Aluna and Oscar, and they are just wonderful little children. Aluna doesn't like eating breakfast. She lives in Switzerland. So, early in the morning, we have a Zoom call where I eat my breakfast, and she eats it at the same time. So, when I say I eat, she says, now it's my turn, and, that way, the breakfast disappears. And, my younger daughter is in teaching, and she's doing really well -- a perfect human being.

Babu:

So, I still remember as a dad, you would sit there, and then I remember, initially, really, I was very protective. And then, you said, no Suresh let them walk along the Smoky Mountain rivers. I still remember those experiences. I actually named Anisha because of Anika.

Bhadeshia:

So, that's Anika and Maya. Sorry. Do you know what Maya means?

Babu:

It's an illusion.

Bhadeshia:

It's a word from the Sanskrit. She was so beautiful that I thought it was an illusion. And Anika, of course, the inspiration came from Sweden. I spent a sabbatical in Sweden with ESAB, and there were lots of Annikas but spelt differently, you know, with a double "n," whereas Anika here is A-N-I-K-A.

25:54 Mentoring PhDs – Create New Knowledge Out of Confusion and Dig Deep

Babu:

Thanks, Harry, for sharing, and that leads to mentoring. So, one of the things as a professor, one worry I always have is probably I'm not doing a good job in mentoring, challenging, and providing a caring atmosphere for them to excel. So, might we talk about a lot of mentoring styles and also how enthusiastically you share new knowledge and inspiring others to dig deeper as we walk through. And, kind of give us guidance on, there are three topics I would like you to give guidance; I'll go one by one. One, let's say it was a budding student who's thinking of embarking on adventures of steel and iron metallurgy. And, I took the word from adventures of steel metallurgy from your conference and phase transformation. If you have to mentor that budding student? What would that be?

Bhadeshia:

This goes back to what I said earlier, that the student must have an idea of what they would like to do. There's a very famous book written, it says how do we create a genius like Einstein, and so on, and there's a very simple conclusion. If there are a lot of confusing data, that inspires a genius. Whereas, if you just jump on to do a PhD in graphene, simply because there's a lot of noise about it, that's not a good way to start a PhD program. I was invited to give a talk at a graphene meeting, a big graphene-meeting, and I demonstrated to them that they haven't really achieved anything compared with steel. It was fun; they appreciated it. So, if you really are interested in a PhD, which stands for Doctor of Philosophy where you create new knowledge, you've got to identify an area where there is a lot of confusing information. In physics, for example, the obvious one would be that gravity and quantum mechanics are not united. That is the key aspect that I would recommend is to find an area which has significant confusion.

Babu:

That's great. So, this going along, I'm moving from students to the people who are already in the field and contributing. So, I know we don't have a magical way to look at it, but there is one approach if you can give them a kind of guiding thought process on what should we do as a way of going to pushing the boundaries to the next level?

Bhadeshia:

I think you've got to have a determination, and the common saying that it's 99% perspiration and 1% inspiration remains the case. So, if you want to do something special, as opposed to the run-of-the-mill PhD, you have to actually dig really deep. If there's something you don't understand or you need help with, you find the people who are working on that area, and you work and collaborate, for example, not for the sake of collaborating, but because you need to understand. Obviously, a PhD is time-limited, but if you actually go somewhere towards solving a problem and creating new knowledge, that really inspires. I mean, with neural networks, I worked for 24 years with David MacKay without any funding.

29:53 Sustainable Solutions – Reducing CO2 Emissions

Babu:

So, Harry, some of the conversation we had is a community as a whole, and we should aspire to the future. One of the things I still remember when we thought about having a special conference for you, you indicated that, Suresh, you need to think about what our whole world is going through climate and all other things. So, look at it from our own microcosm of metallurgy and steel and everything. What can we do to address some of the challenges we face in the world right now?

Bhadeshia:

There are two things which I think are really important. One is we need legislation, international legislation, to cut the consumption of steel, because, right now, you could cut it, I think, by a factor of a quarter, by using better steels which are somewhat more expensive. You just look at the example of the automobile legislation, and, therefore, we have much better steels used in smaller quantities but more expensive. So, steel production, I can't remember the figures, but it might be 7% of all the CO_2 emissions, and that is not sustainable. We should not be producing 1.6 billion tons of steel every year and consuming it. Coming from a steel person, that sounds crazy, right? But, I think enlightened companies [should] focus on how to reduce CO_2 by cutting consumption and by new technologies. This morning there was a talk given by a startup company in India on exactly the CO_2 problem and what they're trying to do with that. That's one aspect.

The second thing is absolutely accurate. And, I presented this at a talk in Russia, and the United Nations supports this as well, that we should become vegans. The idea of eating meat and milk products and dairy products, it's a secondary production, which results in a huge CO_2 cost and methane cost. Overnight, we could meet all the targets if everybody became vegan. If you go to Canada, you see vast fields of crops; they're not being grown for human consumption; they're being grown for animal production. If everyone becomes a vegan or tries to become vegan, that would make the biggest dent on the environment, in the timescales that are necessary.

32:49 Recycling Steel, Sustainable Energy Sources, and Legislation Which Drives Innovation

Babu:

Thank you, Harry. That's a good way to project into that. Once in our coffee time, we talked about the early steelmaking, about direct iron reduction. So, is there any way when you're taking that steel to reduce the consumption? Is there any different ways of making the steel, not like integrated steelmaking, so that locally we can recycle or even making can we do locally? Is there any way to think about that way?

Bhadeshia:

Yes. Steel is the most recycled material in the world, actually. And, you can't gain much more from recycling, because it is recycled so well. But, the idea of local production, for example, by electrolysis, that only works if you have the electricity to do the job. And, you can use the electricity in many ways: you can produce hydrogen, and it is possible to do direct reduction or even put hydrogen in blast furnaces as Sarakunda was talking [about] this morning. The key is, if we have sources of energy which we can use to cut the CO_2 emissions, and that's possible. So, for example, in 2020, wind turbine power in the UK was so high, the proportion, it was something like 45%, that we did not use any coal at all. And, many gas-fired plants were shut down. I think it is possible to produce steel with hydrogen, and, in Sweden, they already have a pilot plant, or they are building a pilot plant to do exactly that. Although, the problem of where the hydrogen comes from is not solved, you need to make a start. Legislation would help because, obviously, the companies that are investing, they will actually beat everybody else in the future. But, if there is legislation that really drives innovation.

35:17 A Thank You to Professor Harry Bhadeshia – An Inspiration

Babu:

So, that takes to one of the things, as you are going through from your academic career, professional development, and future projection. One of the things I still remember is this final question I talked about already; you go very rapidly through the department, you are very physically fit, you play squash. What is your magic? How do you keep winning in squash and all this? How do you keep it up all the time?

Bhadeshia:

It is true that in the last set of games I played, I beat Apparao Chintha, who is less than half my age. But, of course, there are many people that I'm not able to beat. I like cycling, long-distance cycling, right now, that's not possible, simply because of the pandemic. We're not supposed to go outside of our local areas for exercise. But, I bought a really nice rowing machine. Every time you row, the water swirls around, so you actually get the feeling of being in water. And, last night, I was doing synchronized rowing over Zoom with a Professor of Quantum Mechanics in our Department of Applied Mathematics and Theoretical Physics. It's a lot of fun. It's not simply exercise, but it's a lot of fun.

Babu:

So, one of my regrets in my PhD is I never played squash with you.

Bhadeshia:

You know, there's time. There's still time to make amends.

Babu:

So then, the only thing I picked up is running. So, right now, I do that. That takes us to the last concluding part of that and wrap up in our meetings. So, let me give a little bit up, and then I'll open up to you to give more comments. As I was preparing questions for this interview, I still remember our walk. And, this is personal for me mainly because, after one year, I still remember that I was ready to quit my PhD because I was comparing myself with everybody else. I still remember your words to me. You said, "Suresh, don't compare your PhD with reference to others; you put your own standards. So, you meet your standards, and did you do a good job today? Did you try to move it to that?" And, those kinds of walks, I'm walking through, and I still talk about that in my class, about those experiences.

More than the technical and science inspiration is about that caring nature. And, I really liked that. And, in fact, I'm really happy that you introduced curry lunch in Darwin. I still remember, I looked forward to our curry lunch and go and have a coffee. I still remember, we talked about the controversy of bainite with another student who works with Professor Aaronson. I think I forgot his name; it escapes me. I believe we started around 1:00 PM and went on till 3:00 PM. I still remember. Those are the ones that make up as a research, as a career, also. At this time, I take this opportunity to thank you, on behalf of everybody who has been touched by you. Not only [those] who talked to you in person, but there are also a lot of people who follow you, and then they quote what you say many times in their own emails. Many students who I happened to know; they talk about you. I'd like to thank you for your caring nature, and also enthusiasm and encouragement, and also tireless service to the community. That is one of the hallmarks of, as I look at it, I look up to you. I wish I could do at least 5% of what you have done. And, I look forward to that. With that, I'll close for any comments from you; I'll open it up to you.

Bhadeshia:

Thank you very much for saying those things, but what is important is that everybody I've worked with is actually doing better than me. That's the principle, that your students should actually do better than you. So, well done.

Babu:

That's great.

Bhadeshia:

And, thank the AIME, also, for organizing all this.

Babu:

Thank you, Harry, and this comes to the conclusion of our Zoom meeting with Professor Harry Bhadeshia. Thanks to the AIME staff for allowing us to share our thoughts and have a dialogue. With that, I will stop this interview. Thank you

Bhadeshia:

Excellent.