

My Journey as a Materials Engineer



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At the outset let me confess that when I received an invitation from the President, INAE for contributing an article for the INAE newsletter, I readily accepted without giving it much thought. I did not anticipate that writing about one's own life and work and making it interesting enough to hold the attention of the readers would be such a challenging task. But after struggling for months to finish the article (and often regretting on why I accepted the invitation), I can say that I am glad that I accepted the invitation because it gave me an opportunity to reflect on my life and career.

My tryst with engineering started very early in my life. My father was a civil engineer working with - Gammon India Ltd which is one of the premier construction companies in the country. He was responsible for building dams, bridges and power plants all over India. These projects were usually in remote areas of the country and thus the only source of entertainment for a young kid like me was wandering around the construction sites. I thus had the good fortune of seeing massive civil structures evolve from scratch and let me tell you that is quite awe inspiring for a child. I distinctly remember that at that time my dream was to follow in my father's footsteps and become a civil engineer and construct even bigger structures!! You can say that I was no different than any other young, impressionable child who thinks that the world begins and ends with what their parents do!

Most of these construction sites did not have good schooling facilities, and so my parents had no choice but to send me to a residential school. They chose an excellent school (Sanjeevan Vidyalaya) in Panchgani, a lovely hill station near the better known town of Mahabaleshwar in Maharashtra. The education there was well rounded with equal emphasis on academics, sports and culture and I still retain pleasant memories of my time spent there. Eventually my parents (my mother) decided to set-up a home in Bombay (or Mumbai as it is known today) and I completed my final years of schooling in King George, Mumbai a very well known school. Gradually, visits to my father's construction sites became holiday-only (summer and Diwali) affairs and as I became older, I began to realize the comforts and benefits of living in a city and how tough the life of an on-site civil engineer really is. I distinctly remember that by the time I was in 10th standard my motto in life had changed to study "anything but civil engineering". However, in that era, the career options for any reasonably bright student were limited to "Engineering" or "Medicine". I had no aptitude for medicine so the choice was limited to Engineering (other than civil of course). I would like to thank all my teachers in both the schools because it is my belief that the values that they instilled in me in my formative years played a major role in shaping my personality and helped me become more adaptive and independent.

To take the journey forward -I was extremely lucky to get through JEE as I did not specifically prepare for it and was content on focusing on my 12th standard syllabi. Times were simpler then,

and an IIT admission was not a mind-numbing long endeavour as it is today. I remember visiting IIT Bombay campus on a rainy day in June in 1981 for counselling and was required to fill a form specifying twenty choices. At the time, my JEE rank I believed, was good enough to get either Mechanical or Chemical Engineering in one of the five IITs. As a result, I did not pay much attention to what my choices were beyond the 10th option and filled in random options on a lark. As luck or destiny would have it, IIT Kharagpur, Metallurgical Engineering) my 18th choice was where my next four years would be spent. The fact that I had to study Metallurgical Engineering did cause some initial panic, as I had no clue on what Metallurgical Engineers did for a living! My knowledge of engineering branches at that time began and ended with Mechanical, Electrical, Civil and Chemical. And this was a time before “Internet” and “Google” so there was no easy way to obtain information on what Metallurgical Engineers did for a living. A friend claimed that his brother’s friend’s cousin had studied Metallurgical Engineering and was now working in a mine in Dhanbad. I was now cursing my luck and regretting my decision to not choose Civil Engineering as an option since working on dams and bridges and building massive structures above ground looked way more attractive than seeing the underbelly of a mine! To make matters worse, the same friend (a self-acclaimed know-all) told me that among all IITs, IIT Kharagpur had the worst ragging.

With grave apprehensions, I landed in IIT Kharagpur in July of 1981 as a fairly naive 17 year old. I will spare you the gory details of the ragging I had to undergo!! (really speaking it was not bad at all). It so happened that 1981 was the first batch where the IITs were changing over from a 5 year to a 4 year B.Tech. Programme. As a result the first year curriculum for the new programme was crammed to cover the syllabus of what was taught over two years for the five year batch. The first year passed like a whirl and before I knew it I was in the 2nd year when the first Departmental courses start. My first introduction to Metallurgical Engineering was a course on Metallurgical Thermodynamics. In cricketing parlance (especially for old timers), it was like starting your career facing Michael Holding and Andy Roberts on a fast and bouncy Sabina Park pitch. Luckily, I survived and gradually started to realize that Metallurgical Engineering involved much more than looking for metallic ores in mines!! The 4 years in IIT really flew by and were most definitely the best years of my life. Although I did fairly well academically (being the Silver Medallist in my batch), I would be not be stating the entire truth if I said that by the end of my final year I was a true blue blooded Metallurgical Engineer. In my own evaluation, I had a decent foundation but not much of a super-structure. This had less to do with the quality of the faculty at IIT Kharagpur Metallurgical Engineering Department, which was in fact excellent, and more to do with my lack of maturity at that age to appreciate the finer nuances of the subject.

I was again at a cross-road; I had three choices: take up a job, study management at an IIM or go abroad to do Ph.D. I chose the last option since most of my friends were headed abroad and I can say today (almost 30 years later) that I am glad I did!! I had a fellowship from The Ohio State University (OSU) at Columbus and my interest in and appreciation of Materials or Metallurgical Engineering really commenced as a result of my experiences at OSU. For this I would like to thank all my Professors and fellow Graduate Students at OSU, but the bulk of the credit would go to my Ph.D adviser, John Hirth. I have not met a more knowledgeable and nicer person before or since. His humility (despite his many achievements and stature) as well as his willingness to discuss problems with his students at their level, is a character trait that I admired the most. I have no hesitation in saying that my career has taken the shape it has mostly because of my interactions with Prof Hirth during my three years at OSU. Although, one of my everlasting regrets has been that I failed to reach even 10 % of his funda levels!! Coming back to my Ph.D thesis, those of you who are familiar with Professor’s Hirth’s classic book on “Dislocations in Solids” would have guessed by now that my thesis would be something to do with dislocations. You are both right and wrong. My main work was on studying the deformation and fracture behaviour of particulate reinforced metal matrix composites which were then just emerging as materials of great promise (unfortunately they never delivered on their promise). However, I also looked at how image and

coherency stresses influence interface dislocations in multilayer heterostructures, which was a very important issue to be resolved for improved performance of microelectronic devices, as an appendix of my thesis. The interesting thing was that during my thesis defence, 90% of the questions were from the appendix part !!

Dr. G. Sundararajan, from DMRL, happened to visit OSU (incidentally also his Alma Mater) and gave a lecture on the work going on at DMRL, just as I was completing my Ph.D and contemplating on what I should do next -: take up a faculty position in US or India or work in a Research Laboratory. I was very impressed with the nature of research as well as facilities at DMRL and decided to apply to DMRL. Prof. P. Rama Rao, who was then the Director of DMRL, offered me an Ad-hoc Scientist position and upon completing my Ph.D and a short stint as a post-doctoral fellow at Washington State University at Pullman, WA, I joined the Defence Metallurgical Research Laboratory (DMRL) where I have now spent the better part of 25 years interrupted by a brief two year stint at the Group for Forecasting of Systems and Technologies (G-FAST) at DRDO HQ. I would always be grateful to Professor Rama Rao as well as all the subsequent DMRL Directors for the freedom and encouragement they gave me. This helped me integrate very easily in the laboratory and helped my career flourish. Along the way, I worked on several structural materials developed in DMRL for various defence applications These include Particulate Reinforced Metal Matrix Composites, High Strength Aluminium Alloys, Al-Li alloys, Titanium alloys, Titanium Aluminides, Tungsten Heavy Alloys, Ultrahigh Strength Steels, Nickel Based Superalloys and Silica/Silica Composites. In the initial years of my career my research focus was on studying the correlation between processing, microstructure and mechanical properties in these structural materials; however, as my career progressed my research encompassed other areas such as Mixed Mode Fracture, Mechanical Behaviour at Small Length Scales and Stress Corrosion Cracking. In recent years, I had the opportunity to lead and direct R&D on Rare Earth Permanent Magnets (REPM) as well as various Advanced Magnetic and Ferroelectric Materials in both bulk and thin film form for various functional applications as well. No other institution in the world could have provided anyone the opportunity to work on such a diverse set of materials and areas. Additionally, the R&D work in DMRL, is always application focused. Research culminating in an application is always much more satisfying, especially for me.

I will briefly highlight our team's work on REPMs as it encompasses the entire gamut from basic R&D, technology development as well as lab scale production. Among the front ranking high performance REPMs, SmCo_5 , $\text{Sm}_2\text{Co}_{17}$ type and NdFeB alloys are technologically the most important. High residual magnetic induction and high energy product values are characteristics of these REPMs. They exhibit excellent combination of second quadrant (of B-H plot) characteristics and offer additional advantage of device miniaturization by virtue of their high energy product, because the volume of a magnet required for a given application is inversely proportional to its energy product. With these REPMs, it is possible to design for reduction in the size and weight up to 10 times for many electro-technical devices without compromising on their performance. Due to this advantage, they are used in a wide range of applications ranging from consumer products to very specialized areas of tele-communications, automotive, microelectronics, avionics, defence, space and wind power. While NdFeB magnets are preferred for ambient temperature applications on account of their higher energy product, SmCo magnets (1-5 and 2-17 types) are used for applications where the magnets can experience elevated temperatures due to their higher Curie temperature and lower temperature coefficients of remanence and coercivity.

The rare earth permanent magnet technology is currently possessed by very few countries in the world because of various factors such as complexity of the technology, availability of raw materials (rare earth metals) and patent related issues. In fact, it should be noted that China not only has a monopoly (97 % of production) over the rare earth metal resources such as Sm, Nd, Dy and Gd which are the key raw materials for producing these REPMs but it also dominates the production

and supply (50%) of REPMs. Within the country, DMRL is the only organization that has worked assiduously to understand the basic science as well as establish the technology for producing these rare earth permanent magnets. The home-grown technology has been exploited to develop and supply speciality magnetic components for various DRDO and ISRO Missions. Till recently, the laboratory facilities were sufficient to meet the demands of the strategic sectors. However, in recent times, the demand for these REPMs from the strategic sector has gone up tremendously. We are currently exploring the possibility of transferring of our REPM Technology to Indian Rare Earths Limited to set up a pilot scale plant to begin with. It will give me great pleasure, if such a plant is set-up, as it will be the ultimate fruit of our R&D efforts.

Finally, I would like to end by saying that although my journey to becoming a Materials Engineer was not something I aspired and planned for, I do hope that my narrative will motivate at least a few youngsters to seriously consider Materials Engineering as a career option, by design.