Advances in Additive Manufacturing of Materials: Current status and emerging opportunities

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Lecture 01

Hello everybody, welcome to this NPTEL course on additive manufacturing. My name is Bikramjit Basu and then title of this course is Additive Manufacturing Process Science and Emerging Opportunities. I am currently professor at Indian Institute of Science, Bangalore. Please note my email address and you can reach out to me at this particular email address. More details of our research in the area of additive manufacturing can be found in our website. Before I formally begin this course, I would like to mention that additive manufacturing is one of the technologies that are expected to revolutionize the manufacturing industry in a significant manner.

It also it is also going to replace in a thoughtful manner many conventional manufacturing methods in the industries. However, I personally believe that one has to develop more insightful understanding on the process science of this additive manufacturing techniques or different additive manufacturing techniques before they can thoughtfully utilize this additive manufacturing to develop various engineering components. which can be made up of either metals, ceramics or polymers or composites. So therefore, process science involved in different additive manufacturing techniques are of paramount importance.

The title of the course also says that emerging opportunities so as the field has grown over the years. We have to also exploit the concepts and understanding of other relevant fields so that these fields progress can be accelerated in the years to come. So, one of the important component of this course will be on utilizing data science concepts like you know how the artificial intelligence and machine learning can be adapted in the additive manufacturing field. Another component that I am going to also show you is that how to conduct this additive manufacturing experiments or bioprinting experiments under microgravity conditions for example space bioprinting. So these are some of the emerging opportunities which will be very interesting to all the viewers and all the students of this particular course.

As far as my research course, our research group has been using particularly 2 different variants of the additive manufacturing. One is laser based additive manufacturing that is either SLM or LPBF that is called laser powder based fusion processes or SLM stands for

selected laser melting. or DED, DED stands for directed energy deposition based AM processes. Throughout this course whenever I will use the abbreviated form AM capital A capital M that essentially means additive manufacturing unless otherwise mentioned. Second variant of additive manufacturing what our research group has been investigating is the 3D extrusion printing and this 3D extrusion printing is used for soft materials like hydrogels, primarily for biomedical applications.

For the first variant whether it is for SLM, I repeat selected laser melting or DED, directed energy deposition processes, we have been investigating their efficacy to develop complex components primarily of metals and 3 different metals that our group is investigating. One is stainless steel 316L grade, second one is this titanium 6 aluminium 4 vanadium alloys and third one is cobalt chrome alloys. These three materials are used for diverse engineering applications from structural to biomedical applications and cobalt chrome alloys is particularly we are investigating for biomedical applications. So, those will be more from our particular research field and as I will show you in the next few slides, I will be essentially showing you that some of the examples of that. This is the relevant details of this course.

This course will be for 12 weeks for 30 hours. Undergraduate and postgraduate students in the disciplines of material science and engineering, mechanical engineering, biotechnology, biomedical engineering and bioengineering. are expected to be greatly benefited from the content of this course. And both these, particularly these multiple discipline students, this course will be highly relevant from students and researchers from these multiple disciplines. At this point, I would also like to mention is that many of the fundamental concepts or design related aspects which are relevant for additive manufacturing will not be covered under this course.

This is because of the fact that there is already similar courses are available on this topic. One such example is the course by Professor Sajan Kapil from IIT Guwahati Mechanical Engineering Department. The course name is Fundamentals of Additive Manufacturing Technologies and you can see that he has given 12 weeks lecture on different aspects particularly the CAD planning for additive manufacturing, liquid additive, sheet additive, wire additive, powder additive manufacturing processes. So, this essentially covers that most of the fundamentals or at least some of the relevant fundamentals as well as the some of the different types of additive manufacturing. So, I am not going to cover those part of the course.

So, interested viewers or students can refer to the course and then I have also mentioned the web link for this particular course. Although I am not going to cover any of these fundamentals but I will briefly mention the what I believe that is kind of very important

concepts in couple of slides at relevant lectures and in the powder additive manufacturing I will be as I said I will be mostly showing you case studies and this case studies of larger relevance to researchers. This is the second course and this is under NPTEL SWAYAM course, this course was covered offered by Dr. Sharad K. Pradhan from National Institute of Technical Teachers Training and Research, Bhopal.

And the title of this course is 3D printing and design for educators. As you see in the content of this course, it has additive manufacturing introduction and CAD, a computer aided design, data preparation for 3D printing, 3D printers and softwares, 3D printing materials, solid based 3D printing, liquid based 3D printing, powder based 3D printing. I believe this course also would be useful to some of the viewers and students who are taking this particular NPTEL course. So, I would encourage you to go through the course content on this particular web link which is also available in YouTube for more details on this course. Having said that, let me now briefly mention the course content that I am going to cover under this specific NPTEL course.

So, as I said that I am not going to too much details into the concept, but particularly I will be touch upon very relevant concepts and importance of additive manufacturing, particularly fundamentals of engineering design, basic elements, STL file format, computer softwares. I believe that this much introduction is required because these concepts essentially will make also this my NPTEL course is a standalone course. And therefore, this NPTEL course can be referred can be useful to a broad spectrum of researchers. My background is material science, I am a metallurgist by training. So, therefore, as a material scientist how I learnt and then how my research group has utilized many of these engineering design concepts in the field of additive manufacturing I am going to share.

So, that many students or many researchers from similar background also will be benefited. Next I am going to touch upon the structure and properties of engineering materials and there again I will be discussing on the metals, ceramics and polymers and composites. What are the distinct attributes? What are their specific properties? How each material class is different from another? and what is the motivation of developing composites, all those aspects also would be discussed. At the same time, I will be pointing out what are the advantages and disadvantages of the each material class. This will be followed by overview of some important Am processes, additive manufacturing processes, particularly high energy laser, electron beam, UV, laser stereolithography, 3D inkjet printing.

As I said in the beginning that process science is very important. And here I will be showing you many experiments that can that have provided us to obtain a greater

insights into the process science of the selected AM processes like binder jet 3D printing, 3D extrusion printing, I am going to show you. And when I said that many experiments in our group, what I mean by those experiments are more quantitative experiments like it provides more quantitative data to demonstrate that how to how to tailor the printability of different materials or buildability of different materials. Next we will go to this process science of other AM processes like laser powder based diffusion, LPVF directed energy deposition. and those things I will be covering but those will be more for the metals whereas 3D extrusion printing is more for soft hydrogels which are polymeric based materials and binder gel 3D printing also will be shown for some of the ceramic based materials or metallic based materials.

one of the interesting component of this particular course which will distinguish this course from other NPTEL courses in similar in similar area would be scientific case study, clinical applications of 3D printing, regenerative engineering and also emerging opportunities, these three aspects. So, in the scientific case study, I will be showing you mostly the materials which are developed and their properties that were investigated or explored using binder jet 3D printing. And, these three materials include titanium 6 aluminum 4 vanadium, zirconia these are like model metallic materials, model ceramic materials and on the new material side it is a binder jet 3D printing of strontium, magnesium, phosphate. This will be followed by a series of scientific case study based on 3D extrusion printing of gelatin-based hybrid biomaterial inks. It can be either gelatin methacrylate or alginate gelatin-based materials.

Then, DED-directed energy deposition of stainless steel, LPVF-laser powder-based fusion of Ti6L4V. Subsequently I will show you that how additive manufacturing was useful to develop clinical models and that how those clinical models were used to fabricate patient specific bone flaps which were used for cranioplasty surgery in two different hospitals in India and where 20 patients were treated using this particular technique. how this 3D printing and bioprinting is going to revolutionize the field of regenerative engineering. This is followed by data science approaches and here I will be taking more classroom lectures on the very fundamentals of artificial intelligence machine learning. And, then how they are useful for 3D printing and the two examples I will be showing one is called regression analysis one is called classification analysis.

In the regression analysis is more used for the 3D printing process prediction and classification analysis is more for additive manufacturing part quality evaluation both are very important. and also concepts of AI- ML and then AM under microgravity conditions and then current challenges and future perspectives. In both these cases you know in the series of lectures I am going to give it over next 12 weeks I will be showing you a number of videos And those videos are of two variety, one which will essentially show

you how 3D extrusion printing is used in research laboratory like ours. and how directed energy deposition as a large facility has been installed and operational at Indian Institute of Science and their functioning and how different components have been produced. also I have been collaborating with a number of industries and therefore I will be showing you some of the videos which we have we have taken from my industry collaborators from to demonstrate the fact that how additive manufacturing equipments are used to fabricate large number of materials with different part complexity with varying process parameters and so on.

Here, one disclaimer is that those videos should not be considered as those for promotional purposes or for any commercial gains. So, those videos should be purely considered for academic learning exercise purposes. two teaching assistants of this course and both belong to my own research group at Indian Institute of Science. Their email addresses are mentioned. Please feel free to reach out to them with any of your queries, clarifications and so on.

Let us now start very briefly or revisit the definition of additive manufacturing. What I wanted to give a textbook, I wanted to give a more textbook type of definition to additive manufacturing. So, the way I have defined is as follows. This is a computer controlled manufacturing process involving layer by layer building of materials. I am going little slow to emphasize important terms in this particular definition.

In a predefined manner as per the design, design means either computer aided design model CAD model or a digital model either can be used in this. in this particular manufacturing process to be constructed and this inter manufacturing process is expected or will lead to creating a 3 dimensional objects often with complex geometry and topology. So, it can be either geometry like you know outer geometry like different components like for example gear or it can have complex topology. Now from this particular definition it should be very clear to you that what conventional manufacturing process cannot do in reality additive manufacturing process can do the same thing and that is where the additive manufacturing has attracted so much global attention from multiple disciplines not only from material science but from mechanical engineering. from electrical sciences and many other disciplines, chemical engineering, biotechnology, bioengineering, biomedical engineering and so on.

So, there is only a handful of technologies for example additive manufacturing, data science that perhaps have attracted millions of researchers around the world because of their tremendous potential and relevance not only particularly one particular scientific or engineering domain but also to a multiple domains across the spectrum of technologies right. So I repeat additive manufacturing is a layer by layer building of materials. It needs

a CAD model or digital model which needs to be given as an input to the manufacturing machine which is computer controlled and the output of this entire process will be a 3D object made of either metals, polymers, ceramics or composites and so on. and with a complex geometry and topology. This complex geometry and topology is very important keyword and this complex geometry and topology cannot be achieved in many conventional manufacturing processes so easily and some of the parts I am going to show you that is only possible in the additive manufacturing.

technique. So, I hope this important definition can be remembered by all the viewers and reader and then students of this course. Many times I have seen that you know many young researchers many students they are using additive manufacturing technologies different machines and so on but whenever I kind of discuss with them I converse with them that you know what is the definition of additive manufacturing and all. They may miss out some of the important keywords so that is the reason I am re-emphasizing the need to remember various keywords which constitute this specific textbook type of definition. So, this is the historical overview.

In 1980, Dr. Kodama filed the first patent for rapid prototyping technology. Many a times people are confused and they use the term interchangeably rapid prototyping, additive manufacturing, 3D printing. These many of these terms are synonymous in nature but one can be subset of another. One can be more generic term like additive manufacturing, 3D printing is more kind of either synonymous or subset of this additive manufacturing in general. So, this particular patent was on UV photo curable polymers.

However, this particular thing was never commercialized. Then comes Stereolithography apparatus SLA patent, this is done by Charles Hull in 1984, co-founded the 3D system corporation. So, essentially it leads to establishment of a company. In 1988, the selective laser sintering patent was filed by Carl Deckard and 3D system first commercially sells SLA-1 3D printer around the same time in 1988. In 1989, FDM that stands for Fused Deposition Modeling was patented and then this is Steven Scott Crump from Stratasys.

This is another world globally known company that was involved. In 1993 MIT professor first developed that inkjet 3D printer and commercialized and jet corporation that was the company who started selling this 3D binder jet printer. In 1995 SLM printer so more than 30 years ago around SLM selected laser melting was invented by Fraunhofer Institute of Laser Technology in Germany 1995. In 1999, 3D printed urinary bladder, that is again for 3D bioprinting, Anthony Atala at Wake Forest Institute of Regenerative Medicine, his research group has shown that how to essentially manufacture the 3D printed urinary bladder. And that has gone through clinical studies

and clinical trials with a limited number of patients.

2009, 3D bioprinter essentially was manufactured by Organovo and 2016 I think that Celllink that is a Sweden based company who started manufacturing, selling this 3D bioprinter across the world. So, this slide perhaps presents the overall historical overview of this 3D printing or additive manufacturing in general, starting from rapid prototyping. As you see, the time scale essentially starts from 1980, it is around 45 years ago. So, this field is actually rapidly progressing and what is not mentioned here that more than last one decade or you know at least around 10 to 15 years, last 10 to 15 years NASA scientists, European Space Agency scientists, Russian astronauts and you know the Japanese scientists they have been using this additive manufacturing under microgravity conditions and then field which is currently known as the space bioprinting. I am going to cover that space bioprinting also in towards the end of my towards the last phase of my this particular course.

So, as you see that it is not only ground level experiments people are doing individual research laboratory, it is not that people are utilizing or industry people are utilizing the additive manufacturing in the shop floor to manufacture different complex shaped components, but also the researchers or space scientists they are using this additive manufacturing under microgravity conditions. So, indeed their additive manufacturing has been continuously revolutionizing the field the way we use the way we manufacture materials for different applications. So, I will come back to you in the next class with to continue with more details. Thank you.