

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

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Welcome to this lab demonstration on directed energy deposition at the additive manufacturing facility in Indian Institute of Science. I am wearing the mask because I'll be handling a lot of powders and then I will be showing you that how powders are handled, what are the characteristics of the powders. for the purpose of recording this video, I am not I am now removing the mask so that you can listen to me much more clearly. But whenever I'll handle the powders, I will wear the mask and that time my voice can be heard little bit at lower pitch. This is the Directed Energy Deposition Facility, DED facility. It is one of its kind in India and this facility was established a few years ago with the generous support and financial assistance from Minister of Heavy Industries, Government of India, under the Samarth Udyog Programme.

this is a formalloy machine. What you see inside this particular machine, we have a laser system and Shiva is going to explain more details when he will be showing you the key components of the laser system. this particular laboratory demonstration video is composed of few parts. The first part I will be showing you the different metallic powders.

which are regularly being additively manufactured using this DED facility. Second part of this lab demonstrations will essentially involve the demonstration of the commercial engineering design softwares essentially to show you how to design certain structures which can be printed using this DED facility. And in this second part, essentially I'll be showing you some of the 3D printable design structures and these 3D printable design structures, I will show you how to create the STL file and then after that STL file to the G-code and this G-code will be transferred to this machine and the machine will read the G-code and then laser path will be synchronized with the information that is contained in the G-code. The third part of these demonstrations will essentially involve the demonstration of the key components of this 3D printing machine or facility and also what is their specific functions. Essentially I will show you how the G-code is loaded into the machine, into the computer and then we will start the printing operations and I will show you how the laser beam is guided during these 3D printing operations.

And then last part I will show you that how this post processing, what are the approaches for the post processing and what are the different 3D printed parts that were manufactured using this particular facility along with some of the functional components. let's start with this powder part. What you can see that this is the typical metal powder for additive manufacturing and this is the TiAl powders. TiAl powders, so this is already.

.. this is the TiAl powders, titanium aluminate powders, and you can clearly see that this company has clearly mentioned this is the metal powders for additive manufacturing. these kind of grades one has to buy for this metal printing. This is another one. This is the Ti6Al4V powders, titanium 6% aluminum, 4% vanadium powders, and they are essentially used for applications ranging from aerospace to biomedical applications. This is that Inconel 625.

This is that super alloy powders. And this is also we have used to print some of the structures. This is a pure aluminum powder. So you can say this is the plasma atomized 99.9% purity and size is 45 to 110 micron.

this is the size range typically are very good for 3D printing. Now you can see this titanium powders. one of the important things that I will show you that these powders need to be easily flowable. if I put it in this funnel, then you can see that this how these powders are are flowing through this funnel with a particular orifice. this good flowability also it depends on that what is the monomodal size distributions or particle size distribution in the powders.

this is like a titanium powder I am showing you. This is Ti6Al4V powder. there are also different type of powders that we have tried titanium niobium alloy powders then tantalum powder this is one of the another refractory materials which are used and i can show you for all the powders if you put these metallic powders it is very good flowability so flowability is an important attributes for the 3D printable powders These are also titanium powders and these are niobium tantalum powders. niobium tantalum powders is another type of alloys which can be 3D printed of specific compositions. As you have learned in the class that you know that powder particle size distribution is very important.

Powder purity is very important and flowability is also equally important. So let's now move on to the design aspect. Now you will be shown that how to design the structure on a computational platform. As Professor demonstrated, we need the file format should be in G-code format for using it in the machine. So I will demonstrate how to convert the CAD file to a G-code.

This is the Mastercam software. In the Mastercam software, we have an add-on for using additive manufacturing toolpath. first, we will be opening the CAD model, which is to be used for generation of G-code. the first step will be opening that thing. file, in open, browse.

it is the file is in desktop so this is the file now this is the file which we are going to print so i will show you, this is the part which we are going to print. The first step what we need is like we have to orient the part in such a way that the part should be printable in the Z axis. This should be oriented along the Z axis and also its origin we have to set. The origin should be at the bottom of the part so for that we have to go to transform and move to origin we have to give and we have to select the base so that it will go to the origin . So now you can see this is the part which we are going to print.

It is having a slot at the bottom and it is having a cut section at the top. The next step is like a selection of machine. For that we have to go to the machine tab and in the middle section like we have already predefined thing for the formalized system. I am clicking that. Then we have to do the toolpath for the AM machine.

We are going to AM laser section. There we have multiple options. for slicing like the part in the three axis and also for the five axis system we have for multi axis we have and for a radial slicing we have an option and for a rotary laser slicing also we have an option so now we are going to do slicing with respect to the three axis system so you have to click AM slice laser so then we have to select which part we want to slice so i have selected the path then you have to give any selection so now we have to give the process parameters required for the slicing so the geometry that we have already selected this part Then toolpath we have to give. For that we have to put what is the layer height we need. This layer height definition we will do by process parameter optimization in the initial stage.

Then we will find what is the layer height which is required for printing. Then those data we will put here. Here we are using a layer height of 0.5. Here we have a different other options also whether during printing whether it should print only in the same direction for second layer whether it should do printing in the reverse direction those things we have options here.

Right now we are printing along the same direction. Then the second step is like we have to select the tool. For a tool selection like we go to the already saved libraries, we have different tools available in our library. we will select the tool which is required. here you have to choose the laser thing.

laser powder head it is in mm. This we will choose. Then like our beam dia is like one mm. We have to choose one mm spot size.

Then this is done. Then this option is like for setting the boundary. If you are printing like outside and inside. There is an option for giving outside boundary only or inside boundary only. But for this part we are currently not using the boundary option. You can untick these two things.

then thin wall, our part is having very small thickness so we are going to the thin wall printing so here the we can set the parameters like maximum thickness deviation of 0.25 and other things is if we are printing like the part so how much overlap we need so those parameters we can give. And between one bead to next bead, how much the bead width should be there, those things we can give. After that, we have to give the process parameters required for printing. Here, we will use the travel speed of 700 and the laser power of 300 and the nozzle gas of flow rate of 14 in liters per minute and the shielding gas of seven liters per minute and we are going to use the first hopper and also like we you can set the feed rate here then the next step is like our part is having like two regions one is like the bottom region is having some solid portion so for solid portion we have to infill the material so for infilling we will use the fill option so in fill option you have to give what is the hatch spacing so hatch spacing is the space between the one layer and the second layer so here usually we will give like a 30 % hatch spacing normally and also in this you can set like what should be the change in angle like after every layer so once you once it will print the first layer the second layer on top of it you can print at 90 degree or 0 degree 180 degree or 67 degree whatever you need so those parameters you can give it here like change in angle per layer then similarly the process parameters you have to set here i will be using at a thousand and like laser power of 400 watts and like gas flow rate everything and the source everything we have said and we have to click the button so now the slicing operation has happened so like we can simulate the things like how the slicing has happened. after slicing so far simulation, you can go to here and you can see how the printing is happening.

it is printing the boundary walls, then it is printing the fill options. you can see the simulation like how the printing is going on. you can see the whole part is getting printed so there is an option to see how much time it is going to take so when you give all the parameters correctly, for the generation of g code there is an option called g1 here so when you press this the g code will be generated so here is the g code so here in the g code you can change the parameter like what is your power disk speed and what which hopper you are going to use so here in this formula machine we have an option of four hoppers. Now the G-code is generated. from this G-code, we can start printing the parts. This is the procedure of generating the G-code.

Once the G-code is generated, you can transfer the G-code in pendrive to the machine so that you can use this G-code for printing your components. Hello everyone welcome to smart factory so we are going to explain metal additive manufacturing, this is the one of the technology of the additive manufacturing by DED technology directed energy deposition method so here laser and powder simultaneously deposited the material layer by layer so now we are going to see the DED Components this is the nozzle. It consists of two nozzles. One is outer, one more nozzle is inner nozzle.

between gap the powder will flow. In the center of the hole the laser will be flowing. so this is the process camera and the nozzle laser will be centering using this camera. This is IR camera, this is indicate how much temperature will be the melted part is showing in this monitor. This is the base plate. This is the dimension 200 by 200.

It is already fixed here. Then here the coordination system, the table will move in X and Y direction. Nozzle will move in the Z direction. Now we are going to pour the powder feeder inlet. This is the SS316 material.

We can go and feed the powder. This is the powder feeder. Now we can remove that four knobs then pour the powder. Now I am removing the four knobs. When pouring the powder we can use the funnel. Now we can

close the powder feeder inlet knobs.

Here two valves are there for separate feeder we can now turn it on the powder feeder one valve. now we are going to discuss about laser so this is a placed laser here so the maximum capacity of the laser is 2 kilowatt we are using diode type of laser then wavelength is 760 nanometer there is a five axis system so by one by one axis i will demonstrate now. x axis like x moment Now, Y-axis.

Then Z-axis. Now, tilting axis. Now, rotating action. now we are going to machine operation part so the g-code will be already loaded here so now the moment of the z and the xy direction we have to offset it so we can move somewhere like the exact position wherever you want to build will be printed so you can move the nozzle there now we are going to discuss machine operation so the g code will be already loaded here, we set the work of satellite here mentioned g54 so here we mentioned g54 so that's why we can set the work offset by g54 so now all the axis will be set it so set it by all it is done then we can directly go for gcode position then we can go for directly cycle start So far you have learned about the metal powders, the design aspect, how to make the G-code based on the CAD file, and also Shiva has shown you that where is the powder hopper location, how to load the powders, and then how G-code is imported into the machine in the computer which is directly controls the laser path and also powder delivery processes and also gives the instructions so that the layer by layer manufacturing of the powders into the design constructs can be pursued. So we are now starting the operations and as you see laser head is being lowered down and then you can slowly you will see that you know it is started the operations the powder hopper actually delivers the powder at the same location where laser beam is impinging on the substrates and based on the information content in the g-code now the layer by layer manufacturing will be under progress You will also notice a lot of sparking during these laser powder interactions and then directed energy deposition of the molten powder and solidified molten and solidified powder on the substrate. And these sparkings actually remind you something related to this welding or brazing operations That you know from the conventional manufacturing aspects. If you recall that you know that when the laser beam and then powder they are their delivery is synchronized then powder particles also have the possibility of interacting with the laser beam before it even strikes on the substrate.

Powders already interacting with the laser beam and then after they are being deposited there again, they are getting melted and solidified. If you recall our discussion from the NPTEL lectures that this is not a powder bed fusion processes. This is not the SLM process. This is the directed energy deposition process. You might recall that SLM process perhaps is the most widely investigated 3D printing process, but a directed energy deposition processes are not that well explored and also commercially used to the extent that SLM has been used across different industries from aerospace for the biomedical applications and so on.

once this printing process is over, you will be shown that how the 3D printed structure looks like or how the 3D printed parts look like. And thereafter, I will be showing you that how different components have been can be manufactured using these directed energy deposition facility. So you will be in a position to appreciate that some of the complex designs can be manufactured using the DED facility. And this manufacturing process can be done using a wide range of powders. And then I may reiterate that these powders can be either titanium aluminide or titanium 6 aluminum 4 vanadium or stainless steel 316L powders or inconel 625 powders or different alloys.

of niobium titanium and so on. Now what you see in this computer window is that value of x, y, z of the field, particularly the value which is of our importance or of our relevance is the z value. z value indicates what is the height of the part being printed so far and what you see here 4.8 millimeter and if you look at here it is 4.8 millimeter corresponds to around 16.

9 percent so 16.9 percent of the total build has already been constructed and then you can also see here very closely that different the coordinates, X coordinates and Y coordinates, like, you know, how the laser beam is tracing its path, that X and Y coordinates, it comes very rapidly and you can see that line number. And then you can see that sometimes certain instructions are given, you know, and those instructions are also appearing on

screen. what you see, it is a G code is continuously running and then information is being sent to the machine. Now machine can only read those information and accordingly laser beam is scanning on the substrate according to the X and Y value, right? And then also powder delivery is synchronized with the laser beam path so that this construct is being dynamically built up.

Now the jet value is moved from 4.8 to 5.8 millimeter. So we are now very close to 20% of the total build volume has been constructed so far. Another 80% is remaining and it will take time. Whatever the 3D printing parameters that we have given, accordingly, total build is being constructed. If you recall, these 3D printing parameters include laser power, scan speed, powder delivery rate, or what is this, RPM, that what is the disk rotation, so that powder is being delivered, powder feed rate they call, PFR, and also layer height. Based on this combination of these 3D printing parameters, this build is being constructed.

And if you recall, in my... course lectures, I have also emphasized that how artificial intelligence and machine learning can be implemented to accelerate the process parameter optimization. For any material, for any structure to be built up, one has to do N number of experiments with variation in all these 3D printing parameters. Once you generate a large number of experimental data sets that can be used in machine learning algorithm, you can train the data sets using various machine learning algorithms and then you can optimize the process parameters and then you can even validate the predictive model. Now, those things I have also covered under the emerging topics and there you have seen that how regression analysis can be used for the single track morphological analysis or classification algorithm can be used. For the predicting different type of defects if they are generated and those defects, the classification algorithm essentially allows you that what are the parameters that you can select to get the high quality 3D printed parts.

High quality 3D printed parts means it should not have lack of fusion, it should not have keyhole, it should not have intra-track porosity, it should not have balling. It should represent the pure case of conduction so that this build will not have any porosity, any blowholes, and that will have the robust mechanical properties. These are all those things you learn, and then you can see now that we are at the additive manufacturing facility at Indian Institute of Science, and that is being housed in the Department of Design and Manufacturing, which was formerly known as Center for Product Design and Manufacturing. And this is the facility, I once again reiterate, this is one of its kind facility in India. You will see that lot of SLM facilities in the industry as well as the different academic institutes, but DED facility is not there to a large extent in many academic institutions in India.

We are at the build height of 8.6 mm and this corresponds to around 24.9% of the total build volume. Overall I think you are able to comprehend that how this entire 3D printing experiments are being conducted in the laboratory at an academic institutions and it starts from powder to design concepts, to the 3D printing parameter setting, to import the G-code, and then the 3D printing operation starts. You can now see that the nature of sparking has considerably reduced as the build height has increased and the laser beam is now tracing the periphery of the component that is being currently manufactured in this directed energy deposition facility. Now we are going to stop the 3D printing operations and we'll be first closing the program.

We are aborting the program. Then we will open the 3D printing chamber. I will show you the component being manufactured so far and then I will explain it further that what are the different type of components that one can manufacture using this machine. Yes, Siva. Once it is done, you can see that immediately it gets cool, right? We can open the chamber and then you can take out the machine. But before that, one has to make sure that laser head actually is lifted up to a sufficient height so that it will not be damaged during that manual handling of the components to be removed from the chamber.

We have to also switch off this laser. We are opening the chamber. Now you can see that this is that component. This is the stainless steel 316L component.

Stainless steel 316L component. We are removing the powders. Now you can see that this is the structure being

manufactured. It is still a little hot, but I am able to touch it. So it's okay. This part, this is the full scale component.

And you can see this is the component that will be manufactured. this is the substrate. I have also told you during the class that both the substrate and the material to be constructed this should be of the same material. Therefore this is a SS316L substrate and this is the SS316L part being manufactured now. Now what you notice here that this is fully joined, fully welded to the substrate. First operation is that you have to remove the substrate and then you have to machine these particular components or you have to remove these components.

Then these components will look like this. You have to little bit grind it. You have to do some of the surface finishing techniques. to get the components with the correct surface roughness, with the appropriate quality requirements that is required for certain engineering applications. Now I will demonstrate that different kind of components that are being manufactured using this directed energy deposition.

this is that illustration. This is the examples of the bent pipes that are being manufactured. Now if you look at the bent pipe, very closely you will see first five millimeter this is the inconel 625 and on the top of the this is the ss316l so this is the composite kind of tube and it clearly shows that you can change the powder hopper one from Inconel to SS316 during a single printing operations and then you can get a continuous structure without any defects and this continuous structure some part is made of Inconel 625 and some part is made of the stainless steel 316. this is a cone material. This is the cone shape that you can see very clearly, that you can see the perfect cone that you can manufacture here. This is cylinders, You can see this is the cylinder, cylindrical that you can manufacture It is a good surface , particularly in the inner wall.

So this is another component which is very important. This is that called twisted cylinder components? if you look this twisted cylinder, you would be able to notice that how the external surface has twisting, has a morphology which clearly resembles like it is a twisted cylinder, cylinder, cylinder morphology. this kind of components if you do the conventional manufacturing, conventional machining it takes significant amount of time but in one step you can do this kind of twisted cylinder components in the directed energy deposition DED process. The next component you can see is the rocket and you can see this rocket and the next I will show you rocket nozzles. this is a scaled down model of the rocket that you can clearly see and you can see inner surfaces also very clearly that how this component has been manufactured.

And then last one I would like to show you is the rocket nozzle. you can see this is the rocket nozzle that has been manufactured using this DED technique. And you can see it is completely welded on the substrate. And then structure also resembles very close to this rocket nozzle structures. with this you are now in a position to appreciate that how directed energy deposition process can be used to manufacture components of different materials, components of different sizes, components of different shapes and components of different designs. And some of the designs can be indeed very complex and we should take a conventional manufacturing like machining operations significant amount of time whereas in this layer by layer deposition processes what you have seen today that is very convenient that is a very smart manufacturing approach without significantly reducing the material loss and also at the same time enhancing the quality of the products or without compromising the quality of the products as well as shorter possible time. Thank you very much.