Mathematical Modeling of Manufacturing Process
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Lecture no.#32
Principle and Development of Additive Manufacturing Technologies

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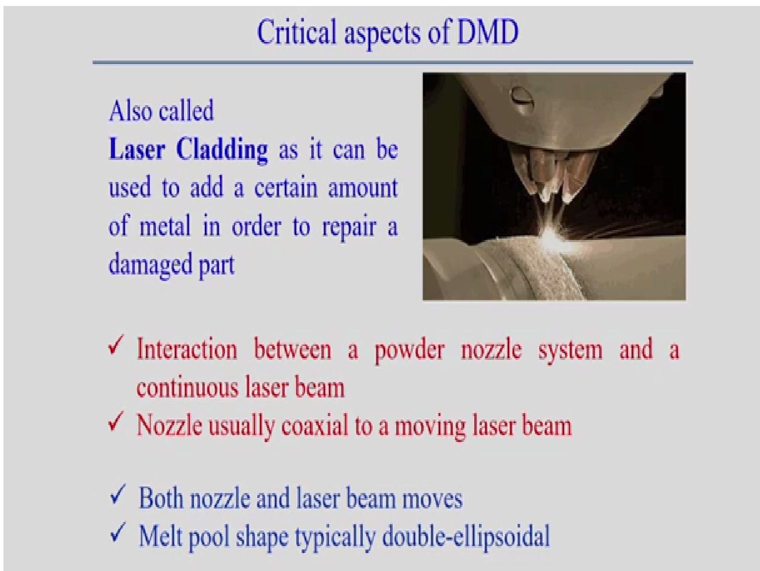

Direct metal deposition is one of the critical aspect and there maybe some development happens in the additive manufacturing technology. So, but the modeling approach of direct metal deposition needs, the so many aspects we need to consider. And of course, and different perspective, we have to look different physical mechanism involves during this direct metal deposition process.

So, of course, we just if you look into this picture, here we can see that at the same time that coaxial nozzle has been used and that actually focusing the injecting the powder in a particular point and of course, that which point that meeting all these are the focal point focus point of all this four nozzles exactly at this point the laser is also focusing such that it can melt the maximum amount of the powder in that cases and then it is deposited on the substrate.

So, this physically indirect metal deposition technique that we need to control that powder flow rate at the same time we need to focus, a need to control the heat source and mostly in this case is either we can use a laser beam heat source or and because we can use an electric beam also but of course, this technology actually having some similarity of a laser cladding process also.

Because in the laser cladding process also we can similar philosophy use for the development of melting some cladding system the surface and on the surface basically to inject the throw the powder on the surface and then after that, we just focus the any kind of laser sources that there may be some layer, deposition may happen at the same deposition as well as melting of the deposited powder particles happens.

And on most of the cases the laser cladding system normally uses to repair a damage part so similar principle can be used, but probably in this case, it is a more controlled way, we need to look into as compared to the laser cladding processes such that some bill build, building up of a particular object can be done layer by layer deposition process. So, therefore, interaction of nozzle system.

And the continuous laser beam is one of the major aspect to optimize the position. The laser focus them as a coaxial lasers so nozzle usually coaxiall to moving but at the same time, it is coaxial but, it moves in a particular direction. So there is a, therefore both nozzle and the laser beam together moves, that kind of strategy you need to cover and at the same time we have look into that during moving the typical weld profile zone is look like the double illusider.

And most of the cases we observed in case of the moving laser welding or any kind of arc welding processes that typical shape is more or less is moral equivalent to the nature of the double illucuder. So, by just looking into that kind of beam profile, we can optimize the laser scanning speed and of course, the powder feed rate all, all shielding gas bullets all parameters also we can optimize.

So, look into that what are the typical aspects we have to consider for the development of the direct metal deposition technique.

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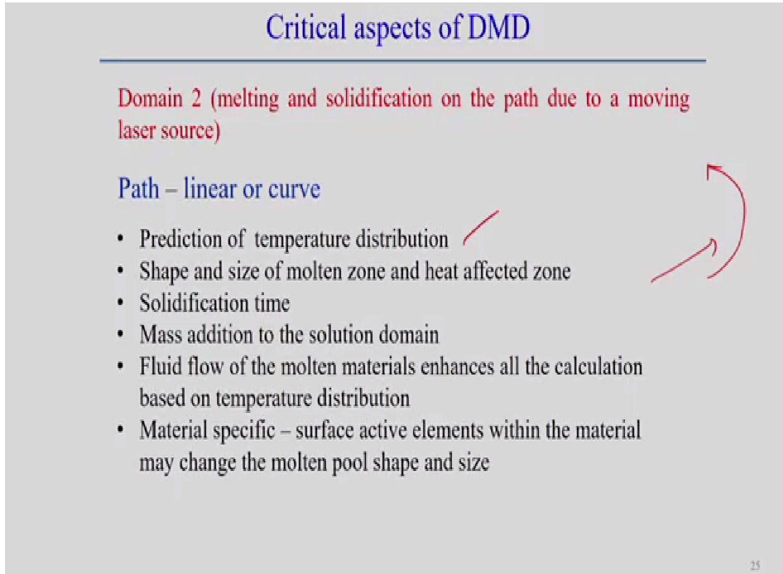

So, therefore, I am just mentioning the typical area direction were we need to focus on the first calculation of the temperature distribution in the coaxial powder stream, in the coaxial powder steam, the calculation from the temperature profile we have to ensure such that if we estimate the temperature profile.

At exactly which location and the Powder is traveling and maybe at which location the it starts melting. And of course, maybe at which area that there is a may not be the melting of the powder or partial element of the powder also may happen so, that can be decided first using to develop this DMV technology. So, therefore, of course prediction of the projected area by powder. So, any powder is projecting a particular area.

What is a projected area and which project area we are focusing? That information is also required. And of course, it depends on the geometric shape and size of the nozzle, the nozzle can decide what may be the projected area and of course, powder flow rate. So, what is a powder flow rate and what we are mixing the powder and the shielding gas such that it can create some specific area projected area.

And accordingly we can decide the what is the laser focus diameter on this projected area. And of course, other parameter for example, distance from the nozzle. Also the influence all this thing if you look into this schematic diagram, we can see that nozzles are there and from the nozzle there is a powder is coming along with the shielding gas of course with a with a certain pressure and the with certain flow rate is following.

And since on just come out of the nozzle, so, the beam actually diverge and it actually this indicates that actually this is the projected area. So, on the surface of course this projected area on the surface maybe, if it is a flat surface. So, it is easy to handle the estimate the projected area and accordingly we can take the decision.

What may be the powder flow rate and focus them on what the same time if it is a kind of concave or convex type of surface over each powder is actually throwing in that cases we have to be more careful to use the proper parameters just by looking into the projected area of the powder on the surfaces. So, see here you can see that it is a moving system, that means nozzle as well as the laser source is moving in a particular velocity.

And at the same time shielding gas flow rate is also there and according to this projected area, maybe this may not be very circular rather, I say that this projected area maybe elliptical in sense. So that that depends, we able to predict these things just looking into this moving, if you consider the moving source what we normally tackle the moving heat source problem in case of welding processes similar we can tackle this DMD technology also.

And of course, we need to, it is possible to estimate what is the projected area for a moving laser or for moving powder flow rate for a moving powder. seen that cases we have to consider the effect of the velocity with similar strategy of welding process So, definitely finally, prediction of the width and deposition of the height after melting That is the ultimate objective, for a particular development of a printer metallic printer.

Such that we will be able to predict ,what is the width and what is the height and maybe what is the surface roughness of this or finally can it is it can decide that what is the resolution of this printer. So, that means, what surface finish we can expect from this particular sense by optimum setting up the all these parameters.

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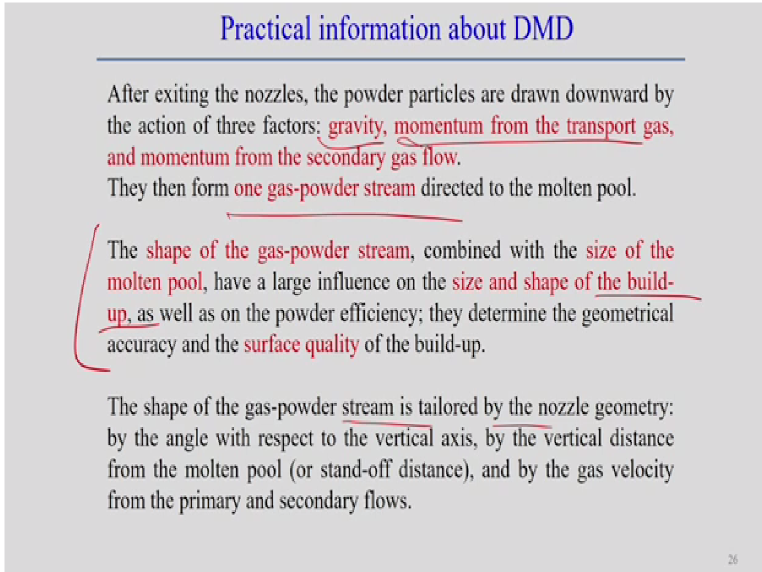

Now, that is all domain one of course, the domain 2 means.

That once we projected the powder in a particular surface and then powder is melted. And of course, this what is the molten zone dimension and the solidification melting and solidification behavior on the laser path or of course, these lasers will become more complicated when it is under the moving laser source. So, that path prediction of this path the same size of the molten zone heat affected zone and that is more important so path can be linear or curved path.

So, laser can be move depending upon for the geometric shape or it can be some curved path. So, based on that, we can the temperature prediction of the temperature distribution is important in any kind of modeling approach all these things shape and size of the molten zone as well as the heat heat affected zone is also necessary to predict and of course, solidification time such that we can decide the gap between the successive layers.

Based on the solidification time of course, mass addition to the solution to domain because the within the solution domains in the domain 2 that means, while we are trying to analyze the temperature distribution, so, there is a continuously powder is adding So, therefore, mass is adding to this domain so, that we have to take care, we need to incorporate that effect of this this domain.

And of course, although the material is not very super heated condition but till fluid flow consideration may be significant and that in increase the prediction of the temperature distribution. So, therefore, fluid flow can can also included it can also be included in the domain 2. While we are trying analyze the temperature distribution of course, in metric if we use any kind of surface active elements within the material.

We change the molten pool shape and size so, in that case is probably fluid flow will help to actually determine the shape and size of the molten pool or specifically during when powder is actually projected and after projection we just the powder is basically melting in domain 2. So, therefore, all this prediction is necessary to decides or to select the optimum range of the parameters for the development of the DMD technology.

So, therefore, the some modeling of course having some influence if we look into to incorporate all the physical phenaminon in the modern approach that can take help to take some decision for the setting of the parameters in a direct metal deposition techniques

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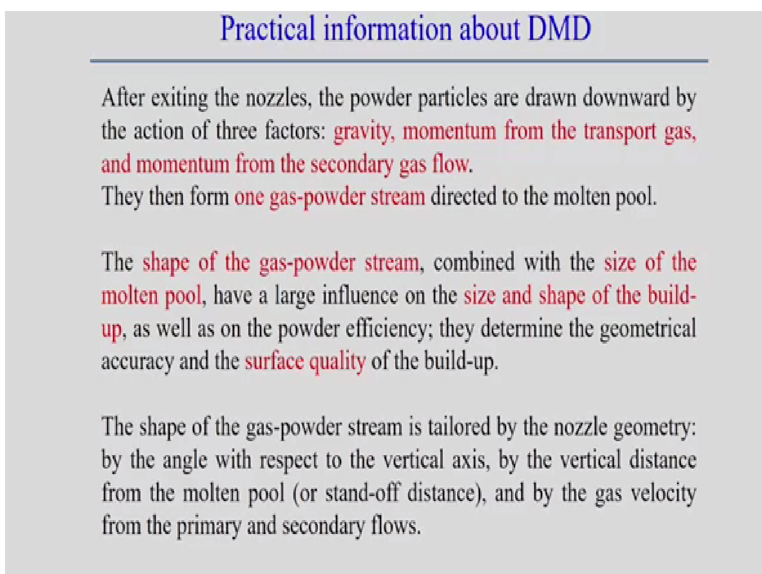

but some practical information about the direct metal deposition and techniques is maybe useful when you try to develop some critical metallic printer.

So, first, existing the nozzle the powder particles are drawn. Basically powder particles is drawn downward to the action of the 3 factors so, there is physically the gravity force is not important momentum of this from the transport gas, who momentum because there powder is not carried just only by gravity. Because there is some transport gas mixed with the powder such that this transport gas actually carry the powder to the desired position.

So it will be easy to project in a particular position and momentum from the secondary gas flow secondary that apart from this transport gas we use a shielding gas as well also do this So, momentum of the shielding gas also helps to decide the final shape and size of the deposited layer. The thickness and surface roughness also. So therefore, actually one gas stream is directed to the molten pool.

That one gas stream that gas stream along with the powder is physically directed and the shielding gas just protect the molten fluid. Of course, momentum from the shielding gas are also test also influence the surface roughness produced, that is basically we will be able to know after the solidification of this particular zone.

So therefore, the shape of the gas powder stream what at the same particular and projected area exactly on the surface combined in the size of the molten pool and having have a large influence on the size and shape of the build up so the shape of the gas powder. stream that stream and of course size of the molten pool. All actually influence on the size of shape of the build up area physically that decides the build up area or size an shape, width and thickness of build up area also. As well as the powder efficiency.

Because if we project the powder beyond that exactly the beyond the molten fluid zone so most of the cases wastage if this powder with out melting this thing powder efficiencies also important to analyze all this effect and therefore determine the geometrical accuracy and hat actually decides the geometrical accuracy surface roughness of the build up.

So. there for that is also an important part of the DMD technology. So the shape of the gas powder stream is basically tailored by the nozzle geometry. So definitely shape of the gas stream powder basically decided by the nozzle geometry or by the angle, the making the nozzle angle with respect to the vertical axis and the distance between the from the molten pool to the basically stand up distance molten pool in the nozzle exists and of course the gas velocity

From the primary and secondary flow primary flow is the gas velocity of the transport gas and secondary flow basically the shielding gas. All this flow actually need to track or need to analyze to correctly predict the geometrical accuracy of the build up in use in case of direct metal deposition technique.

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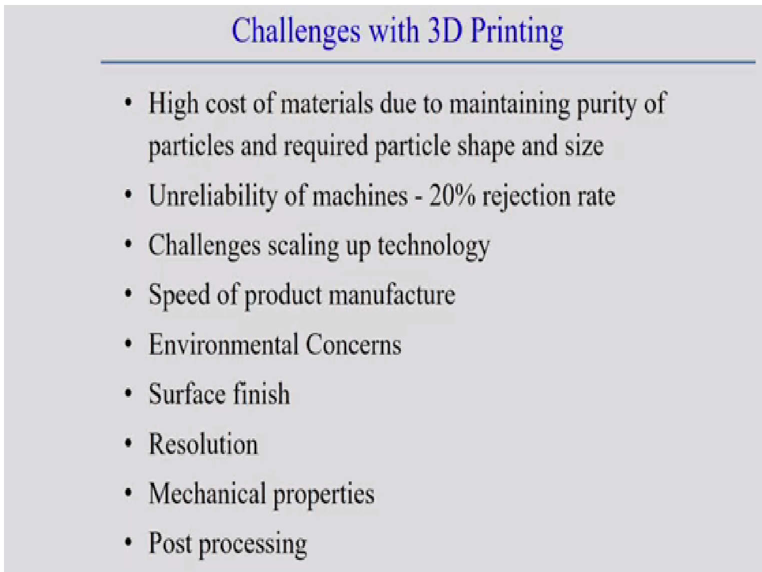

So, we have discussed that different metal printing technologies mostly focus with metallic printer printing processes.

There is a development of different area maybe arc based metallic printing or a powder based metal printing processes. We have already discussed and discussed may be mainly focused on this module. But overall, if you look into the The 3D metal printing process is having several challenges to develop first is high cost of materials, is a overall aspect.

We are trying to look into that first high cost of materials due to maintaining the purity of the particles. So, of course, when you are using the powder particles, so, it is always necessary to maintain the purity of the particles and because and required particle shape and size. So, two aspects that purity of the particles and second is the particular shape and size is very much important that actually decides, the surface roughness.

We can achieve during the metal printing technology. So, therefore, in that in that case, so, if you want to the purity of the particles production of the pure particle to maintain the purity of the particles and with the particular various small size, then powders becomes more costly as compared to the materials most of the cases there is a chances of the oxides, so, therefore, unreliability of the machines.

So, of course, the actually the metal printing process or domain of the parameters exists in the very narrow domain, so, range is very narrow. So, therefore, in that sense, maybe there is not much scope exactly to vary all the parameters over a wide range. And even it is not for a narrow range as well also. And of course, this depends on the different Machines to Machines. So, that is indices The liability of the Machines of a particular metal printing processes questionable and most of the cases we can assume its a 20% rejection rate wanted to develop.

Some kind of product, of course still the research is going on for the development of this Machines. So, of course, challenges scaling up the technology. So, maybe a very small component, very small component size, the surface roughness, we can actually very good surface roughness and maybe in that amount of the surface was very sufficient if the component sizes very small.

But when we try to produce a very bigger component probably may not be very economical using this laser based with or electron beam based metal printing technology. So, in that case, for really large volume there is a large volume deposition is required probably arc based, additive manufacturing technology may be more suitable in that case. So, speed of the product manufacturers of course, if you try to achieve a high resolution of the printer.

If you want to achieve or to achieve very good surface finish, then speed of the machining speed of the process to produce a particular product is in the 3D metal printing technologies little bit less as compared to the other conventional techniques. So, therefore, time constant or maybe large amount of the time is required to produce a particular build up a particular component that is also one constant, one challenge in the 3D metal printing technology.

And of course, environmental concerns because handling the powder or maybe sometimes difficult that may be may be related to environmental concerns anyway, if you try to look into the metal printing technology using the other conversional method also definitely in other cases also maybe some kind of environmental issues also there and since using the laser We are melting the components and it is above melting point temperature.

So, some contamination to the maybe some that were in the shielding gas also., that contribute to the environmental pollution and or maybe health hazards are to handling this technology. So, therefore, in that sense and environmental concerns, it may be important in this case so, surface finish is one aspects. So, surface finish depends on the intuitively on the process parameter what is a particle size were using.

And if you look into the other way also if we reduce the size of particle if you try to reduce the size of the particles then cost of manufacturing of the powder particles then cost of manufacturing of powder particle will will increase. So, therefore in the sense surface finish, achieving surface finish without machining by using additive manufacturing technology is really a challenging task and resolution of the printer.

Of course resolution of a printer in how fine surface finishing can achieve using in a particular or how exactly replicate the CAD the geometry of a particular object and that depends on the that decides the resolution of the printer. Therefore, to achieve the very high resolution of course, the may be build up size can be reduced or in other way also powder particles can also be reduced to achieve all these things.

So, mechanical properties for only layer by layer deposition. So, in that cases may not be achieved or homogeneous mechanical properties or isotopic mechanical properties may not be possible using this additive manufacturing to so, that is one concept to achieve isotopic material properties. In the case of layer well, deposition process, and of course, most of the processes associated with some post processing to get a desired surface finish..

So, definitely that is one of the limitations of the 3D printing processes. So, thank you very much for your attention.