Surface Engineering for Corrosion and Wear Resistance Application
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Lecture – 54
Laser Assisted Materials Processing : Processes

So, welcome to the 54 lecture of Surface Engineering. We have now started discussing generation from all of way generation to various scopes of application of laser for material processing as well as surface engineering. So, in the previous lecture we discussed, how do we generate laser, what are the various characteristic features of the laser, what are the material properties which actually determine the level of heating and how does heat propagate in the solid and what kind of various forms of processing we can do.

Particularly for engineering applications, how we what are the 2 main parameters that we vary to generate different levels of heating in the solid and eventually we can make use of that heating for various kinds of change of shape, change of dimension, change of our joining of solids and surface ending of course.

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Now, having understood this fundamentals of laser material processing, we would now like to concentrate on the various types of processes that we can do using laser so in this part B.

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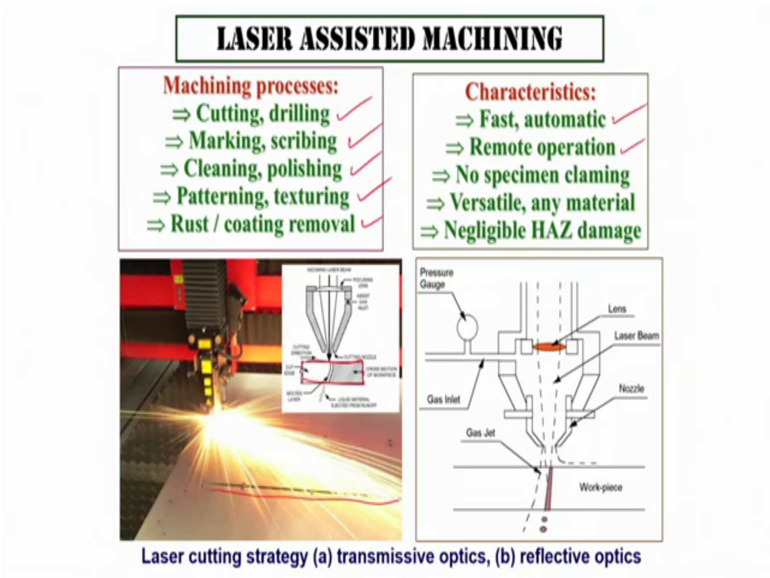

So, the first and foremost is material removal. I told you that by proper combination of interaction time and incident power density. If you have very high power density and applied for a very short period of time then the heating effect will be completely confined to a very small volume and in the process in this short period of time and in the small volume temperature will not only cross the melting but, even vaporization temperature.

So, when it crosses the vaporization temperature then; obviously, you actually will convert the solid immediately into vapor. Now, this can be done purely by heating process or in some cases with which certain shroud gases but, in some cases you can use an active carrier gas, which could be oxygen. So, during heating, it will also allow oxidation and in the process it will vaporize very easily. So, what you need is an incoming laser and there are 2 possible strategies; one is the transmitive transmissive optics, the other one is reflective optics.

So, you will have a laser beam, which will be incident onto the solid. So, this is the solid that we are irradiating with the laser beam and the beam comes with the through a nozzle and there could be flow of gas either a shroud gas or an active gas like, oxygen surrounding this laser. And when the beam interacts with the solid, it actually can create immediate vaporization and depending on the interaction time the depth of cut will be determined and there has to be a the relative motion either the solid moves or the laser beam itself, with the nozzle it moves.

So, we should create a relative motion and so just like this wave graph here, you can see that, immediately. So, you create you sputter actually droplets and these droplets fly off in the process they also get oxidized. So, you see just like what we see in the days of Diwali. So, you also see such sparks flying all over but, the interaction is on a very small line and as a result. So, for example, here is a line that you can see is defined by this cut ok.

So, by way of machining we mean cutting and drilling, marking or scribing definite you can etch out a name or a design or cut exactly according to the design, you can do cleaning and polishing removal of control depth of material, you can do patterning or texturing and you can also remove from the surface patina or a certain layer, which is unwanted. The process is desirable because, it is very fast and completely automated, there is no manual operation involved in particularly this kind of a cases.

So, the specimen is not destroyed, there is no also immediate, you know lot of the wastage is minimal then, it is very versatile and any material practically any solid can be machined using laser and there is very little or negligible amount of heat affected zone.

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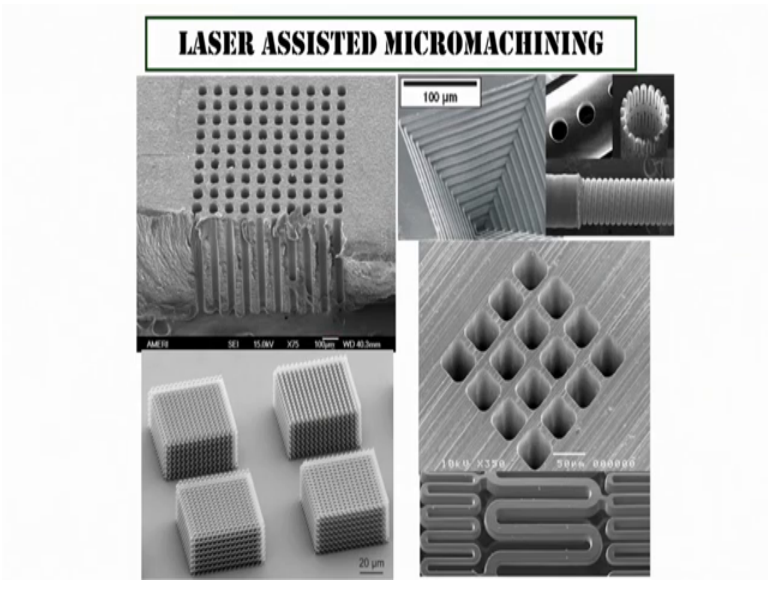

So, machining particularly since we are talking about a beam and we can not only control the intensity and the interaction time, we can also control the shape and the size and the focus of the beam. Now, one other important thing will soon discover particularly with regard to joining operations is that the focus of the laser beam with respect to the surface, determines what is the power level that is delivered at that point of time. So, we can actually create a very sharply focused beam and make it extremely fine so, fine as finer than let us say 10 micrometer.

So, depending upon the size of the beam we can create features which are easily few tens of a micrometer. So, if this length scale is a 100 micrometer here then, we are talking about features which are created and depth wise several 100 micrometers or maybe almost like half a millimeter depth of cut and such sharp and completely smooth vertical wall of cut and these the diameter of these holes could be easily some 20, 30 nanometer and 20, 30 micrometer. So, extremely fine size.

So, this micromachining features can be also not only completely vertical, can also be inclined. So, actually one can start by drilling a hole, rectangular or square hole at the very bottom like this and then in order to reach there you actually can have various cuts, with various widths. So, essentially you can create a step like structure and with very precise geometry using laser, you can have you can likewise you can create this very specific drilled holes of certain dimensions and the wall in inner wall actually need not be vertical it can be inclined.

So, you can make certain holes, which are having inclined surfaces, one can also create such heat pipes or heat sinks or certain features, which will expose very high surface area for heat dissipation. Even can make such heat dissipation devices or heat exchangers where because of the sharp features any gas that passes through our air, will have much will actually be able to throw away heat, much more efficiently through this kind of structures than you know otherwise solids structure.

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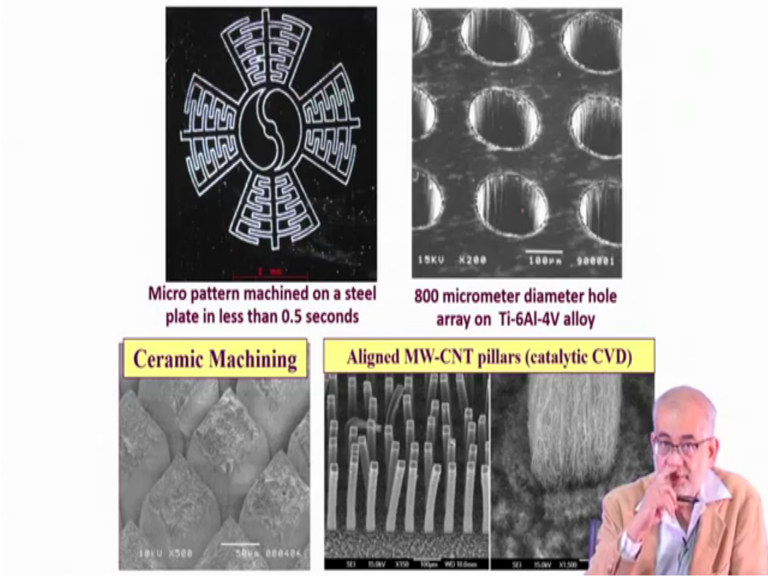

So, the same micromachining patterns could be done on steel, on semiconductors, on polymers, on any solids and with very large aspect ratio the like this nano pillars of carbon nanotube or you can drill holes on a silicon wafer, maybe a few almost half a millimeter or so deep or you can create channels and vias and various other structures of very specific dimension.

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That can be done very easily on laser on metallic surface. So, here is an example from a commercial house that you can create so many markings. So, many types of marking can literally create different markings and scribings on metallic surface, you can even bring in colors by way of control oxidation.

So, various forms of color tinting possible by exposing a certain amount of gas and controlling the interaction time and power. So, the depth of the oxide layer that you create will actually determine what would be the color on the surface and of course, the basic composition of the substrate is important.

Similarly, we can make such cooling channels micro fluidic cooling channels on a you know on a semi conductor device or on metallic heat exchanger devices and this could be a stainless steel or nickel base invar alloys, titanium, aluminum, polymers like polyimide, polycarbonate and other forms of commercial plastics and polymers.

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Now, laser can also be an extremely precise tool for cleaning or finishing seen. As I said since the beam can be focused can be shaped and focused such a way that the diameter or the at the focal point the diameter could be just a few micrometer as sharp as small as that. And also the you can deliver power in such a controlled manner, that you not only heat you actually vaporize a very thin layer up to a depth of let us say 10 nanometer or maybe 5 nanometer and not 1 nanometer more.

So; that means, it can be that precise and there as a result of that one can actually a clean the surfaces of human teeth, to such metallic molds or glass objects or various solid surfaces and you can easily make out the difference of these even surface topography can be made very smooth. So, this kind of a surface rough surface can be made very very smooth by such laser assisted surface finishing and these kind of surface asperities can be very easily handled by controlled removal of material from the surface.

Now, after these controlled cleaning or finishing operations, let me take another very interesting example, you know the very priceless art objects paintings or sculptures, if they have to be cleaned, you cannot afford to do that cleaning by physical means, you cannot allow a cleaner to scrub the paintings of say the priceless Mona Lisa or a sculpture of Michelangelo or some so much like that.

So, in that case you actually are allowed to touch those, only if you promise that you are going to remove maybe 5 nanometer or 6 nanometer or not 8 nanometer from the surface. And those objects have developed certain rust or certain chemical coating over a period of time by way of interacting with the atmosphere, you know some kind of sulfide or some carbonate or some you know layers can form which actually cause discoloration. So, you have got to remove those compound layers complex compound layers, by the only way you can do you cannot even use a soap solution because, that will react and make a different kind of a color.

So, the only way is to remove the oxide there or the reaction there from the surface by vaporization and laser can do that very very precisely. So, indeed laser is used for cleaning priceless art objects.

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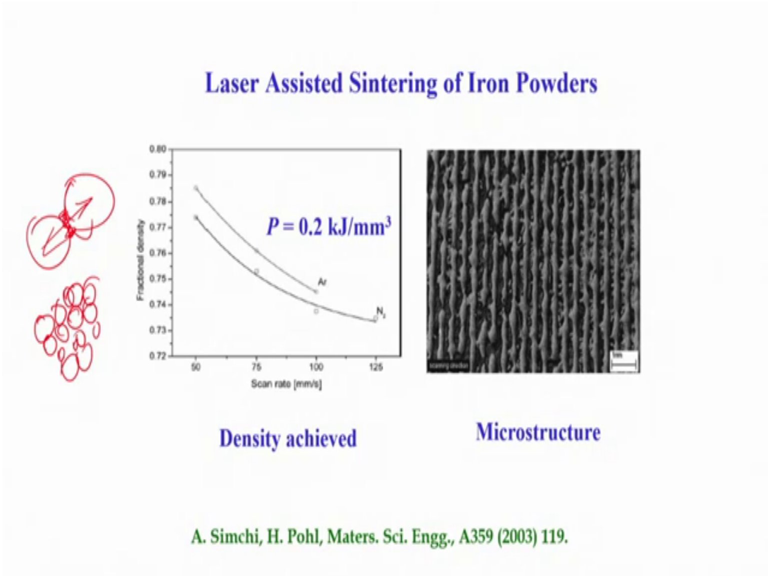

Another form of material processing could be sintering. So, you actually when you are dealing with powders or small objects I mean particulates, you need to sinter them, join them together.

So, in this usually this could be let us say powder masses of various either similar size or various size, so, you can have small or big and so on all kinds of possibilities. So, joining will essentially depend upon creation of temporary diffusion bond here, so, that electrons can flow across. So, if you are talking about metals then; obviously, we want some kind of metallic bond to be formed at this, which could be due to melting or due to purely solid state diffusion.

So, if you are heating a bulk like this, up to a certain depth from the surface. So, you can do layer by layer or you can do in a controlled manner such a way that you heat up to an extent. So, that the surface sees the highest temperature. So, the heating effect will be maximum at the surface and hence the powder particles will actually get heated up such a way, that a thin layer from the surface reaches fairly high temperature that will allow diffusional bonding to form.

So, it can be solid state, it can be also formation of thin molten layer and so liquid phase sintering and this thin layer may form because, of certain reaction, eutectic reaction at the surface. So, no matter what actually using laser one can actually start with powder particles and then sinter and create a base above the solid. The density of which could be close to the theoretical density, there is always a possibility of retaining some of the porosities and one can actually create a very good routine for sintering to avoid such retention of porosities.

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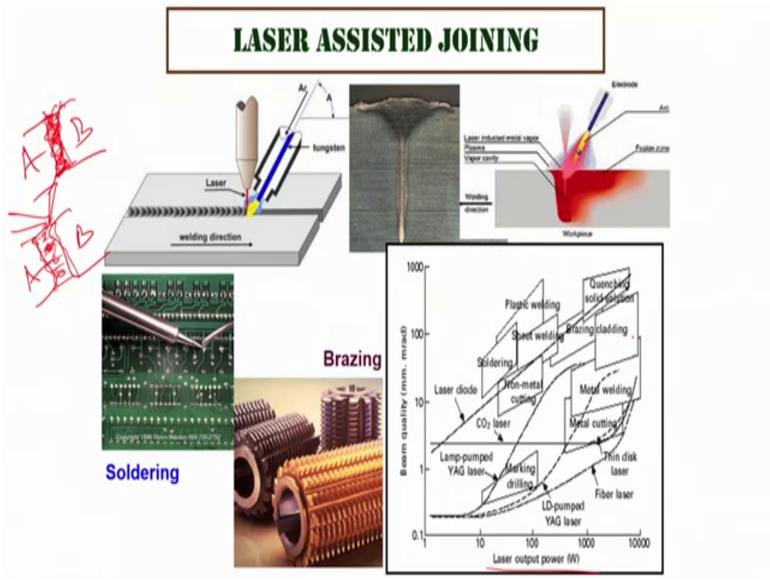

Another very major application is joining. Now, joining not only of similar type where. So, there are 3 possibilities actually one can think of, if we want to join a solid body A and B together, we can simply heat here, such a way that this part melts and some part of the beam melts and eventually they fuse with each other. So, it is a fusion joint created by partial melting of A and B at the edges.

So, that is typically welding but, you may also do soldering or brazing, whereby you have A and B as 2 parts and then you bring in a filler metal and use a laser beam to heat the filler metal. So, that the filler metal melts and allows droplets to trickle in and eventually fill up this gap in between.

So, when this liquid fills up the gap, this liquid actually wets with this solid A and B well and in the process can create a very good soldered or braze joint. If the temperature is higher you call it brazing, typically used for copper alloys or you can do soldering typically for metal to semiconductor or semiconductor to semiconductor joining, let us say below easily below 3, 400 degree centigrade. So, roughly speaking about 400, 450 is a cutoff point anything and joined below that is called soldering and anything above it is brazing, provided you are using a filler metal a low melting eutectic composition which fills up the gap.

But, if the joining process requires melting or fusing, the edges of the 2 solid pieces, without necessarily requiring a filler metal you call it welding and all these welding brazing joining, all these can be done easily with laser. So, here is a process chart in terms of the beam quality and the power that you are delivering and that allows you to do various kinds of joining activities.

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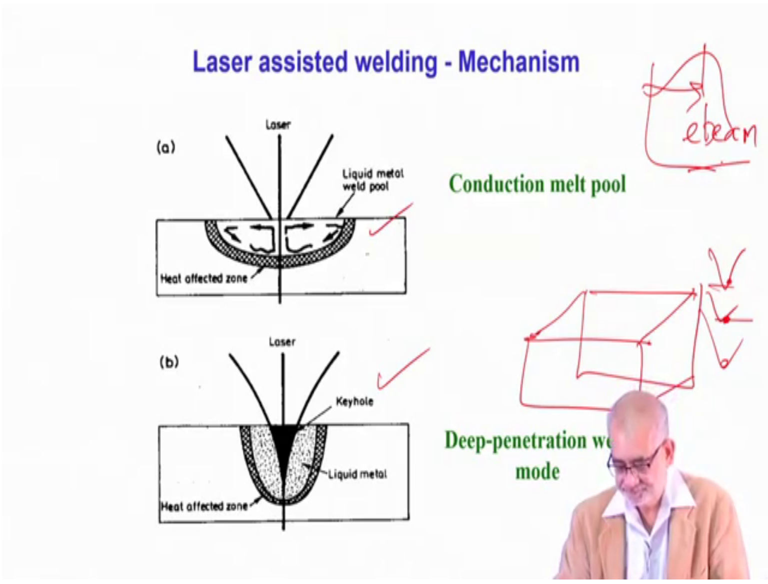

For joining, we already discussed while discussing electron beam assisted joining that if. So, here is the importance of locating or the location of the. So, if this is the solid we are talking about and so, we have 3 possibilities, we have the possibility of the focus, resting above the surface, we have the possibility of the focus, coinciding with the surface or the focus going below the surface.

So, if it is above the surface then the effect of heating will be shallow the will be fairly shallow and diffused. So, you end up getting a conduction melt pool, if the focus is coinciding with the surface or in particular is below the surface in both the cases you actually can see heating profile which will be fairly deep penetrating type and that is the typical keyhole type of joining possible, when the particularly when the focus is below the surface but, nevertheless one must admit that the advantage of using laser based welding is that you can do it in air.

One of the biggest advantage of laser material processing is that you can do either in control atmosphere in confined chamber or you if it is a non reactive metal, you can easily do everything in open air and you can do processing where you actually have a very high melting on one side and low melting on the other side. So, you have to have a correct strategy of joining them but, you can certainly use laser for joining the advantage electron beam enjoys over laser is in terms of it is deposition profile which is Gaussian. So, that peak is below the surface. So, you actually can make this kind of a deep penetration joining, better with electron beam than with laser.

But, on the other hand with laser you actually and other there are other difficulties with electron beam that it has to be done in a confined chamber at very high vacuum. So, you have limitations in terms of size and dimension of the component that you can handle whereas, laser can actually do the processing entirely in open air.

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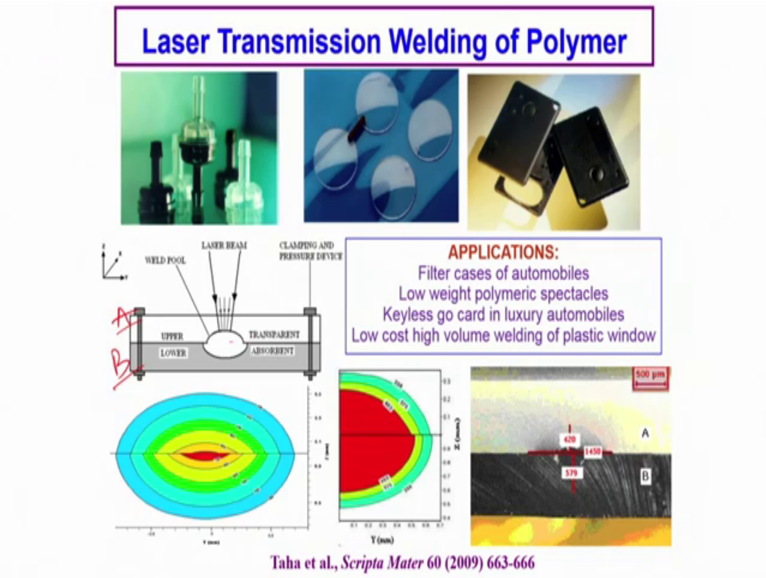

With laser you actually can select the certain wavelength, which will be which will penetrate through pass through or transmit through one solid on the top without creating any heating effect, until the time it actually interacts with the other solid at the bottom and there that is where it can get absorbed.

So, if I have 2 materials A and B, where A is transparent and B is translucent or absorbent then, I can create a situation where and I can actually join the interface. So, this interface can be actually welded or joined by way of laser heating, purely because of the fact that the laser beam is transparent to A but, absorbent to B. So, beam passes through without heating through A but, heats only when it interacts or a only when it is at the interface between A and B and B gets heated up B melts and that is when heat transmits upward and then part of A melts and then you form a joint.

So, this allows various types of very specialized joining for automobiles for you know spectacle, glasses, polymeric substances particularly the transparent ones and various types of applications in or automobiles possible also for plastic, windows and cards and so on. Now, this is just an example as to how this could be very very useful.

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One last thing that I would like to mention is the possibility of using laser for building a solid component, 3 dimensional solid component layer by layer. So, here are two cases of, if this is the prototype then I can actually build this complicated shape or even this one by additive manufacturing process.

So, additive manufacturing would mean that; let us say you want to create this conical shape. So, you would feed in powder here and here is your laser beam. So, and this is my stage. So, in the first case, I will allow a circular motion of the beam or the stage, in this case maybe the beam and the powder hopper. So, the beam interacts here and the powder comes and heats here. So, you melt the powder and you deposit the molten powder at this point and then the beam and the powder they move away and when they move away they go to the next spot and again deposits another layer.

So, likewise, if I make a circular motion then I will create one circular section like this of a particular powder coming from top and of course, I have my ability to control not only the precise diameter or the shape circular shape but, also the height of the shape. So, I build up in the first layer, I build up only up to this depth. So, this is one circular section that I have created.

The next time, I reduce the diameter of this I described a smaller diameter circle. And so, now, I create another one which is shorter, next time even smaller diameter even smaller diameter. So, when these are done not on the same level but, at progressively higher and higher level. So, effectively I should be able to create one layer like this here, the next layer like this here, the next layer like this and like this and if these are all circular sections where, essentially I will end up making a cone out of it, a circular conical shape like this.

So, this is just an example of a simple geometry but, if I want a more complex geometry like this so, I can do that and I can also create a more complex shape like this or any shape for that matter, I can do gradually by feeding the powder and combining the laser, such a way that the powder is melted in flight and then deposited.

And I change the vertical height of this deposition so, that I can create a 3 them not just 2 dimension. So, I convert 2 dimensional first layer into 3 dimensional bulk component, it can be hollow, it can be solid, it can be semi solid, it can leave a control porosity, control diameter inside the volume open volume inside and all kinds of possibilities. So, essentially it all depends upon. So, I can create even controlled holes, control porosities and I can change the angle, I can build a layer with the curved surface, not necessarily a flat surface, I can make a vertical, I can make inclined, so, all these processor possible by an additive way.

So, I add on layer by layer, I add one layer to the next layer to the next layer. So, when I go from one layer to the next layer, I can change the diameter, the dimension the thickness, the inclination, the shape all those possibilities exist. So, in principle I instead of actually creating processing the material or manufacturing the component in a bulk manner where, I create an ingot then I forge I, roll I, do machining, I do extrusion, I do very all kinds of material processing for the bulk, instead of doing all those laborious and time consuming and energy intensive processes I can simply use a powder feed and a source of heating through laser and I can build the final component in one shot, one single manufacturing stage.

So, that is the advantage and beauty of additive manufacturing, an additive manufacturing by the way is nothing different than very simple surface engineering approach called cladding. So, in case of cladding, you simply have a substrate on which you deposit a new layer and here you may or may not have a substrate but, what is important is you deposit not just one layer you deposit multiple layer. So, that cumulative way, it actually can build a complete structure, a complete solid.

So, this allows actually elimination of lot of time, energy, material cost and various other advantages. So, that is why direct manufacturing particularly using laser is the most talked about manufacturing approach of present time and that is possible because, laser gives you a practically immense flexibility and uniqueness in it is approach which is not possible with other types of tools.

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Additive Manufacturing Technologies – Table I

Name	Working Principle
Selective Laser Sintering (SLS)	Uses CO2 laser to selectively fuse polymer-coated metallic powder (stored in bed) one layer at time. Requires debinding, sintering, and infiltration
Direct Metal Laser Sintering (DMLS)	Similar to SLS. Patterns energy in powder bed but directly sinters a two-phase metallic powder system. Requires infiltration
Selective Laser Melting (SLM)	Selectively melts metallic powder with an focused laser. Does not require additional post-processing. Can make extremely small features
Electron beam melting (EBM)	Uses a 4.8 kW electron beam to selectively scan and melt layers of metal powder
3D Printing (3DP)	Use of a printer head to print binder polymer over a metal powder bed. Requires sintering and infiltration
Multi phase jet solidification (MJS)	A metal powder-binder mixture is extruded through a heated nozzle to create layers (fused deposition modeling). Requires debinding, sintering, infiltration

So, there are many many methods available, I just took the liberty of picking up some of them from the published sources and list them out here. So, depending on the approach, some of these are called selective laser sintering or select direct metal laser sintering. So, in selective sintering you will use a laser to a sinter the powder feed that you feed in up to a certain depth and the powder themselves will have certain binder coating on it. So, when you heat these binders melt and they fused and they bond with each other, in case of direct metal laser sintering you actually use. So, in one case you have 2 particles, with certain coating on top and the coating fuses easily and binds.

On the other hand, in direct metal laser sintering, you have 2 metal powders and then they can actually fuse by a typical welding process, you can have even selective melting instead of solid state sintering. You can have selective melting, what happens here, you can do instead of laser you can do it with the electron beam melting, you can do what is very popularly known as 3D printing. So, like for example, you print the alphabet A, with certain thickness dimension and shape and so on.

So, you can also use a powder feed, to create this kind of a shape or a geometry and you can effectively create an A out of only powder. Now, usually the powder feed and the laser can be different coming from different directions but, in principle or in reality even, it is also possible that you have a laser beam coming through a particular nozzle and you have concentric feeder or hopper around them, which can feed one single or multiple powder.

So, if the laser beam is incident here, the powder can also come constant in a concentric manner to the same focal spot. So, this is lot better than having laser and powder coming from two different directions so, this fairly possible. In fact, these days with a fiber laser delivery system, this kind of possibility has become extremely feasible and to make things even more flexible and even more exciting now, actually the whole laser delivery system, with the fiber laser can be loaded on the arm of a robo. In the robo can perform not only, x not only x y or z directional movement, it can also rotate in certain angle.

So, basically a robo arm can define exactly like a human arm can actually define any shape or any size. So, with this possibility the arm can actually rotate, it can move and it can translate and create. So, essentially this robo arm will carry the laser beam the powder feeding system the nozzle concentric nozzle and then both will act simultaneously and now if it goes to a circular motion or vertical motion or lateral motion in x and y direction can create practically any shape. So, it is almost like an artisan moving his hand with clay and then making a 3 dimensional shape.

So, instead of printing letter A on a 2 dimensional sheet, you actually can go layer by layer and then print an A, which is not only a 2 dimensional but, 3 dimensions, so, that is 3D printing.

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Additive Manufacturing Technologies – Table II

Name	Working Principle
Extrusion and Deposition of semi solid metals (EDSSM, or, SSM-SFF)	Deposition of semi-solid metal through a nozzle (similar to fused deposition modeling)
Laser Engineered Net Shaping (LENS) OR, Direct Metal Deposition (DMD)	Melting powdered metals with a high-powered Nd-YAG laser. Metal powder is fed into laser beam by nozzle .
Shape Deposition Manufacturing (SDM)	Combination of laser cladding (LENS process) with subtractive machining
Ultrasonic object consolidation (UOC)	Solid-state joining techniques deposit layers of tape to form solid aluminum parts, followed by trimming step
Layer object manufacturing (LOM)	Selectively cuts stacks of sheet metal and fuses the layer together
Computer–aided manufacturing of laminated engineering materials (CAM-LEM)	Similar to LOM, selectively cuts layers from green tapes, stacks the layers with robot arm, and offers more complex internal geometry and wide material selection

So, you can also use multi phase jet solidification, you can have multiple jets falling onto the surface, you can do extrusion and deposition of semi solid metals and then create a final shape or you can have a powder bed and you can do direct metal deposition or laser engineered net shaping, in both the cases you actually create a complex shape, which you have to define beforehand using a computer aided design mechanism.

So, there are these are various names possible essentially, if you are feeding powder or wire or tape or rod in all these cases that is the feed side that is a material side and it can be one material it can be multiple material with multiple feeding points or multiple materials with a prefabrication process, bonded in the form of a wire or a tape, which is not material a alone but, A plus B or A plus B plus C, in various volume fractions in varying volume fractions and so on.

So, that is how you can the material feed can be changed and material feed can define what material, what geometry what composition and what degradation and so on, you will ultimately develop. And by controlling the laser and its power, you actually can make it melt, you can make it clad or deposit then make it a very firm and a dense structure. You can even create a lot of gradation in terms of thickness in terms of shape, in terms of porosity or other physical or chemical parameters.

So, you actually the possibility is literally infinite, you actually can do a complete engineering of finished component development manufacturing using a single tool of laser with a powder feeder or a wire feed or some other material feeding system. But, this is very much in it is infancy, it is in the nascent state, nobody can claim that, tomorrow itself I am going to build a complete engine block using direct manufacturing laser based direct manufacturing.

Because, it has to go through various forms of testing characterization certification then only you will have the reliability, then we will earn the confidence of the users or the customers. But, this opens up an excellent possibility of going into new direction altogether where, manufacturing would be not only easier, will be much more versatile and faster and will open up new possibilities which even today is not possible.

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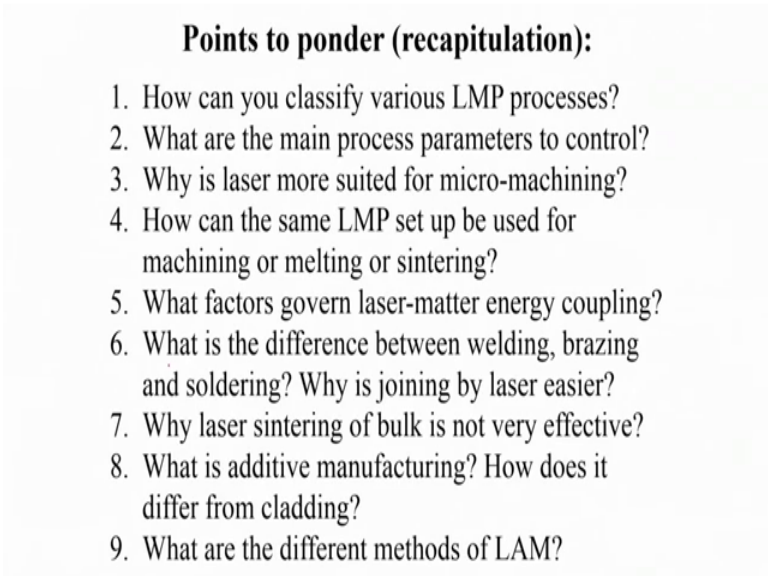

So, by way of recapitulation I would say that we can classify the material processing into 4 major groups of removal, machining, addition or shape changes and shown. So, various forms of manufacturing or we can do joining similar or dissimilar same thickness, different thickness, same composition, different composition or we can do surface engineering. So, these are the 4 major possibilities; forming, machining, joining, surface engineering. The main process parameters remain the interaction time and power density, the focal point and so on.

The micromachining is very possible because of shape of the beam can be not only of the micrometer size but, also the temper the heat deposition profile will be so precise and reproducible that is not possible in any other form of heating and it is a very very transient process, at a time you are heating only a small volume of the bulk and rest of the bulk night. So, only one percent or less is heated up and that heating can take it to the vaporization temperature whereas, the 99 percent can remain at room temperature. So, that adds to the you know various possibilities which otherwise is not feasible in conventional processing.

So, using the same laser actually by changing a parameter the power density and the interaction time, you can do either only heating, you can do sintering for that matter, you can do melting solidification, you can do even machining with or without carrier gas like oxygen. The surface condition is very important in terms of efficiency of coupling the laser matter and also the wavelength the various material properties like the density, the melting temperature at the specific heat and so on and so forth there also very important.

We saw that using laser we can do all kinds of joining processes welding, brazing, soldering and using laser this joining processes are so easy because, I can do it in air and I can do it for dissimilar things and I can do it sub joining processes even for non conducting materials, non electrical conducting and so on so I can try and join even an insulator with a metal.

Laser sintering is a bit of a problematic particularly when you are dealing with the dissimilar sizes or dissimilar composition and that is purely because, at a time you are heating only the surfaces of the powder particles and not it is entire bulk but, one can actually use laser sintering in combination with application of pressure and then make a denser and a more stronger compact or a sintered product.

Additive manufacturing is a very very exciting process and it is cladding can be a precursor but, essentially additive manufacturing opens up completely new possibilities, of producing finished component of very very complex shape size contour and geometry only starting from powder and building layer by layer. So, the different laser assisted manufacturing processes ah, all can be treated with the same setup same machine and can be used to build up various kinds of manufacturing, can be used to conduct various kinds of manufacturing practices and laser is certainly one of the most versatile tool for such applications.

So, in the next few lectures, we will discuss about various surface engineering processes, though the course is about surface engineering for wear and corrosion resistance but, in the last couple of lectures I thought, it would be prudent to discuss various manufacturing processes possible using laser as a non contact tool right.

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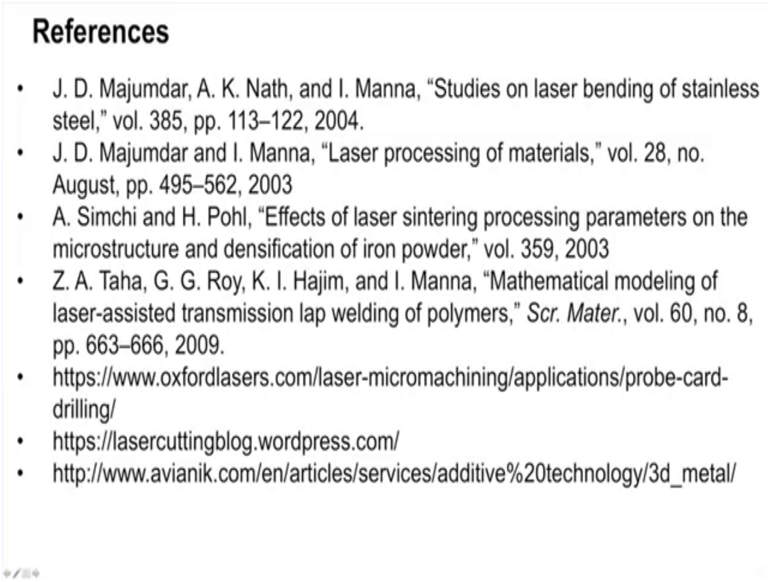

Thank you very much and we will move forward now for surface engineering.