Rapid Manufacturing
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Lecture – 20
Powder based processes (Part 1 of 3)

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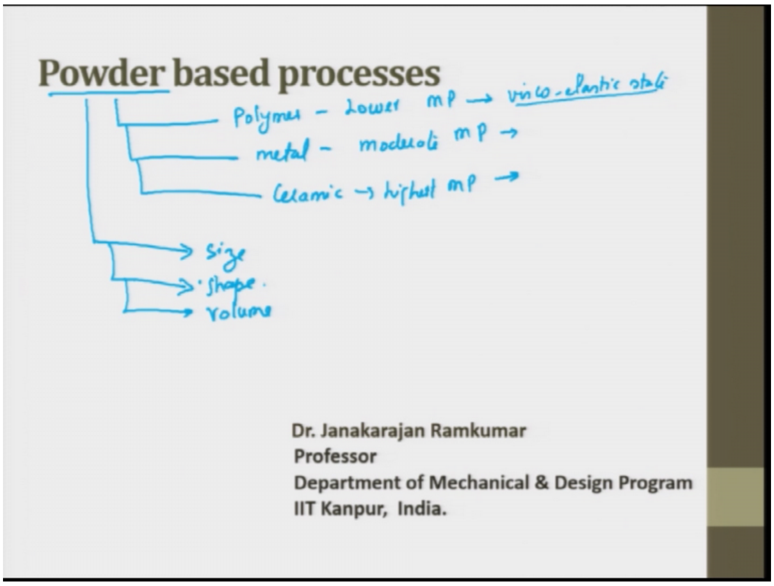

Powder based processes; this is the second in the series. When I say powder based process, there are three types of powder; which can be polymer based, which can be metal based, which can be ceramic based. Of course, the highest melting point, moderate and low ok; melting point. So now, you can understand if I wanted to use polymer powder, then the heat whatever I apply can be very less.

So, in polymer it is interesting it is not going to go to melt state it is it has to go to visco-elastic state. So, when you go to visco-elastic state it can join. As far as metals are concerned you go very close to the melting point, ceramics also you take it very close to the melting point. So, here the visco-elastic state will now the temperature of the visco-elastic state temperature will be slightly lower.

Suppose if 100 is the melting point you will get it at 60 or 70 depending upon the structure you might get an visco-elastic state. This visco-elastic state is used for joining ok. And moment we talk about the powder; so the next important thing come's the size, shape, and the volume all the three things come into existence. So, shape of the powder, size of the powder and the volume of the powder.

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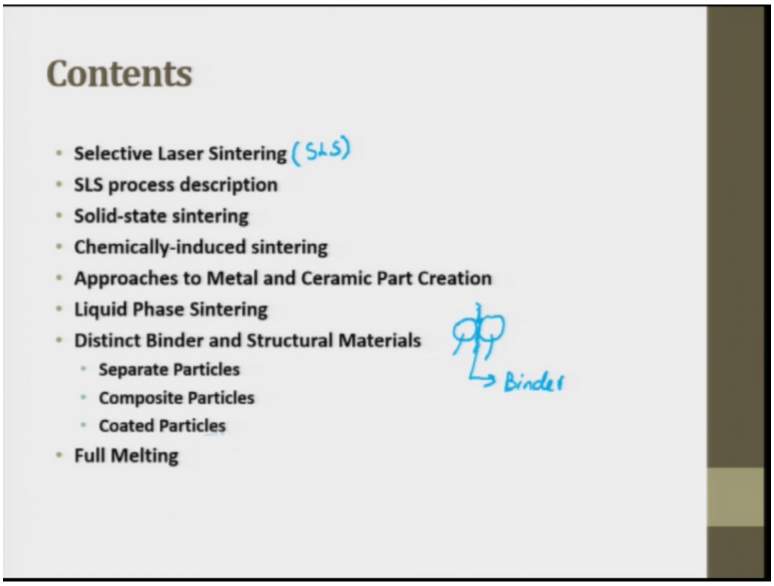

So, in this lecture we will be trying to cover what is Selective Laser Sintering process. So, the selective laser sintering process is called as SLS, so SLS process description will be there. Then we will try to see what is solid-state sintering, then we would look at chemical-induced sintering, then we will have approaches to metal and ceramic part creation, then liquid phase sintering, then we will see about distinct binder and structural material.

Because when we try to have particles like metals and ceramic their melting point is very high. So, in order for this fellows to join what you do is I can melt I cannot take it to such a high temperature what I do is I try to add a binder in between. So, this binder alone I will melt and this melts is used for joining this powders.

So, distinct binders are used these are binders. These are binders are used the binders and structural materials where we use separate particles, composite particles, coated particles. And finally, we will try to see full melting process or full melting.

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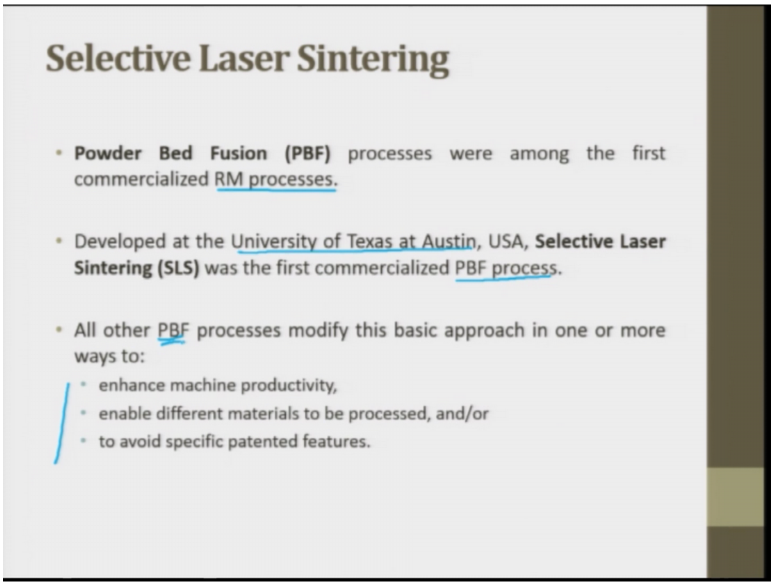

The powder bed fusion process where among the first commercialized RP process. If this was commercially available; even before the stereo lithographic can come go at a fullest extent; the powder bed fusion process; powder bed this is a powder starting material fusion joining. So, powder bed fusion process where among the first commercial RM processes; developed at the University of Texas at Austin USA.

Selective laser sintering was the first commercialized powder bed fusion processes. All other powder bed fusion processes modified this basic approach in one or more way to enhance machine productivity, enable different materials to be processed and or to avoid specific patented features. So, for these three, they have the PBF powder bed fusion process were modified.

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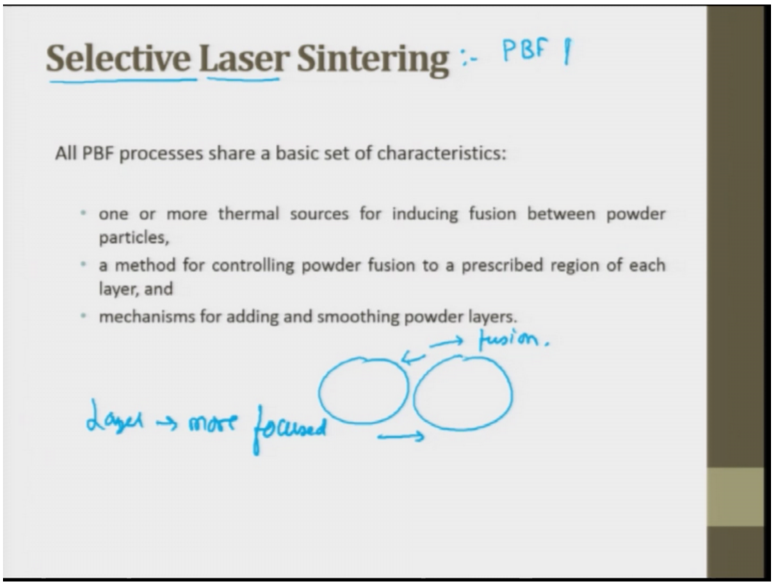

All the PBF processes share a basic set of characteristics; one or more thermal sources for inducing fusion between powder particles. What is fusion powder? particle powder particle joining will be called as fusion ok. A method for controlling powder fusion to a prescribed region of each layer; so this is what is called as selective clear. A method for controlling powder fusion to a prescribed region selective right of each layer then mechanism for adding and smoothing powder layer; so these are the three characteristics.

So, if it is very clear from the name itself we selectively sinter using a heat source called laser. So, why laser? Laser is more focused ok. So, laser is more focused so I can easily have selective sintering by using laser. So, that is why the process is called as selective laser sintering process which is part of powder bed fusion process.

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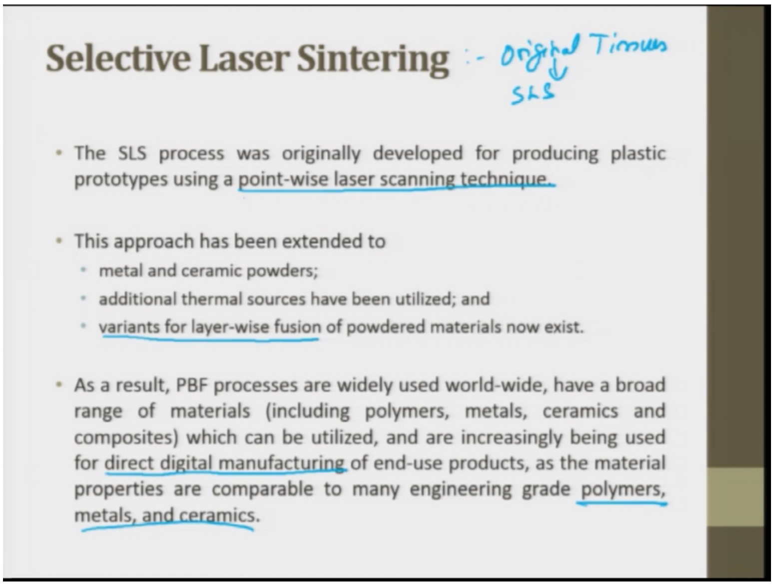

The SLS process was originally developed for producing plastic prototypes using a point wise laser scan technique. We also use the point wise laser scan technique which is vector based which we used in stereo lithography. This approach has been extended to metals ceramic powders today. Additional thermal sources have been utilised today variant of layer wise fusion of powdered material now exist.

So, variant of layer wise fusion of powders also exist. As a result powder bed fusion processes are widely used worldwide have a broad range of material including polymer, metal. When I say metal it cannot be pure it is alloy ceramics and composites; which can be utilised and are increasingly being used for direct digital manufacturing rapid prototyping is otherwise called as direct digital manufacturing of end use products as well as material property are comparable to many engineering grade polymers, metals and ceramics.

Today we are trying to make original tissues right original tissues which can be which can be printed and integrated into our body. So, we use polymers of polymers and we use a process called SLS because we need very high resolution so we use this process. So, tissue which is going to be integrated as part of the body is nowadays printed.

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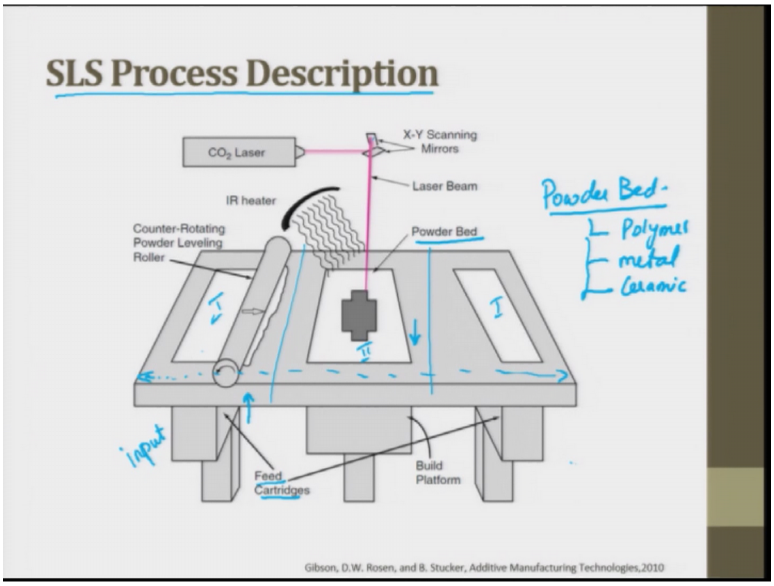

So, if you look at the process the process description goes like this so you will have a table. So, the table if you see it is divided into three segments. So, you have one segment and two segment. The two segment the second segment is going to be powder bed. This powder can be polymer powder, metal powder, or ceramic powder, can be polymer, it can be metal, it can be ceramic powder can be there. This powder which is to be fed on the powder bed comes from the container which is called as feed cartridges.

So, this is a feed cartridge you can call it as in input and you can call it as extra cartridge extra collection cartridge. But it is this to are I think you should call you should call it as feed cartridge only. So, you have one and two which are feed cartridges and in the middle you have. So, moment I say feed cartridge the material flows from this cartridge feed cartridge to the powder bed. So, how can this happen? Every time the table has to sync by a layer and correspondingly the cartridge has to increase by one layer or raised by one layer.

Moment it raises by one layer then a roller, this is a roller this roller starts moving from here it travels to the other extreme end. So, when it travels whatever is the excess powder which is there by lifting this feeder by one layer is pulled and spread over the bed. And anything which is extra the roller takes it to the other feed container or other feed cartridge. Now the roller has come to the other position and it waits there. Now once the feeding is done the powder bed when the roller rolls it trace the material fills it up here flattens everything on the top and keeps moving.

Like what we had a doctors blade, or recoater blade. So, in the same way we have here roll which does. Now, once the roller does this job then comes the CO 2 laser into action. So, the CO 2 laser hits on your scanner galvo scanner and this galvo scanner is passes the light to exactly hit on the surface selectively on the top surface of the powder bed. So, when a when it does it does boundary and also it does hatching these are all internal hatching it does this and this forms one layer of information.

Now what has happened? The table will be sunk down by one layer of information. The roller which was there on the other side will start pulling up the powder from this feed cartridge and keep moving. So, once the powder bed sinks down then this time this cartridge will rise by a corresponding layer thickness. So, now the powder from this side will be will be spread on top of the powder bed and this will keep going.

So, this keeps on be happening continuously and finally, what do you get is layer by layer by layer by layer of selective sintering happens and finally, you get a product. In between we in order to maintain or remove the moisture we always use a IR heater. The function of this IR heater is to remove the moisture or polymer whatever access polymer material some small things those things will be removed. And the temperature will be maintained such that when the next layer is cured the base two layers the first layer and the next layer sticks properly with each other.

Otherwise if there is not a heat there then what will happen the first layer will get cured very fast and then when the second layer tries to cure there will be a delamination which is happening which will lead to defect. In order to remove this we always apply IR heat. This IR heat is to remove moisture and also to keep the base layer not cured or it is semi cured. Then comes the next layer on top of it. So, the selective laser sintering process this is what happens.

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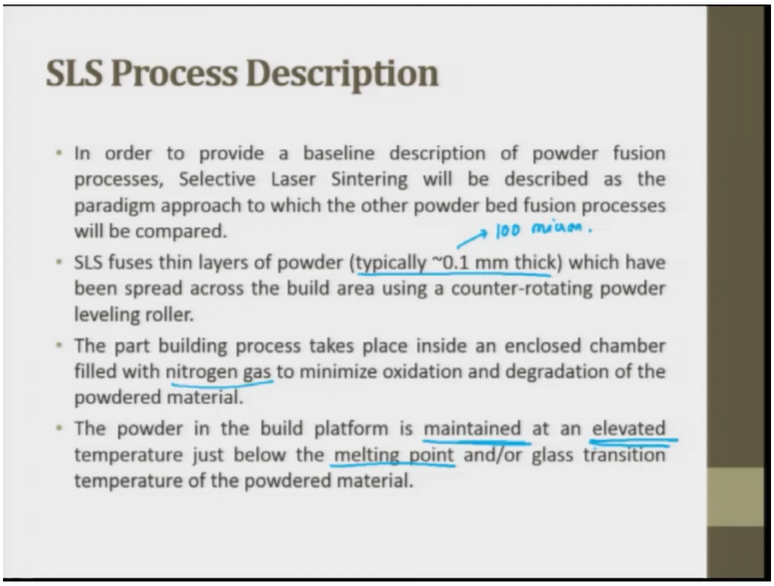

In order to provide a baseline description of powder fusion process, selective laser sintering which will be described as the paradigm approach to which the other powder bed fusion process will be compared. SLS fuses thin layer of powder typically of 0.1 micron this is 100 micron. So, if I can do with SLS process powder based the layer thickness can be few 100 microns which have been spread across the built area using a counter rotating powder level roller which I said roller. The part building process takes place inside and enclosed chamber where this; see in the previous schematic diagram it was open.

But generally what we used to do is we used to do it in a enclosed chamber. And in the enclosed chamber we try to maintain a temperature filled with nitrogen gas to minimise oxidation and degradation of the powder material ok. Because whenever there is a heat there then oxidation easily happens. In order to avoid we try to put a chamber and fill it up with nitrogen gas. Nitrogen gas non reactive the powder in the bed platform is maintained at an elevated temperature just below the melting point. The powder in the build platform is maintained at an elevated temperature just below the melting point or glass transition temperature of the powder such that; it is sticks with the previous layer.

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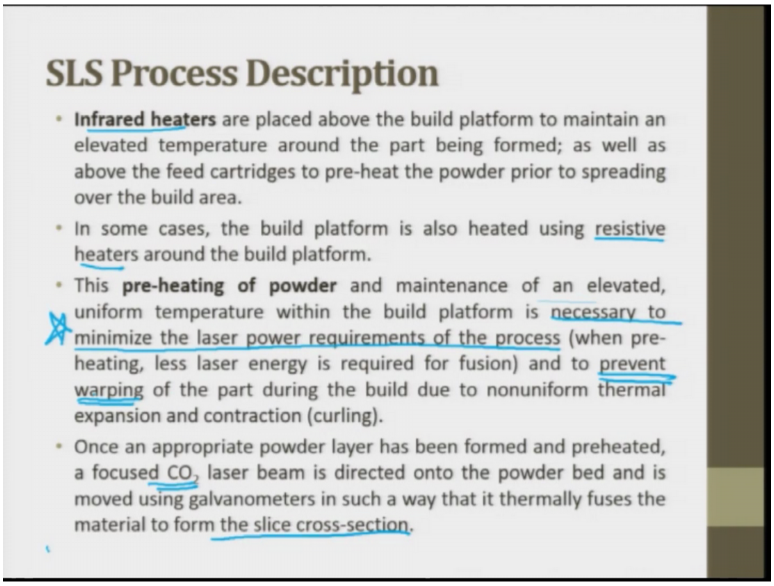

Infrared heating; infrared heaters are placed above the build platform to maintain an elevated temperature around the part be informed as well as above the feed cartridge to preheat the powder prior to spreading over the build area. That is what I said if there is any moisture if there as any un toward or which is not required polymer slightly mixed or something. All these things when you start preheating they get gassed away and it is removed. In some cases the build platform is also heated using resistive heater.

It can be infrared it can be resistive this preheating of powder and maintaining at elevated uniform temperature within the build form is necessary to minimize the laser power requirements for the process; very important point that is why we try to preheat the powder necessary to minimize the laser power requirements of the process. And to prevent warping of the part during building due to non uniform thermal expansion and contraction so this is the other thing.

So, it removes warping prevents warping necessary to minimize power prevent warping these two are important points prevent warping on the part during the build due to non uniform thermal expansion and contraction. Once an appropriate powder layer has been formed and preheated a focused CO 2 laser beam is directed on to the powder bed and is moved using a galvo mirror in such a way that it thermally fuses the material to form a slice cross section clear. CO 2 laser so first requirement is to reduce the laser power. So, then prevent warping prevent oxidation and also have this.

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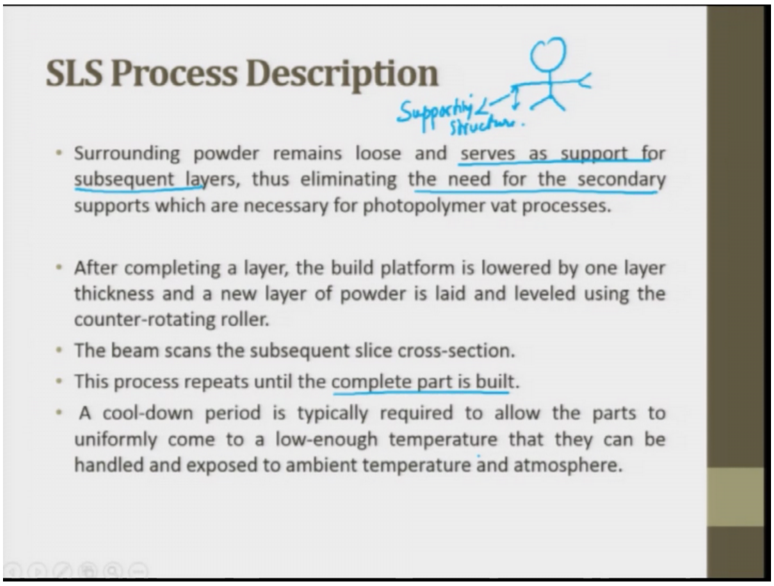

Then surrounding powder remains loose; which is not used and serves as a support. See earlier you remember I was trying to talk about the structure like this right. So, we said so we he will have a supporting structure. So, as far as in SLS process is concerned we will not have a supporting structure. So, this is a supporting structure in SLS, there is no supporting remains loose and serves as supporting. So, here we do not put a supporting structure the powder whichever is not cured acts as a supporting layer.

Thus eliminating the need for secondary support which are necessary for photo polymerization VAT process. After completing a layer the build platform is lowered by one layer thickness. And a new layer of powder is laid and levelled using the counter rotating roller. The beam scans the subsequent slice cross section this process repeats until the complete part is built. The cool down period is typically required to allow the part to uniformly come to a low enough temperature that they can be handled and exposed to the ambient temperature and atmosphere.

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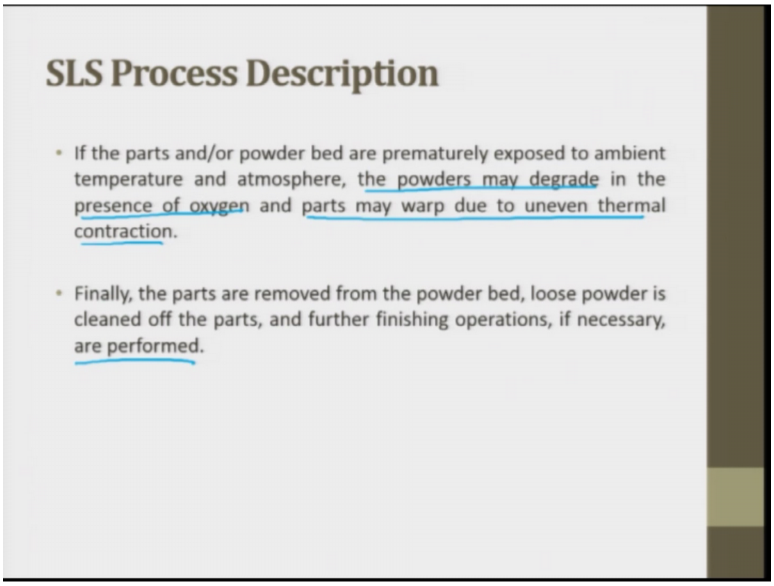

If the part or the powder bed are prematurely exposed to a ambient temperature and atmosphere. The powder may degrade in the presence of oxygen and the parts may wrap unevenly. Finally, the parts are removed from the powder bed loose powder is cleaned of the parts and further finishing operation if necessary are performed. So, these are called as secondary operations which are done.

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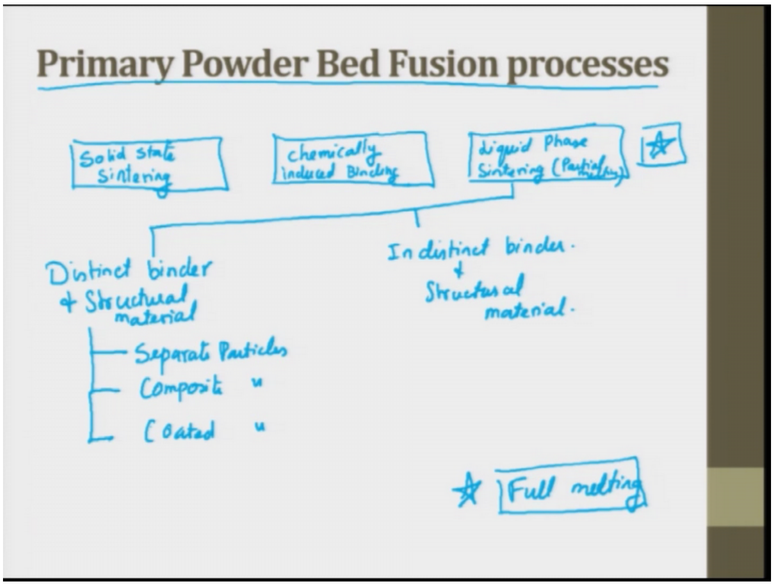

So, when we look into the primary powder bed fusion process we have the following classification. So, we have four classifications ok. One is solid state sintering, next one is chemically induced binding. The third one is liquid phase sintering which is; partial melting. And finally, you have one star I will write the star here as full melting ok.

And this partial this is distinct binder and structural material. One is separate particles composite particles and coated particles when I try to look at; indistinct binder and structural material ok. This is how we try to classify the primary powder bed fusion processes solid state then we have liquid state in between we have chemical induced binders.

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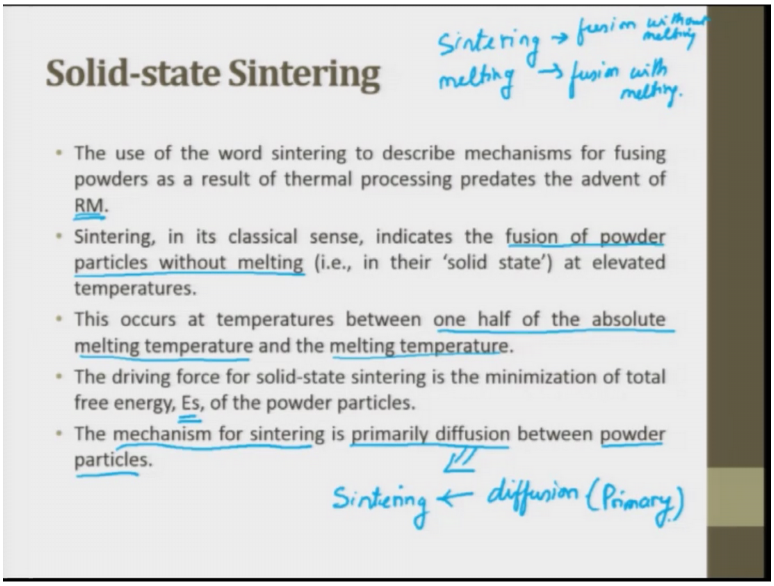

Solid state sintering the use of the word sintering to describe mechanism for fusing powder as a result of thermal processing predates the advent of RM. Sintering in it is classical sense indicates the fusion of powder particles without melting very important powder particles without melting. So, sintering, sintering the other one is called as melting today we call it selective laser sintering selective laser melting.

So, when we talk about melting the fusion of the powder particles. So, here fusion without melting so here it is fusion with melting ok. That is in there solid state at elevated temperatures. This occurs at temperatures between one half of the absolute melting temperature and the melting temperature. So, the driving force, driving force which drives for solid state sintering is the minimization of the total free energy of the powder particles.

The mechanism of for sintering is primarily diffusion the mechanism for sintering is primarily diffusion between powder particles. So, this is very important sintering process sintering the primary mechanism is diffusion. You have many more, but this is a primary process primary mechanism.

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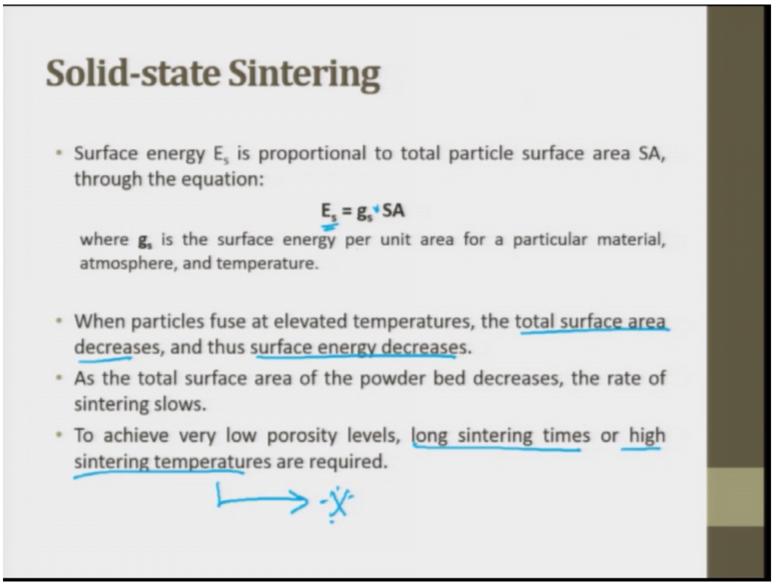

The surface energy so you can see here free energy E s the surface energy E s is proportion to the total particle surface area SA through the equation. So, E s is equal to g s into SA where g s is the surface energy per unit area for a particular material atmosphere and temperature so, this is a star. When particles fuse at elevated temperature the total surface area decreases.

Particle fuses at elevator temperatures the total surface area decreases. And thus surface energy decreases total surface area decreases surface energy also decreases. As the total surface area of the powder bed decreases the rate of sintering slows. To achieve a very low porosity level long sintering time, or high sintering temperatures are required sintering time sintering temperatures but sintering temperature is important ok. So, surface area plays a role then temperature also plays a role.

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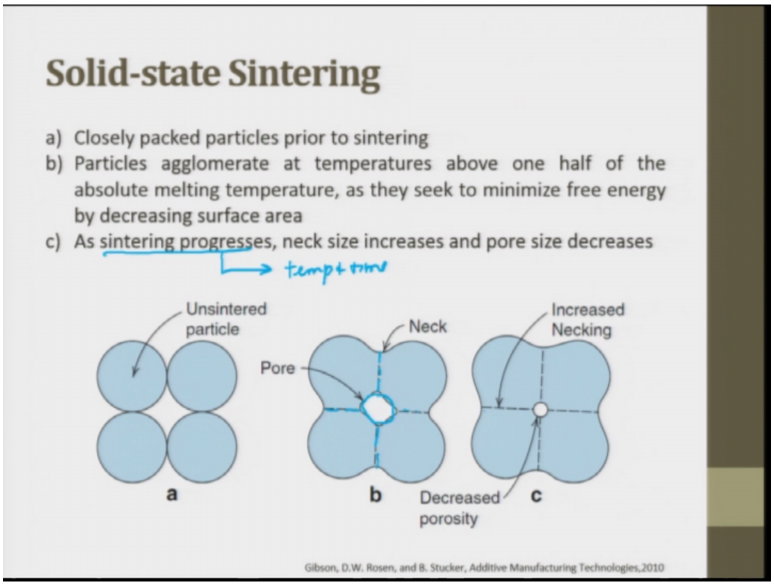

So, when we look very close so a is closely packed particles prior to sintering un sintered particles. Then particles agglomerate at temperatures above 1 half of the absolute melting temperature as they seek to minimize free energy by decreasing surface area. So, in this what happens? You can see here there is a necking phenomena happening on all four sides and this leads to a pore in the centre.

And if you want to decrease the pore so then what we do is we try to take it a much higher temperature you see the pour size has reduced. So, as the sintering process progresses the necking size increases the necking size this is the necking size increases and a pore size decreases. So, it is very clear sintering progress what a sintering it is temperature and time combination of this. So, you can try to reduce the pore size and increase the necking area.

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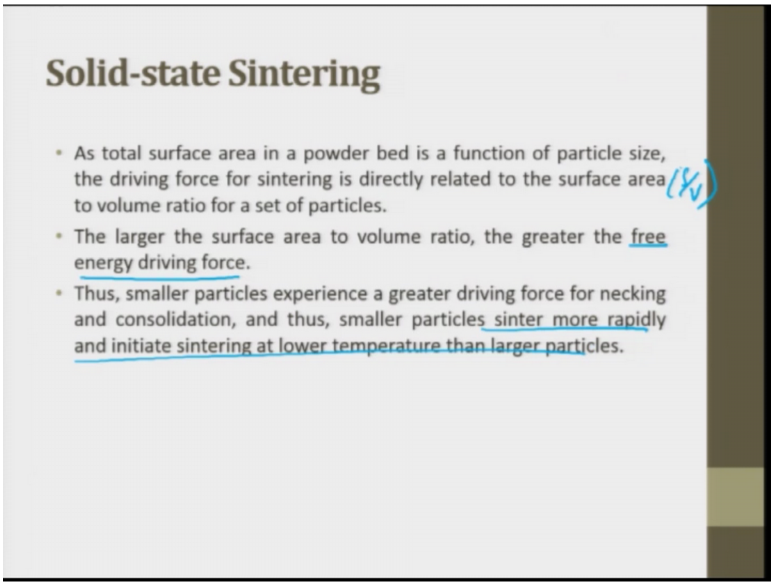

As total surface area in a powder bed is a function of a particle size the driving force for sintering is directly related to the surface area to volume ratio this is nothing, but s by v ok. The total surface energy is related to s by v ratio of the set particles. So, particle size and the volume of the particles is aspect ratio of place about. The larger the surface area to volume ratio the greater the free energy driving force.

So, if the particle size is smaller and smaller and smaller; nano particles the volume will be very small surface area is very high. So, you will have a greater energy drive to push the particle. Thus small particle experiences a greater driving force for necking and consolidation. Thus smaller particles sinter more rapidly and initiate sintering at lower temperature than the larger particle a very important point.

If you can go smaller and smaller and smaller in your size of the powder, then you will have more driving force more driving force in the sense you will have better consolidation you will get. And once the particle size is very small surface area small volume is small surface area large. So, then the melting point will also reduce.

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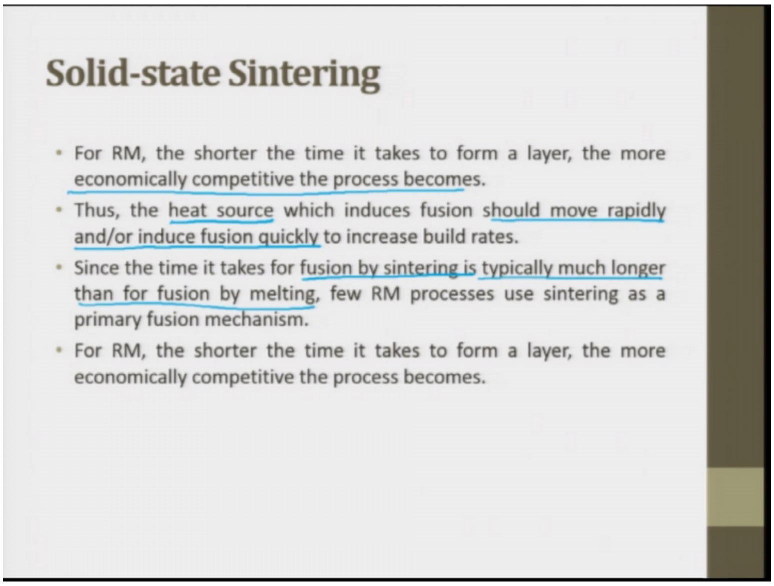

For RM the shorter the time it takes to form a layer the more economical competitive the process becomes. So, you have to use only smaller particles as if you use a large particle size the driving force will be less. So, you will have to apply more and more heat and when you apply more heat it takes longer time for making the parts.

Thus the heat source which induces fusion should move rapidly or induce fusion quickly to increase the building rate. So, the heat source induces fusion should move rapid and to induce fusion quickly to increase the building rate. Since the time it takes for fusion by sintering is much longer than the fusion by melting few RM process uses sintering as the primary fusion mechanism.

So, is fusion by sintering is typically much longer than the fusion by melting. For RM the shorter the time it makes to form a layer the more economical competitiveness becomes the process.

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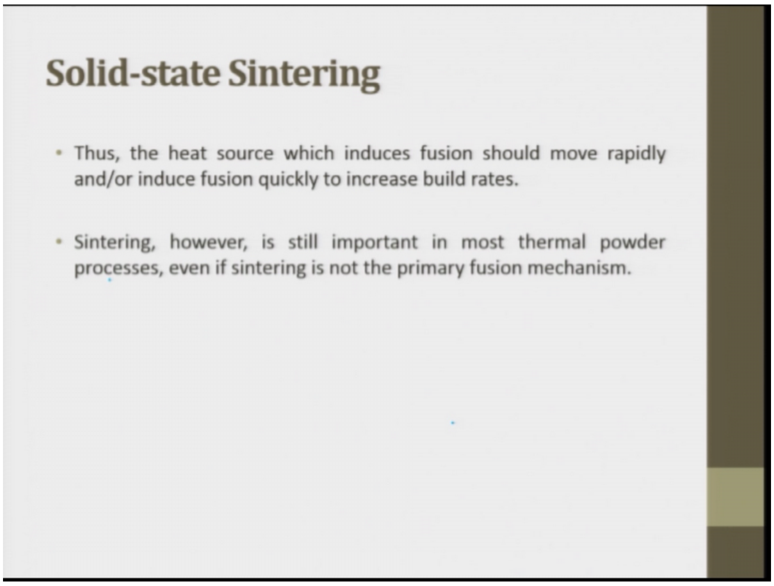

Thus the heat source which induces fusion should move rapidly induce fusion quickly to increase the build rate. Sintering; however, is still important in most thermal powder processing even if the sintering is not by primary fusion mechanism.

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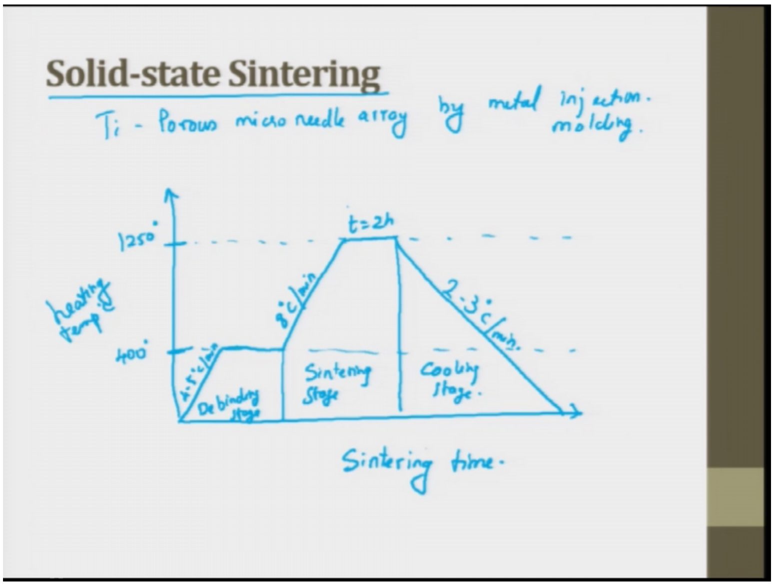

So, let us try to see the solid state sintering for a typical titanium which is porous and which is used for forming micro needle array by metal injection moulding. I will just try to draw the sintering cycle. So, this is a heating temperature ok. So, 400 degrees, 1250 sintering time is a sintering temperature all in degree Celsius. So, here what we do is we divided into three stages; in the first stage it is called as de binding stage, the next one it is called as sintering stage, and the last one is called as cooling stage ok. So, here you will have the it is for 2 hours you hold it at 1200 degree Celsius ok. And here it will be 8 degree per Celsius minute you will increase to go to this. So, here you will try to take 4 to 5 degree Celsius per minute. And here you will try to take 2 to 3 degree Celsius per minute ok. So, this is a typical sintering cycle. If you see here you cannot go right straight to the 1250 and start doing a sintering process, you do it step by step by step and slowly at every stage you try to maintain it for some time so, this is called as soaking time. And you soak it for some time, then you ramp it, then you soak it, then you do the cooling stage.

So, this is a typical stage so first here we have putting the de binding stage. De binding stage means suppose you have some binder intentionally added so that it can glue and you can make a wet process. So, that binder to get removed we call it as debinding stage because they we try to take to four hundred degrees generally we add binder as a as polymer. So, this is used only for the basic consolidation or we call it as grain compaction ok. And then we heat it to four hundred degree Celsius all these fellows gone. And then you start slowly increasing the temperature so this process is called as sintering process. And this stage is called as sintering stage and after it is soak for 2 hours. We remove the temperature and allow it to fall down and we allow also to fall down slowly. So, it slowly cools down and you try to get whatever output you want. So, typically sintering time and temperature this is how the plot is for a particular application.

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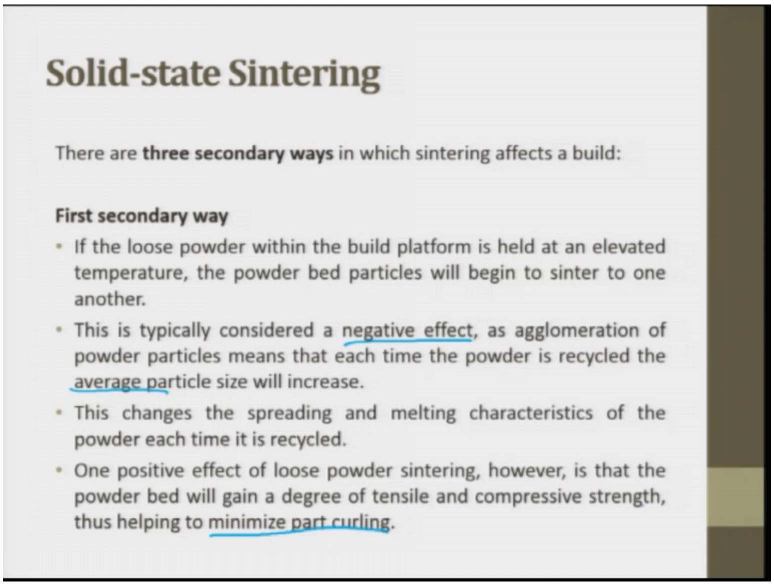

There are three secondary ways in which sintering effects a build. The first secondary way if the loosen powder with the build platform is held at an elevated temperature the powder bed particles will begin to sinter to one another. So, you cannot keep on be keeping at a maintaining at a very high temperature after some we have to maintain slightly lower and temperature such that it does not sinter. This is typically considered a negative effect as agglomeration of powder particle means that; each time the powder is recycle the average particle size will increase because it is all getting stucked. This changes the spreading and melting characteristics of the powder each time it is recycled. One positive effect of loose powder sintering; however, is that the powder bed will gain a degree of tensile and compressive strength thus helping to minimize part curling ok. So, when there is a pre sintering happening. So, you will also have an advantage curling will not be there.

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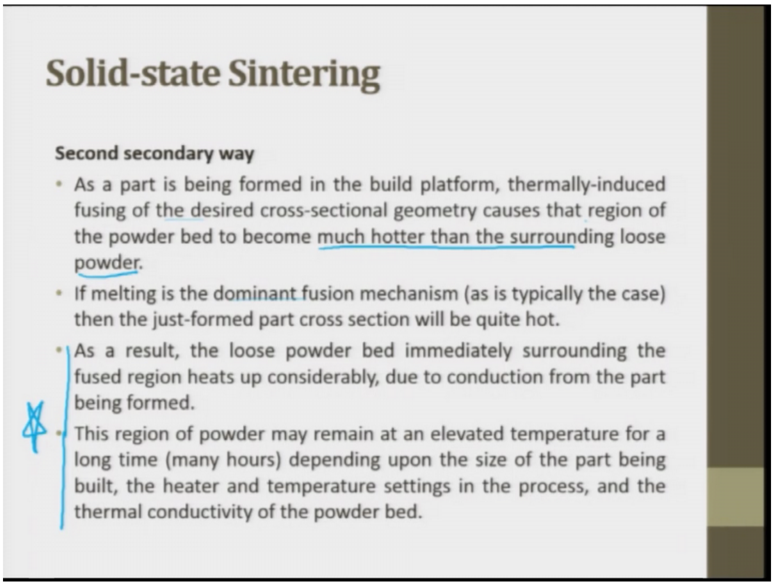

As the part is being formed in the build platform thermally induced fusion of the desired cross section geometry causes that region of the powder bed to become much hotter than the surrounding loose powder at the cross section right. If melting is the dominant fusion mechanism then the just formed part cross section will be quiet hot when you are doing selective laser melting as a result. The loose powder bed immediately surrounding the fusion region heats up considerably due to conduction from the part being formed. This region of powder may remain at an elevated temperature for a longer time depending upon the size of the part being build the heater and the temperature setting in the process and thermal conductivity of the powder bed. So, this part and this part are important. This region of powder may remain at an elevated temperature for a long time depending upon the size of the particle being built the heater and the temperature setting in the process and a thermal conductivity of the powder bed plays a very very important role.

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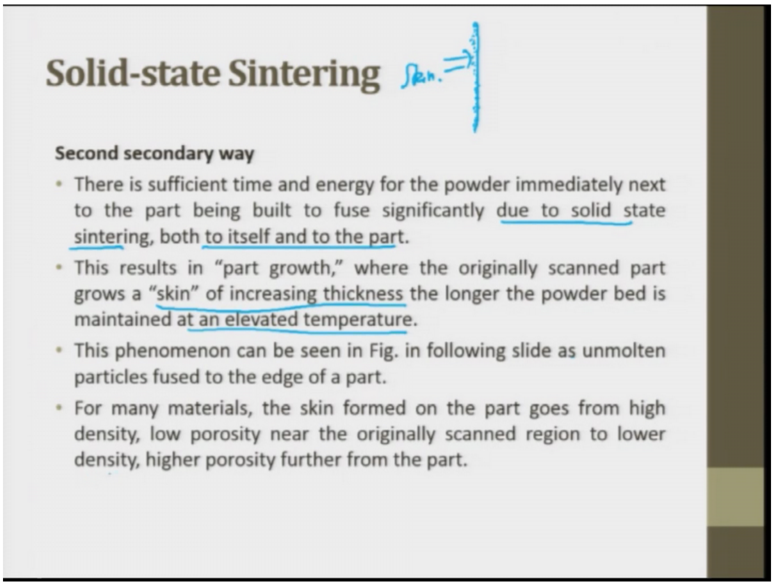

There is a sufficient time and energy for the powder immediately next to the part being built to fuse significantly due to the solid state sintering both to itself and to the part. So, next to the end there will be a sintering happening. This results in part growth where the original scanned part grows a skin of increasing thickness. The longer the powder bed is maintained at an elevated temperature. So, this is what they call it as the skin which is getting which is getting stuck to the surface and you were to get. This phenomena can also be seen in the next figure we will see of as an unmolten particle fused to the edge of the part. For many materials the skin this is the skin the skin formed on the part goes from higher density low porosity near the original scanning region to lower density higher porosity further from the part.

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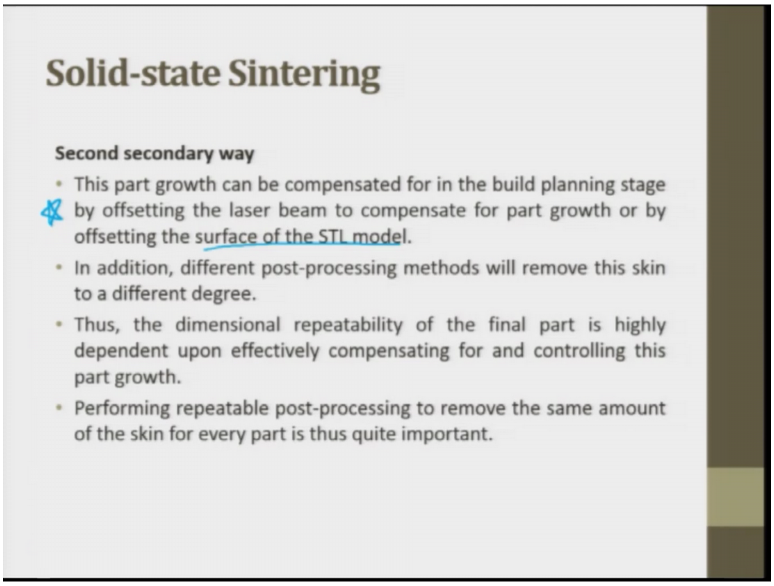

This part grow can be compensated for in the build planning stage by offsetting the laser beam to compensate for part growth or by offsetting the surface of the STL model; so this is also very important point. In addition different post processing methods will remove the skin thus the dimensional repeatability of the final part is highly dependent upon the effectively compensating for and control in the part growth.

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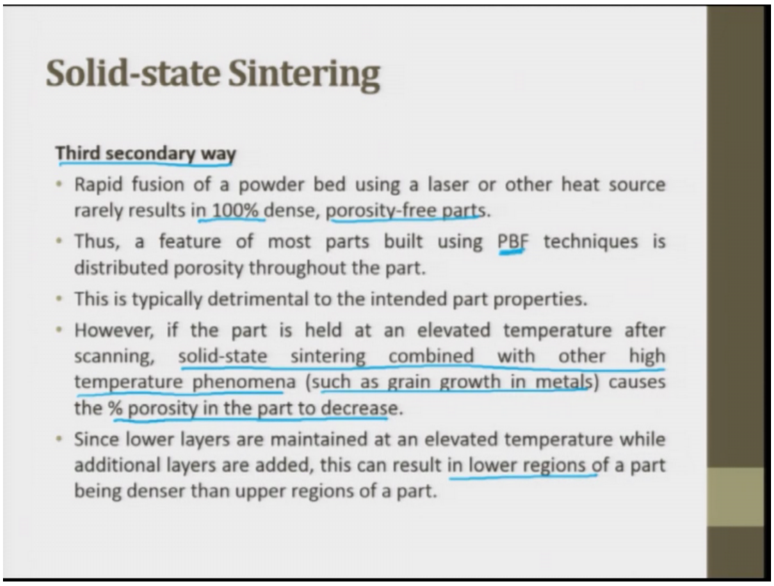

The third secondary way the rapid fusion of them powder bed using a laser or other heating source results nearly in 100 percent density and porosity free parts. Thus a feature of most parts being used powder bed fusion technique is distributed porosity throughout the layer. This is a typical detrimental to the intend part property so which is happening inside. So, however, if the part is held at an elevated temperature after scanning the solid state sintering combined with the other high temperature phenomena causes the percentage of porosity to decrease. So, solid state sintering combined with the other temperature phenomena such as grain growth in metal causes the porosity to degrees. Since lower layer are maintained at an elevated temperature while additional layers are added this can result in lower temperature of the part being denser than the upper region.

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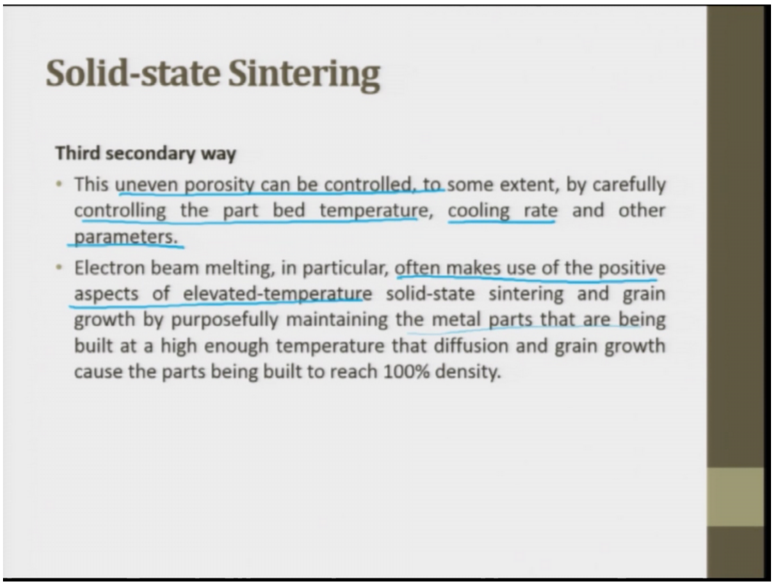

This uneven porosity can be controlled to some extent by carefully controlling the part bed temperature cooling rate and the particle size. Electron beam melting replacing laser by electron beam melting in particular often makes use of a positive aspect at elevated temperature solid state sintering. And grain growth by purposefully maintaining the metal part that are being built at high enough temperature that fusion and grain growth causes the part to be built for 100 percent.

Thank you very much.