Rapid Manufacturing
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Lecture - 21
Power based processes (Part 2 of 3)

Chemically induced Sintering.

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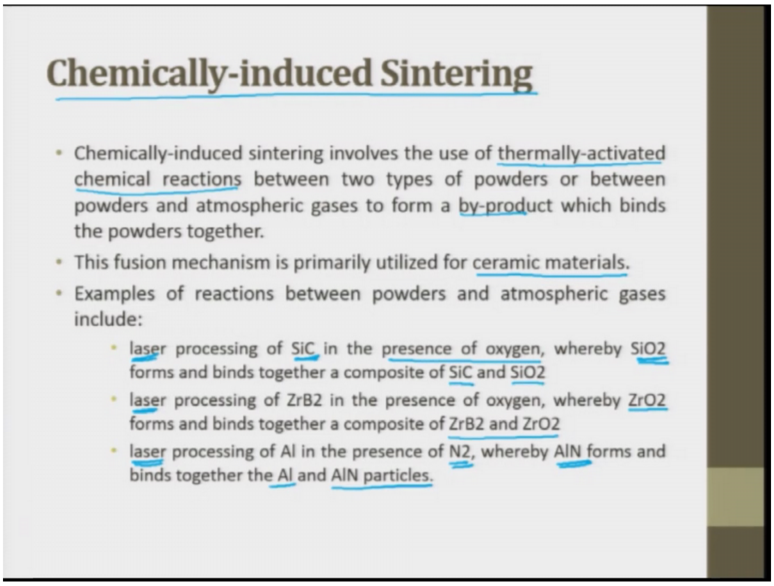

Chemically induced sintering; involves the use of thermally activated chemical reactions between two types of powder or between the powder and the atmospheric gas; to form a byproduct which binds the product together in a very very simple fashion. Such that; you can understand when we make laddu we add ghee to it the function of the ghee is to make sure that this smaller smaller particles are held together right; so here there is no chemical reaction.

But we add a binder in between which completely covers over the particle small particles and then it tries to go in between. Suppose if you if you have it in a solid state it is very difficult to mix. So, when then what we does we heat the ghee bring it to the liquid form pore the ghee. So, that all the laddu [FL] particles all are properly coated and then; what we does we catch it by hand or we put it in a die to give a shape.

So, this thing is called as green strength product ok. In chemically induced what we do is there is involves the use of thermally activated chemical reaction. Here there is a reaction, but laddu [FL] example there is no reaction thermally activated chemical reaction between two types of powders or between the powder and the atmospheric gas to form a byproduct which binds the powder together.

This fusion mechanism is primarily utilized for ceramic materials only. Example of reaction between powder and the atmospheric gas include laser processing of SiC in the presence of oxygen where SiO 2 is formed and binds together the composite of SiC and SiO2. You see in the presence of sic in the presence of oxygen is dissociated and it forms SiO 2.

The laser processing of zirconium boride in the presence of oxygen forms zirconium oxide and binds together a composite of ZrB2 and ZrO2 oxide. This oxide reacts and it tries to split and this ZrO2 acts as a binder. The laser processing, why everywhere you see laser? Because laser gives you high power density laser gives you selectivity that is why we use laser. Laser processing of aluminum in the presence of N2 nitrogen forms AlN and binds together with Al and AlN particles.

So, this is chemically induced sintering please watch out; when we start working with materials you have to understand thoroughly materials. And once you understand it is positive negative what it can do, what it cannot do then what it cannot do you can try to tailor rate by adding some ingredients. So, that is what; is the story behind the slide.

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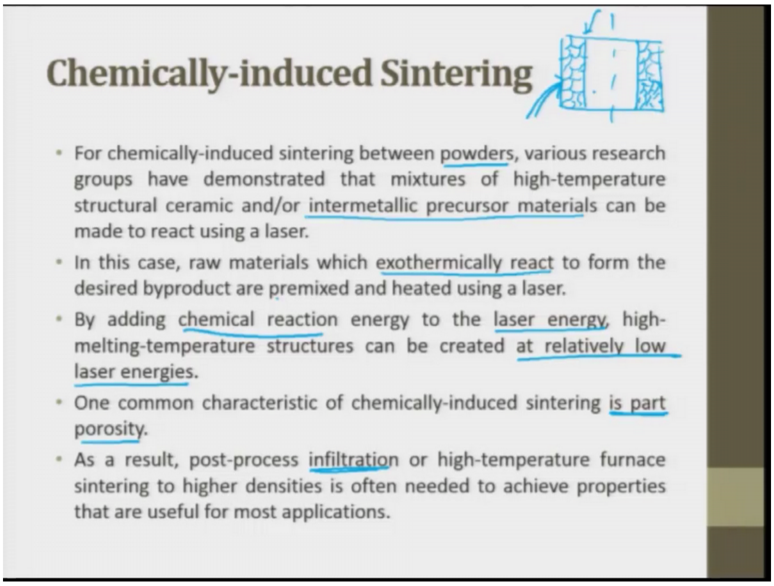

For chemically induced sintering between powder various research groups have demonstrated the mixture of high temperature structural ceramics and intermetallic precursor materials; that can be made to react using laser. In this case raw materials which exothermically react; raw material which exothermically exothermical heat is released while the reaction happened heat is released.

This heat also can be used for binding if we are smart. So, raw material with exothermically reactive to form the desired by product and premixed and heating use of a laser. By adding chemical reaction energy to the laser energy by adding chemical to the laser energy high melting temperature structures can be created at relatively low laser energies.

Why is this important factor? Because if the more and more and more and more energy you need for sintering process the cost of the machine goes very high ok. So, sometimes it also demands for subsystems when the power is enormously high it need subsystems for cooling the laser system. So, now, if I can reduce the power of the laser the subsystem requirement has gone down. So, the machine price will also go down. So, by adding chemical reaction energy to the laser energy we have reduce the laser energy requirement.

One common characteristics of chemically induced sintering is the part porosity which is very very important. As a result post process infiltration or high temperature furnace sintering to higher densities is often needed to achieve properties that are used to for most applications. Infiltration; infiltration means suppose let us assume you have a you have a bush this bush is made out of abrasive particles, you are doing by sintering operation.

And if you see here there are lot of porosities these are all abrasives you can see lot of porosities there. So, now what you do is either you try to post process it the bush once again ok, and try to consolidated or we try to infiltrate. What we do infiltration? Either we try to create a vacuum pressure here allow the liquid from outside to enter inside or you pressurized at very high pressures you push the liquid in between the pores so that process is called as infiltration.

Infiltration gives you a bigger advantage when you talk about lubrication or the porosity sometimes is also porous media is sometimes used for a benefit; wherever you want to have a extraction of heat people try to use porous media. And porous media also gives you a freedom that the densities go slow so the object can start floating ok. So, we use pores for our advantage we use pores for our application based we choose the pores for our applications.

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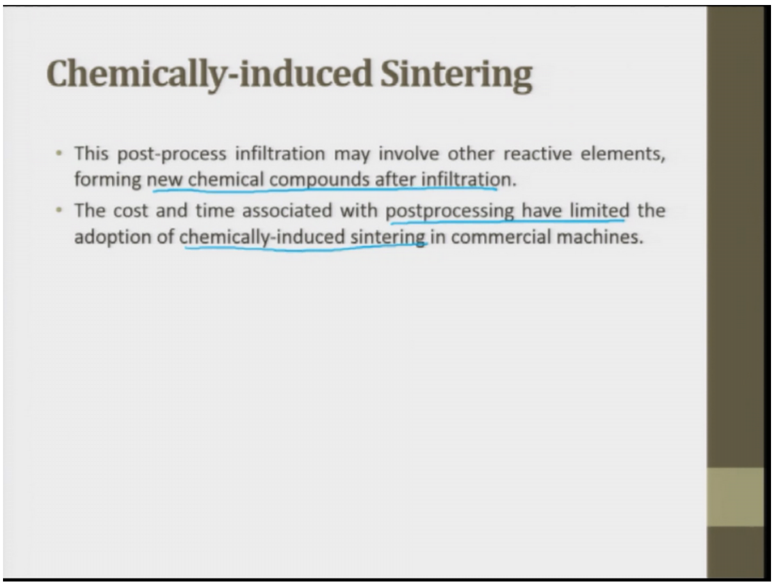

This post processing infiltration may involve other reactive elements forming a new chemical compound after the infiltration. what I was talking is; very high pressure the infiltration is pushing the liquid inside the pores. At some point of time this liquid also can react with the base material and form one more compound or another reactive product which can be used for our benefit.

The cost and time associated with the post processing have limited the adoption of chemical induced sintering in common machine. So, though this advantages are there, but still people are very comfortable with the previous process as compared to that of chemical induced process.

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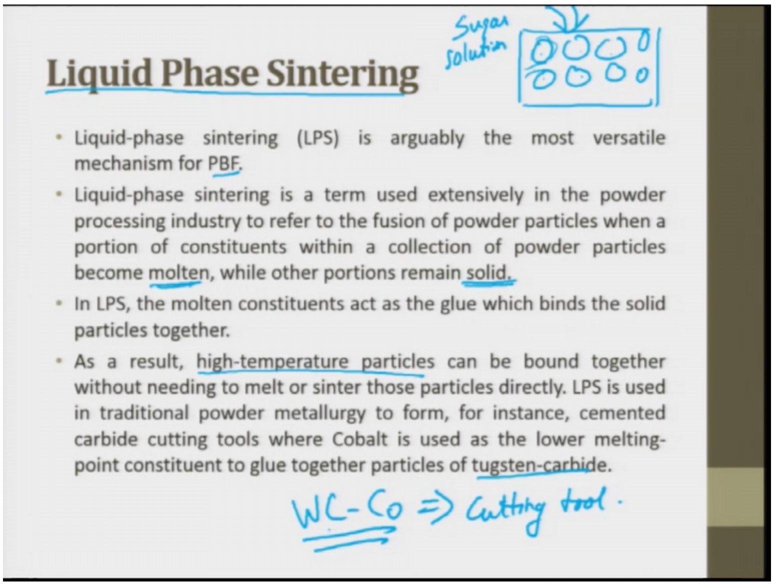

So, liquid phase sintering; so, the liquid phase sintering is arguably the most versatile mechanism in powder bed forming. Liquid phase sintering is a term used extensively in the powder processing industry to refer to the fusion of powder particles when a portion of the constituents within a collection of powder particles becomes molten while other portion remind solid.

Again I would give you a simple example let us take groundnut right and then you are trying to add sugar solution or you are trying to add jaggery to it. It consolidates right the groundnut nothing happens to the nut, but the jaggery or the sugar solution it tries to blend around and tries to hold these groundnut particles and this is a liquid phase sintering.

But here in this case molten metal is poured or the liquid sugar solution is poured, but in selective sintering what happens you try to coat the powder properly. And what it happens is the laser when it heats it tries to melt the portion which is coated alone. So, the to the fusion of the powder particles; when a portion of the constituents within a collection of powder particles becomes molten while other portion remain solid.

The liquid phase sintering the molten constituents acts as a glue which binds the solid particles together. So, here you do not have to worry about melting the nut even. Because all you have to do is melt the coating layer whatever is there. So, the coating will always melt at very low temperatures maybe; 700, 800, 900 degree Celsius so it will melt.

So, all you have to do is take a low power laser and quickly do the sintering process. And this liquid when it melts it tries to fill up all the pores. So, the porosity also will be reduced as much as possible. It is a very advantages process and today people talk more of liquid phase sintering.

As a result high temperature particles can be bound together without needing to melt high temperature particles. Otherwise if you want to blend groundnut and groundnut it is next to impossible ok. Suppose you take as sic particle you want them to sinter to each other you have to apply a huge energy.

So, high temperature particles can be bound together without needing to melt are sinter those particles directly. The LPS is used in traditional powder metallurgy to form, for instance, cemented carbide cutting tools where Cobalt is used as a lower melting point constituent to glue together the tungsten carbide.

So, tungsten carbide cobalt is a typical example which is used as a cutting tool for liquid phase sintering. It is rapid manufacturing; you just mix whatever you want tungsten carbide plus cobalt. The content is varied depending upon your requirements more and more and more cobalt the consolidation whatever you make the product whatever you make is can take tougher and tougher and tougher.

The moment you reduce the cobalt content a drastically down to 1 percent 2 percent it will be predominantly tungsten carbide it can withstand very high thermal shocks or very high compressive loads it can take ok. So, this is a typical example where and which the product whatever you make is directly used for the output. So, it is a typical example for rapid manufacturing. You have manufactured the cutting tool directly.

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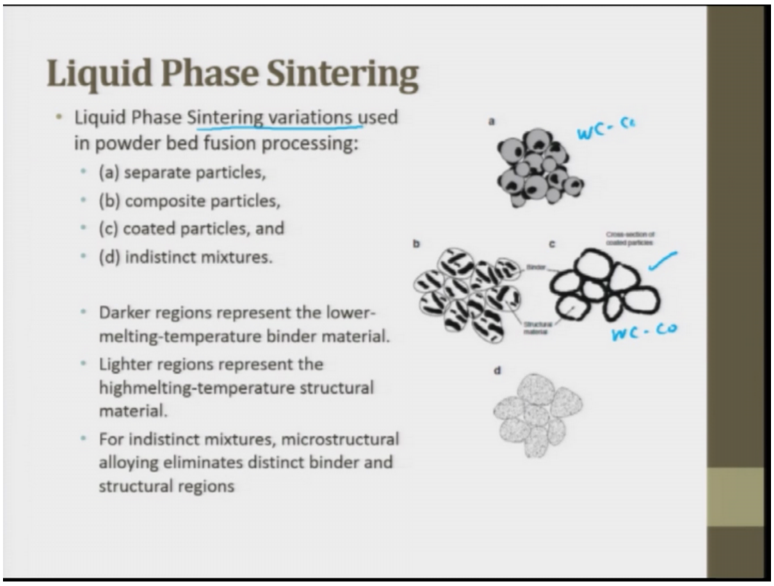

So, the liquid phase sintering variations used in powder bed fusion processes are; a, is separate particles these are all sintering variations separate particles. Then b is composed particles these are composed particles c, are coated section these are all coating particles d, is indistinct mixture so you have all the four. Darker region represents the lower melting point of binding temperature these are all darker lower.

The lighter region represents the higher melting point for indistinct mixture micro structural alloying elements distinct binder and structural regions are not they are indistinct. So, they are there all mixed together so these are the fourth type. So, this was the example which I was trying to take about; you can do like this or you can also do like this right. Tungsten carbide cobalt so where and which is mixed and then you get the required output.

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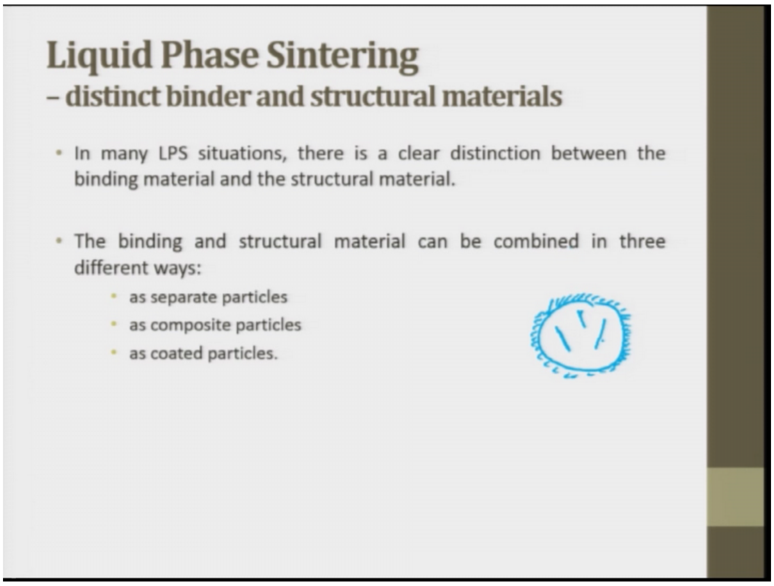

So, liquid phase sintering distinct binder and structural materials in many LPS liquid phase sintering situations. There is a clear distinction between the binding material and the structural material these are binding material very clear distinction was there very clear distinction was there.

The binding and the structural material can be combined in three different ways the binding material and the structural can be combined in three different ways; as separate particles, as composite particles, and as coated particles. You can have any of these three and then you can start doing.

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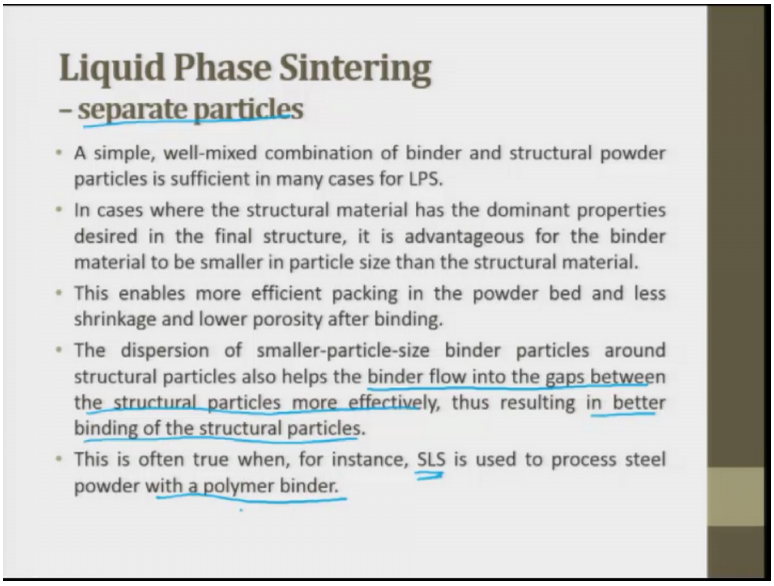

Separate particles; a simple well mixed combination of binder and structural powder particles is sufficient in many cases of LPS. In case where the structural material has the dominant property, desired in the final structure it is advantages for the binder material to be smaller in particle size than the structural material. That means, to say the tungsten carbide only tungsten carbide you would like to have, but cobalt is needed as the binder.

So, here the toughness property is sacrificed and you use it only for compressive load and high temperature withstanding for cutting tool application. This enables more sufficient packing in the powder bed and less shrinkage and lower porosity after binding. So, this enables more efficient packing because the binder size is very small.

So, particle size in the powder bed and less shrinkage because; the particle whatever is going to get melt and which is going to flow only layer structuring. So, now, that shrinking has gone very low and the lower porosity after binding. Because the wherever there is a pore it will get filled up.

The dispersion of the smaller particle size binder particles around the structural particle also helps the binding flow into the gap between the structural particle more efficiently thus resulting in a better binding of structural parts. This is often true when for instance SLS is used to process steel powder with polymer binder. This polymer binders are just left when you heat it this leaves away. And now the steel particles can join each other and try to form a good compact.

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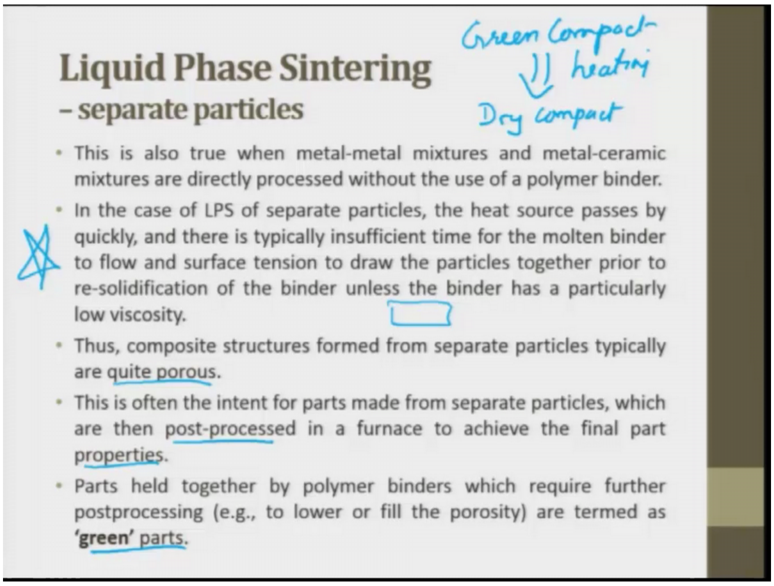

This is also true and metal matrix mixture and the metal ceramic mixture are directly processed without the use of a polymer binder. In this case of LPS of separate particles the heat source passes by quickly. And there is a typical insufficient time for the molten binder to flow and surface tension to draw the particles together prior to re solidification of the binder unless the binder has a particular low viscosity very very important point.

The liquid phase sintering of a separate particle the heat source passes by quickly. There is typically in sufficient time for the molten binder to flow because; it is very small in quantity and the surface tension to draw the particles together prior to re solidification of the binder unless the binder has a particular low viscosity. Thus composite structure formed from separate particles typically are quite porous.

This is often the intend for parts made from separate particles which are then post processes in furnace to achieve the final. So, what we do is we try to have these are called as so we can try to have green compact green compact. And then we can undergo a heat treatment whatever it is or we say dry compact which goes to a dry compact or the final part.

Green compact is where the strength is weak you can break it by hand the shape is given. Or when you put it in real time application this will not be able to be used. So, what we do is, we heat it remove all the binder solidify the binder along the binder to flow do whatever it is and finally, what we get is a green compact. More and more and more liquid are there this liquid shrink and there is a surface tension, it tries to pull there is the shrinkage in the component.

So, these are you can if you understand the basic science you can try to see; how we can modify using laser, and then through RP technique how can you directly go for rapid manufacturing ok. The parts held together by polymer binders which require further post processing are termed as green parts.

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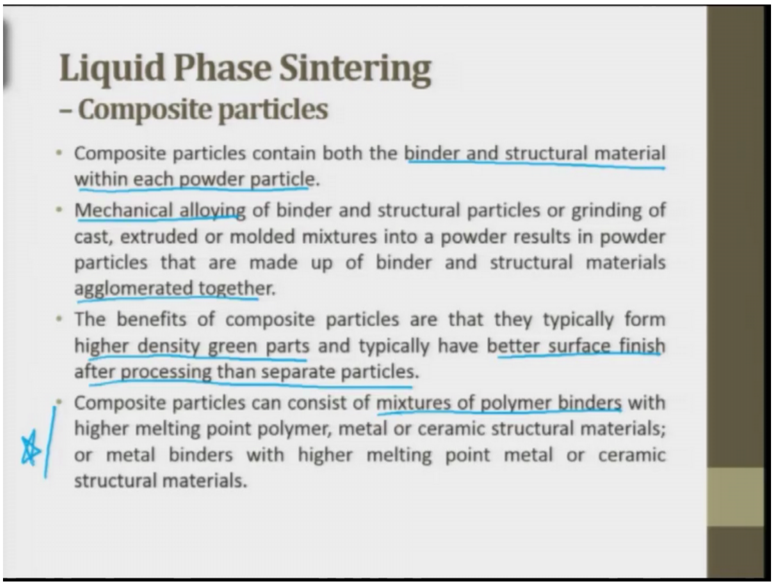

Composite particles the composite particles contain both the binder and the structural material within each powder particle. Composite; let us see the figure composite, so you can see here. Composite b is composite so these are binders, which are inside the particles. Mechanical alloying of binder and structural particles are grinding of caste extruded or molded mixture into a powder results in the powder particles that are made up of binder and structural material agglomeration together.

So, we do mechanical alloying; what is mechanical alloying? See you take you take a powder you take another powder keep heating the other powder. So, slowly slowly the powder can it can form a coat or it can getter inside or something like that. So, we use ball milling ball milling is a process; where typically it is it is nothing, but a mechanical alloying put two different particles put ceramic particles put the metal particle allow it to run.

So, there is an impact mechanically there is a load which is getting applied and because of that there is alloying happening. The other way of alloying is going to be tried to take it to higher temperature heated two particle mix you get an alloying. But here it is only mechanical alloying mechanical alloying of binder and the structural material. It is what I said cobalt and structural particles can be tungsten carbide you can grind it of a grind a grinding of caste.

So, you can mix it together and then break it or you can extrude or you can molded mixture into a powder results in the powder particles. The benefit of composite particles are that they typically form a higher density green part and typically have a better surface finish after processing then separate particles.

The composite particles can consist of mixtures of polymer binders with high melting point polymer metal or ceramic structural materials or metal binders with higher melting point metals or ceramic structural materials. So, this is also important what is that we are doing with each other.

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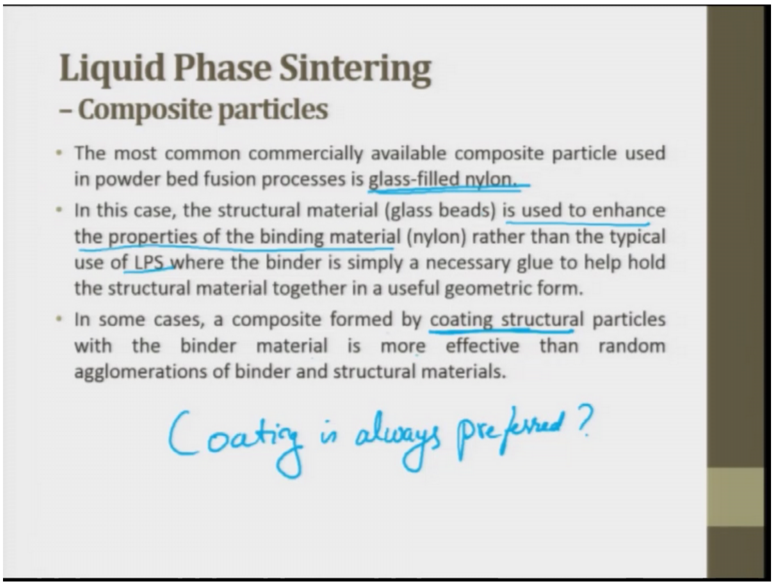

The most common commercially available composite particles used in powder bed fusion process is glass filled nylon. Glass filled nylon in the case the structural material glass beads is used to enhance the property of the binding material nylon rather than the typical use of LPS where the binder is simply and necessary glue to help hold the structural material together in a useful geometric form ok. See this in this case the structural material glass is used to enhance the property of the binding material nylon.

So, nylon is used to enhance the properties of a binding material rather than the typical use of LPS. In some cases a composite formed by coating structural particles with the binder material is more effective than random agglomeration of binder and structural material. Coating is better coating is always preferred always; why is because it will try to give very good properties, whatever strength or other properties.

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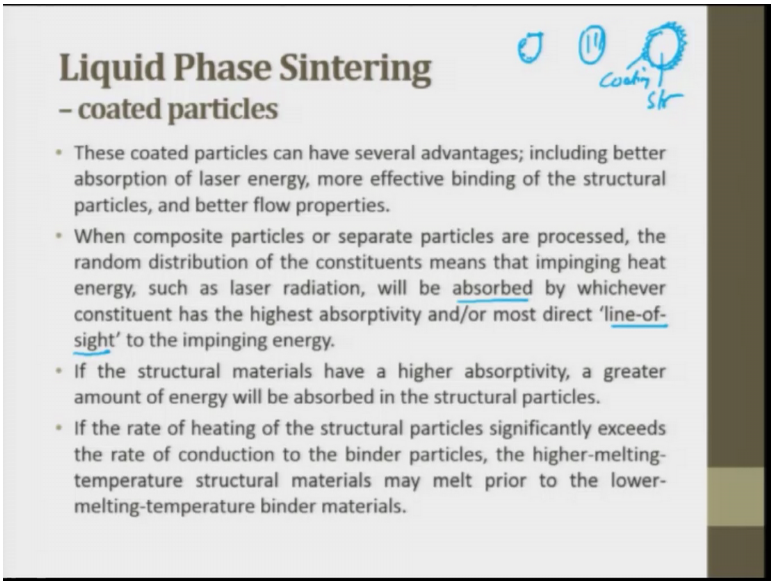

The coating the next phase; so first was you had some particles little little bit here and there then inside the particle you had a binder material. Now the third thing is I am trying to give a coating on top of the powder particles ok. This is the third type of in liquid; how are we preparing the particles for liquid phase sintering these coated particles can have several advantages including better absorption of laser energy because this will can absorb.

See interestingly laser has a property called as absorptivity property. This absorption property is it always depends on the material it is a material dependent property. So, you can have nickel of x percentage absorption copper will not have the same percentage, cobalt can have higher tungsten carbide which is used here need not have anything. So, depending of the of the absorption property of the metal or the particle whatever we use we can use it for the advantage of liquid phase sintering.

So, including better absorption of laser energy more effective binding of structural particles and better flow properties. When composite particles are separate particles are propose processed. The random distribution of the constituent means the impinging heat energy such as laser radiation will be absorbed by whichever constituent has the highest absorvity and most directly line of sight to the impinging energy line of sight is the laser trying to heat at the surface at that surface do we have this material which can absorb more line of sight.

If the structural material have a higher absorvity a greater amount of energy will be absorbed in the structural by the structural material right, that is what I said. It can have varying absorption this is structural this is coating. If the rate of heating of the structural particle significantly exceeds the rate of conduction of the binding particle; the higher melting temperature structural material may melt prior to the lower melting temperature of the binder this same seldom happens. But if you are smart for your application you want tweak you can do this also.

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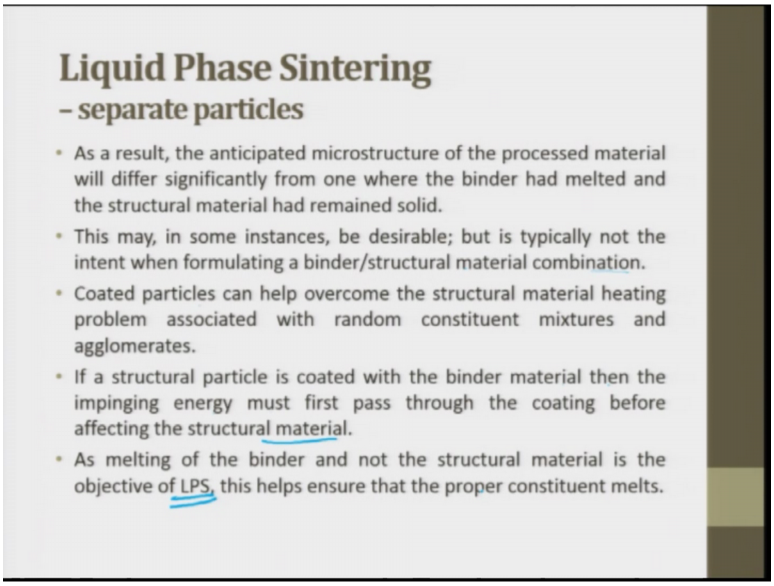

As a result the anticipated microstructure of the processed material will differ significantly; from one where the binder had melted and structural material had reminded solid. Completely different phenomena can happen; this may in some instance be desirable, but it typically not the intent when formulating a binder slash structural material combination. The coated particles can help overcome the structural material heating problem associated with the random constituent mixing and the agglomeration.

If the structural particle is coated with the binder material then the impinging angle must first pass through the coating before affecting the structural material. As melting of the binder and the most structural material is the objective of LPS; this helps to ensure that the proper constituents melting happens.

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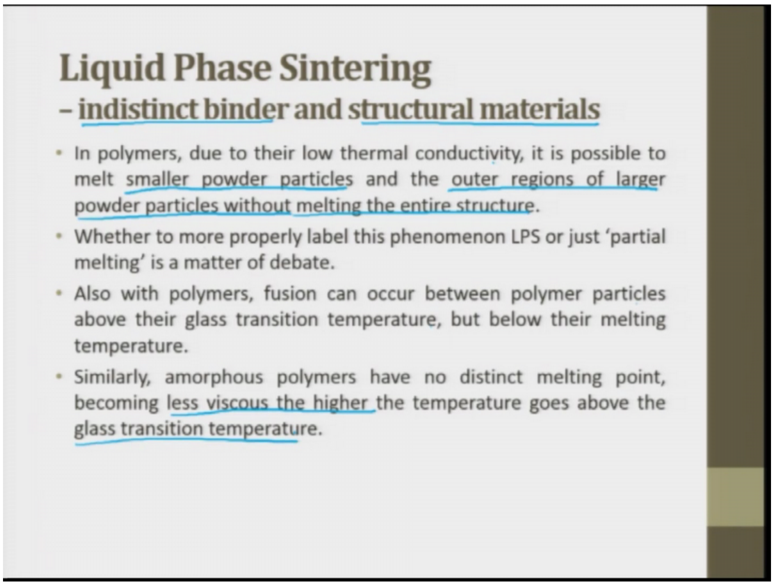

So, the last part of the powder is indistinct binder and structural material. In polymers due to their low thermal conductivity polymers it is possible to melt a smaller powder particles and the outer region of larger powder particles without melting the entire structure. So, sintering; sintering is not melting by the way.

So, in polymers due to their low thermal conductivity it does not absorb heat. It is possible to melt a smaller powder particles and the outer region of larger powder particles without melting the entire structure; smaller powder particles outer region of the larger powder particles without melting the entire structure is nothing, but distinct binder and structural material.

Whether to more properly label this phenomena of LPS or just partial melting is a matter of debate. Also with polymers fusion can occur between the polymer particle above the glass transition temperature, but below their melting temperature. Polymer you have solid state then glass transition temperature and then you go to the liquid state. Similarly amorphous polymer have no distinct melting point becoming less viscous the higher the temperature goes above the glass transition temperature.

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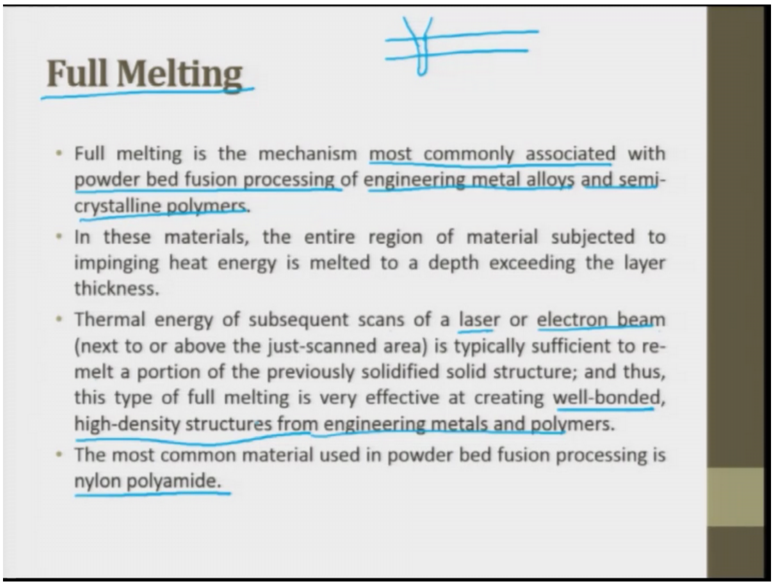

The last one is full melting; full melting is the mechanism most commonly associated with powder bed fusion process of engineering metal alloys and semi crystalline polymers. Most commonly associated with the powder bed fusion processing of engineering metal alloys and semi crystalline polymers.

In this material the entire region of material subjected to impinging heat energy is melted to a depth exceeding the layer thickness. The thermal energy of subsequent scan of the laser or electron beam is typically sufficient to re melt a portion of the previously solidified solid structure. And thus this type of full melting is very effective at creating well bonded high density structures for engineering melts engineering metals and polymers.

The most common material used in powder bed fusion processing is nylon polyamide, where in which we try to the entire region of the material subjected to the impinging heat energy is melted to a depth exceeding the layer thickness. So, if your layer thickness is this so now, the laser heats so the heat goes up to here.

So, what will happen you will have better stitching of layers. So, if it is a better stitching of layers delamination will be very less. So, the thermal energy of the subsequent scan of a laser or a electron beam. So, you can use electron today we are using electron beam, but the only advantage of laser is, it can be used even in vacuum or non vacuum system.

But electron beam pushes you to use in a vacuum system. It is typically sufficient to re melt a portion of a previously solidified solid structure. And thus this type of full melting is very efficient at creating well bounded high density structures for engineering metals and polymers.

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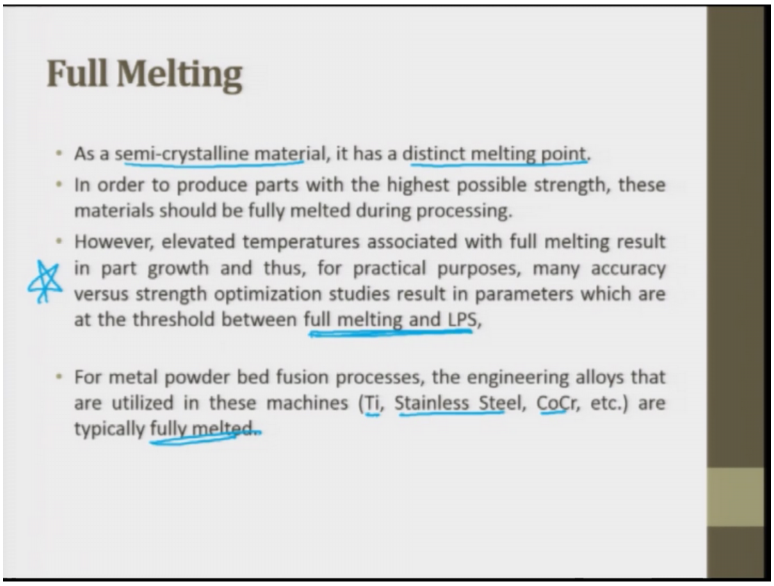

As a semi crystalline material it has a distinct melting point. Crystalline materials it have a distinct melting point amorphous material do not have semi crystalline has somewhere in between. In order to produce parts with the highest possible strength this material should be fully melted during the processing.

However, elevated temperature associated with full melting results in part growth and thus for practical purposes many accurate versus strength you just optimization studies result in parameters which are at the threshold between full melting and LPS. So, this is very very important this portion.

The metal powder bed fusion process the engineering alloys that are utilized in these machines are Ti, stainless steel, cobalt, chromium, etcetera are typically full melted. Full melted is, it is just above sintering temperature; just keep melting the complete powder rather than sintering you just go slightly higher temperature you are. And sometimes if you want you can use a very high energy for doing it.

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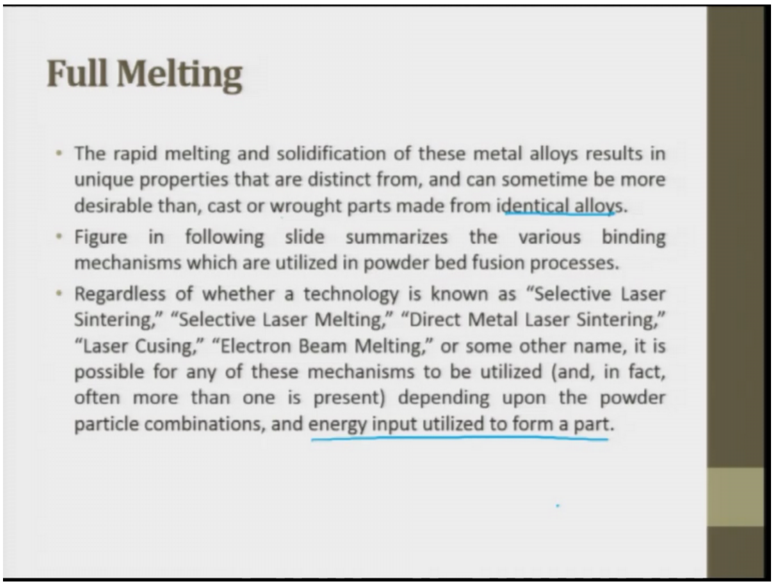

The rapid melting and solidification of these metal alloys results in unique properties that are distinct from and can sometimes be more desirable than caste or wrought parts made from the identical alloys. In the next slide we will saw the summary; the various binding mechanism which are utilized in powder bed fusion process.

Regardless of whether your technology is known as; selective laser sintering, selective laser melting, direct metal laser sintering, laser cussing, electron beam melting or some other name. It is possible for any of these mechanisms to be utilized depending on the powder particle combination and energy input utilize to form a part.

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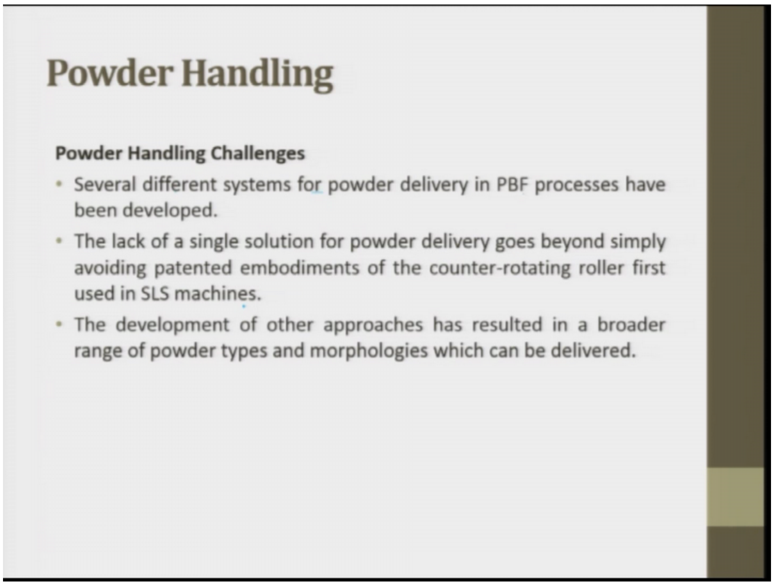

Powder handling challenges these powders are not so easy to handle. Several different systems of powder delivery in powder bed fusion processes have been developed. The lack of single solution for powder delivery goes beyond simply avoiding patented embodiments of the counter rotating roller first used in SLS machine. The development of other approaches has resulted in a broader range of powder type and morphologies which can be delivered.

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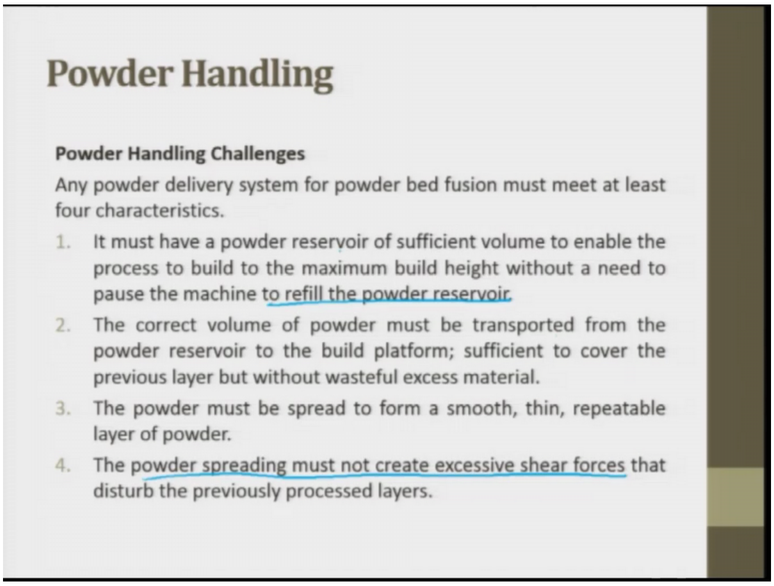

Any powder delivery system for powder bed fusion must meet at least four characteristics. It must have a powder reservoir of sufficient volume to enable the process to build to the maximum build height without a need to pause the machine to refill the powder reservoir. So, this is this is one thing which you have in between you cannot stop. If you stop it refill it and restart it then there will be a delamination.

The correct volume of the powder must be transported from the powder reservoir to the built platform; sufficient to cover the previous layer, but without wasteful excess material. The powder must be spread to form a smooth thin repeatable layer of powder. Powder spreading must not create excessive shear force that disturbs the previous process layer.

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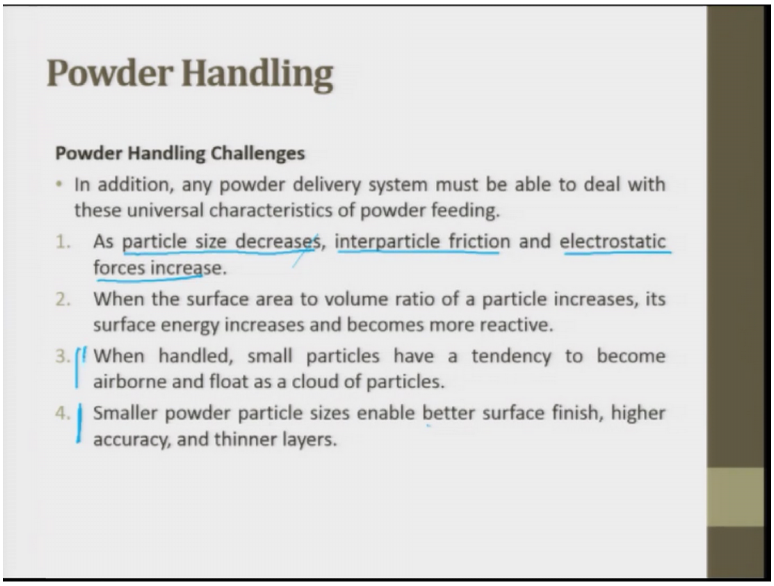

In addition any powder delivery system must be able to deal with these universal characteristics of powder feeding. As particle size decreases inter particle friction and electrostatic forces increases. So, that is why you have agglomeration particle size decreases inter particle friction and electrostatic force increases when the surface area to volume ratio of the particle increases.

When surface area increases nano size, it is surface energy increases and becomes more reactive if the surface area increases the surface energy increases. When handling small particles have a tendency to become air bond and float as a cloud of particles so we should be careful smaller powder particle size enables better surface finish higher accuracy and thinner layer. This is an advantage this is a careful health hazardous thing which you have to make sure.

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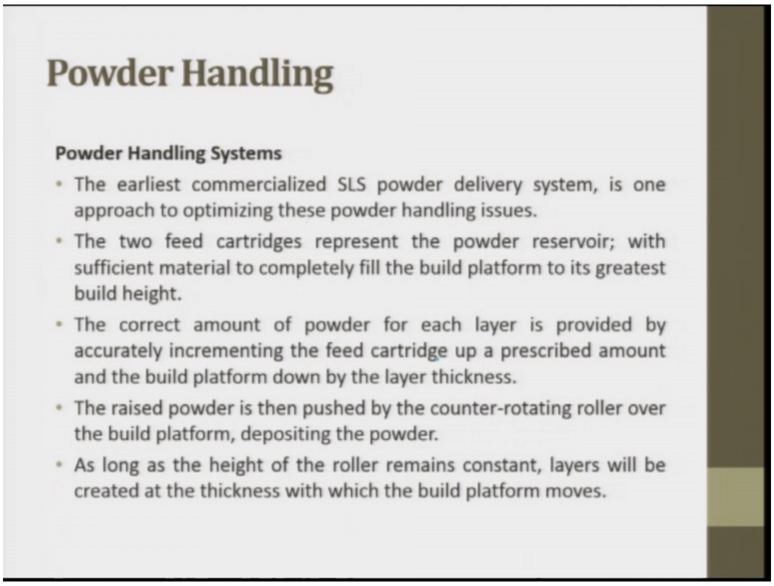

The earliest commercial commercialized SLS powder delivery system is one approach to optimize this powder handling issues; to feed cartridge presents the powder reservoir with sufficient material to completely fill the build platform to it is greatest build height so it was taken care.

The correct amount of powder for each layer is provided by the accurate incrementing the feed cartridge up a prescribed amount and the building platform down by the layer thickness. The raised powder is then pushed by the counter rotating roller over the built platform depositing the powder. As long as the height of the roller remains constant layer will be created at the thickness with which the build platform moves.

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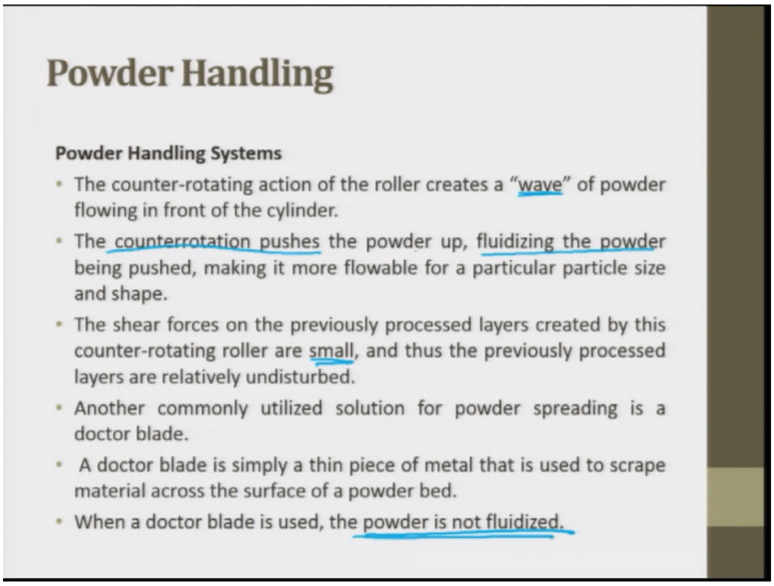

The counter rotating action of the roller creates a wave, wavy of the powder flowing in front of the cylinder. So, this wave has to be made flatten because when the next layer laser curing is happening or laser sintering is happening this undulation on the surface reflects it so we have to be very careful.

The counter rotating pushes the powder up fluidizing the powder by pushing making it more flow able for a particular a particle size and shape the counter rotating pushes ok. The shear force on the previously process layer created by this counter rotating roller are small and thus the previously processed layer are relatively undisturbed.

Another commonly utilized solution for powder spreading is a doctors blade which we saw in the previous discussion also. A doctor blade is simply a thin piece of metal that is used to scrape material across the surface of a powder bed. When the doctor's blade is used the powder is not fluidized it was just moved. So, fluidizing the powder by pushing making it more flow able for a so fluidized bed is you used pressure also to move.

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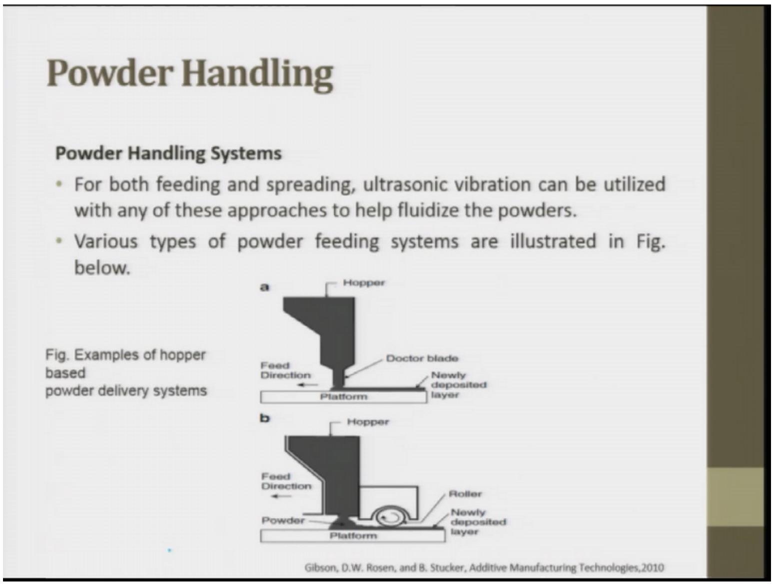

So, example of hopper based powder delivery systems you can use it. So, the for both feeding and spreading feeding and spreading ultrasonic vibration can be utilized with any of these approaches to help fluidizing the bed.

So, hopper you have a feed direction this is a doctors blade and newly deposited layer uniform thickness comes ok. If you look at b you can also put rather than doctors blade you can also put a roller and make sure it is flat so this is also there. So, both tries to give you single layer of information the various types of powder feeding are illustrated here.

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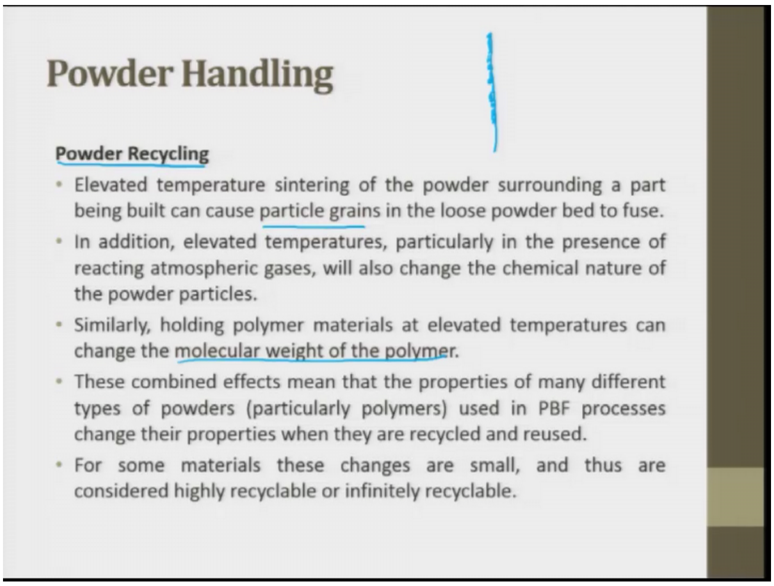

Powder recycling which is one of the biggest things. So, moment you use powder for putting it in the development chamber or in the developing table the two sides the cartridges will have the fresh powder and in the centre what we do is the fresh powder is spread and it is cured.

After the part is made the powder in the centre table in the development table product development table has to be removed. So, elevated temperature sintering of the powder surrounding a part being built can cause particle grains in the loosen powder bed to fuse. So, in addition so this powder has to be supped and recycled in addition elevated temperatures particularly in the presence of reacting atmospheric gases will always change the chemical nature of the powder so we have to be very careful.

Along the part, part layer you will have these powders these powders there is a thermal gradient. So, next to the layer whatever is getting from there will be a melting happening and sticking to it. In addition elevated temperatures particularly in the presence of reacting atmospheric gases will also change the chemical nature of the powder particles.

Similarly, holding polymer materials at elevated temperatures also changes the molecular weight of the polymer. What is a polymer? Polymer either you can use it as a base material or you can use it as a binder. These combined effect means that the property of many different types of powders used PBF process changes their property when they are recycled and reused. For some material these changes are small, but in some material there are huge difference in properties.

Thank you very much.