Rapid Manufacturing

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Lecture - 33
Post-processing Concerns (Part 1 of 2)

Good morning. Welcome back to the course on Rapid Manufacturing, I have discussed rapid manufacturing materials in the previous lecture. And as I said, I will discuss Post-processing Concerns in this lecture.

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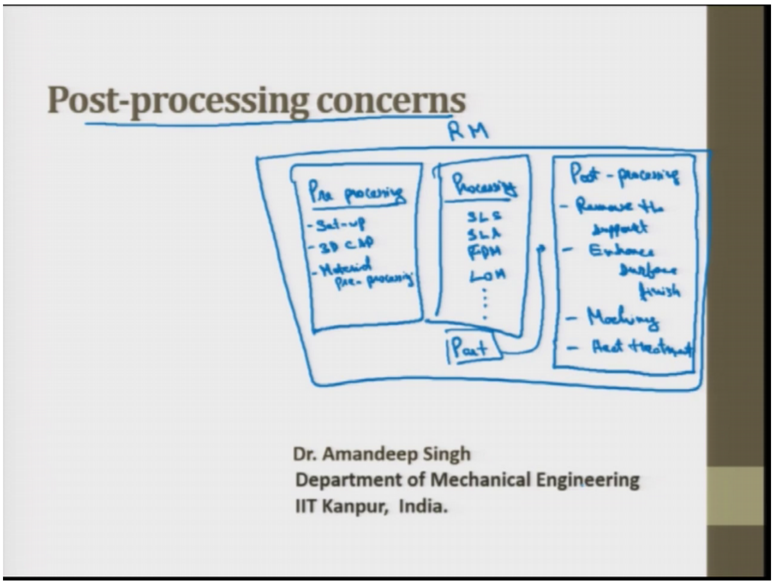

Post processing concerns as I said, we have preprocessing and post processing. Processing are all the techniques that you have seen in the previous lecture, this is rapid manufacturing. Preprocessing is something where we setup the equipment, we make a setup then we have 3D CAD model ok. Then we do some material processing if required material preprocessing are called ok, we generate layer and contoured data and set up the operators. All these are the steps that we follow in preprocessing. In processing, we have different processing SLS, SLA then FDM LOM and so on.

In post processing what happens, now we are concerned with the applicability of the parts that is made here, to get a part ok. We get a part here that is now taken here and we remove the support material or we enhance surface finish or we do certain machining or heat treatment to get the desired product with the accuracy and the properties that we need in the final applications.

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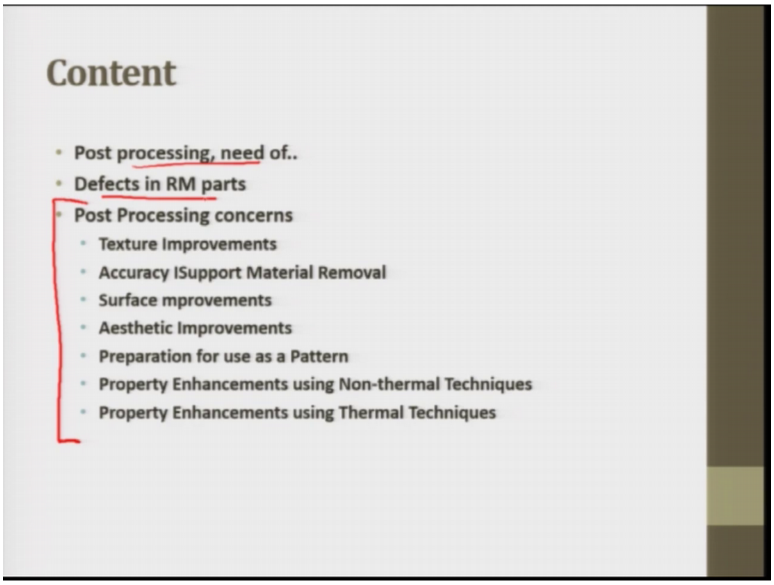

So, before discussing about the post processing concerns we will discuss what is the need of post processing and defects in the rapid manufacturing parts.

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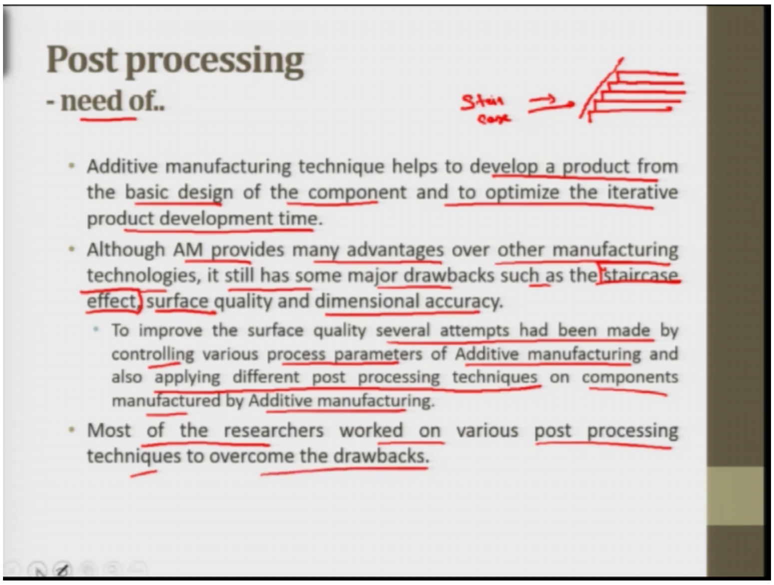

Now, post processing need of additive; manufacturing techniques helps to develop a product from the basic design of the component and to optimize the iterative product development time. Although additive manufacturing provides many advantages over the other manufacturing technologies, it is still has some major drawbacks such as staircase effect this is important. What is staircase effect? Staircase effect is because we are putting a layer on layer ok, it looks like a staircase. So, this is staircase so it does not have a good surface finish here. So, this staircase effect because of layers is there then surface quality and dimensional accuracy are not as good as desired in some of the materials.

So, we need to do some processing after getting the part, to improve the surface qualities several attempts had been made by controlling various process parameters of additive manufacturing and also applying different post processing techniques on components manufactured by additive manufacturing. Most of the researchers worked on various post processing techniques to overcome the drawbacks.

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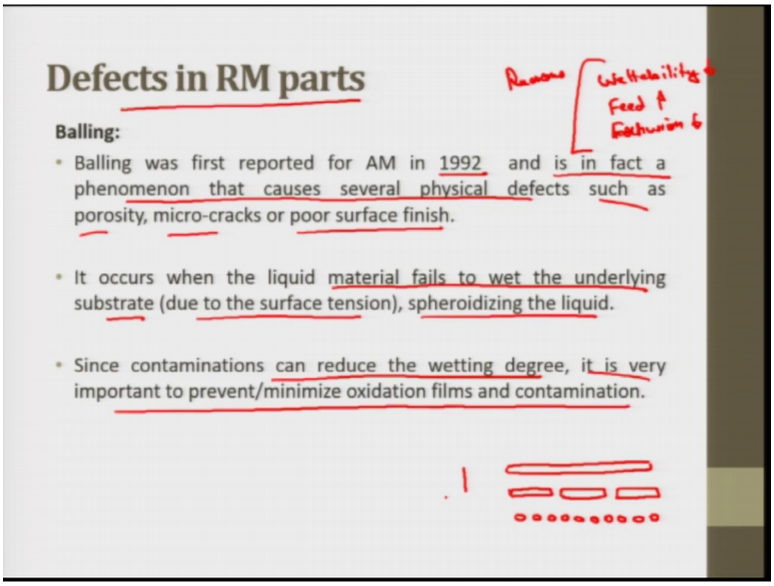

Defects in rapid manufacturing parts first defect is balling. What is balling? Balling was first reported in additive manufacturing 1992 and it is in fact, phenomenon that causes several physical defects such as porosity, micro cracks, poor surface finish. So, it acts as an initiator of multiple defects that was happened. What is balling? Actually material when it is coming in the liquid form that has to flow continuously the flow has to be like this, materials flowing like this something had some what happens the speed of the ejection of the material from the nozzle is lower and the speed is higher. So, nozzle is moving faster, what happens? This has some breaks in between ok. So, this can even be something like this material is making drops like this. So, this is known as balling.

So, it occurs when the liquid materials fails to wet the underlying substrate due to surface tension, spherodizing the liquid so this is also one of the reason. If wetting is not good, it is not able to wet. If the wettability of the material is lower, then also balling is there. So, this is due to wettability ok, low wettability or high feed or low extrusion these are the reasons for balling.

Since contaminations can reduce the wetting degree. It is very important to prevent or minimize oxidation fields and contamination. So, this balling results in a rough and a bead shapes can track that is more prominent in laser fusion process, laser bed fusion process increasing the surface roughness and a also increasing porosity.

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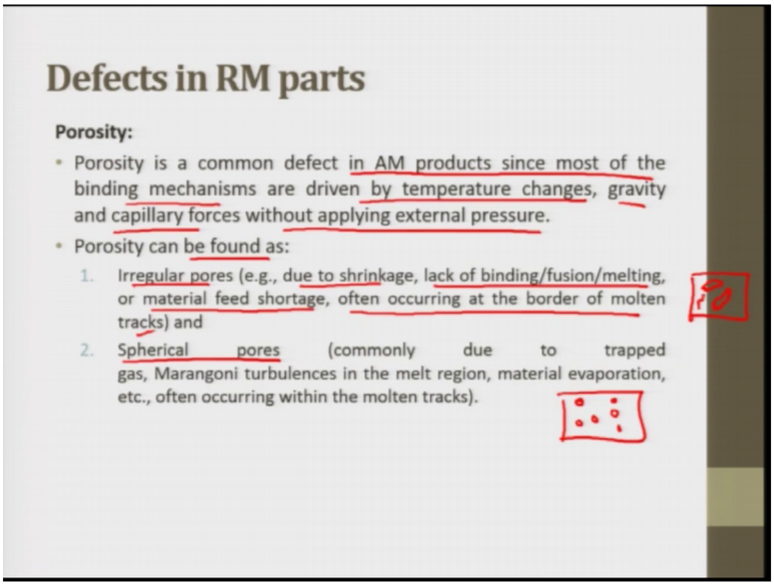

Next defect is porosity; porosity is a common defect in additive manufacturing products since more of most of the binding mechanism are driven by temperature changes, gravity and capillary forces without applying external pressure. Porosity can be found as irregular pores and spherical pores, irregular pores due to shrinkage lack of binding fusion or melting or material feed shortage.

Then often occurring at the border of the molten tracks, spherical pores are due to the trapped gas and marangoni turbulences in the melt drain material evaporation etcetera are often occurring within the molten tracks. So, this is kind of instance this is the material and this is these are kind of spherical pores. Irregular pores can be something like this; a pore is there it is irregular in shape.

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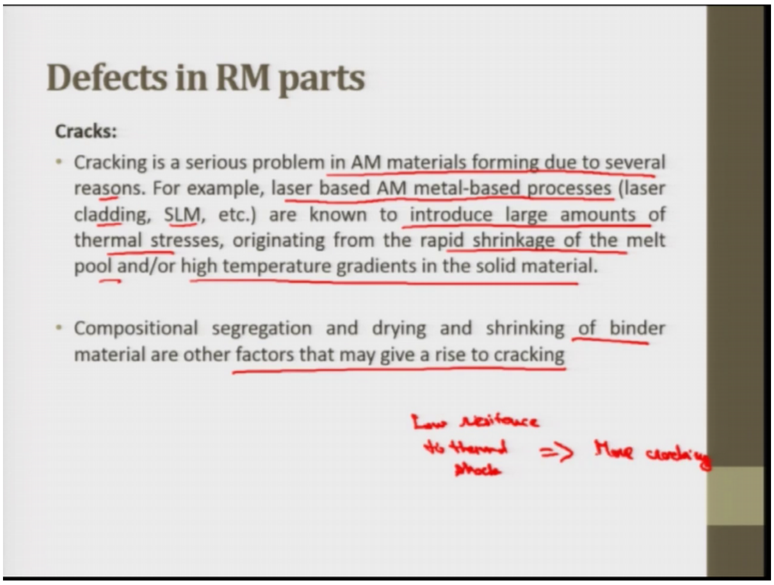

Next is cracks; cracking is a serious problem in additive manufacturing materials forming due to several reasons. For example, laser based additive manufacturing metal based processes that is laser cladding and SLM etcetera are known to induce large amounts of thermal stresses originating from the rapid shrinkage of the melt pool and high temperature gradients in the solid material. A compositional segregation and drying and shrinking of binder material are other factors that may give rise to cracking, to thermal shocks implies more cracking this is one of the defects.

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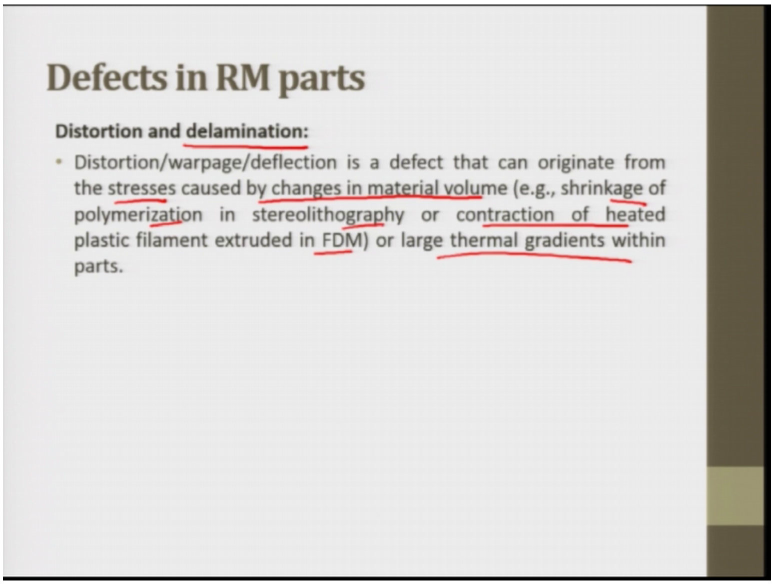

Then is distortion and delamination, distortion, warpage, deflection is a defect that can originate from the stresses caused by changes in material volume. For example, shrinkage of polymerization in stereolithography or contraction of heated plastic filament extruded in FDM or large thermal gradients within the parts. In extreme cases, this deflection can emulate to delamination. This delamination can also due to deflection which is put as it defect here. So, this depends upon the material characteristics processing parameters and approaches.

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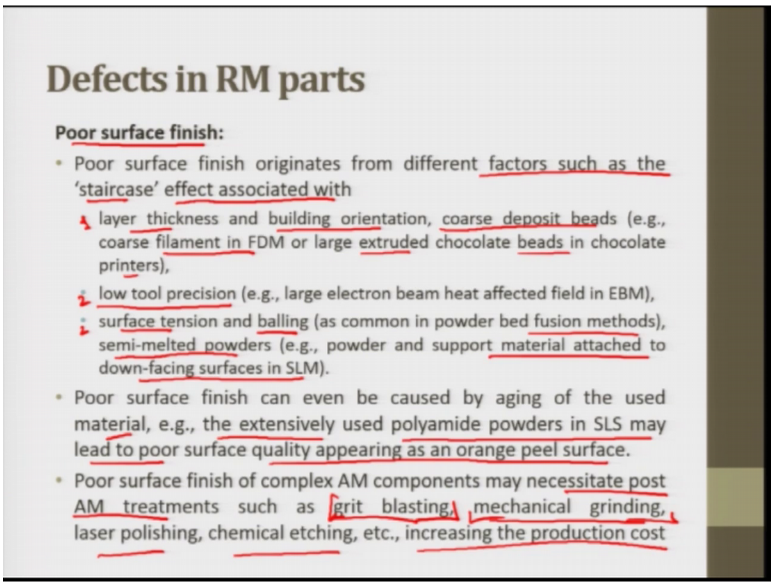

Next as a defect also we can say poor surface finish; poor surface finish originates from the different factors such as staircase effect as I explained which is associated with layer thickness and building orientation course deposit beads. For example, course filament in FDM or large extruded chocolate beads in chocolate printers.

Then second reason for this is low tool precision, 1 2. It is large electron beam heat affected field in EBM, third reason for poor surface finish is surface tension and balling. As common in powder bed fusion methods, semi melted powders. For example, powder and support material attached to the down facing in SLM.

Now, poor surface finish can even be caused by aging of the used material. The extensively used polyamide powder in SLS may lead to poor surface quality appearing as an orange peel surface. Although surface roughness can be improved using a smaller deposit bead and reduced layer thickness this practice may reduce the production rate. Now poor surface finish of complex additive manufacturing components may necessitate post additive manufacturing treatments which we will discuss in this lecture such as grid blasting, mechanical grinding, laser polishing, chemical etching etcetera increasing the production cost. So, these are the techniques to improve the surface finish.

So, there certain techniques to improve the surface finish and more and more techniques are being developed or are being used in rapid manufacturing these days, but we cannot discus all these kinds of techniques in a single lecture. But definitely, we will discuss the prominent techniques which are used and the techniques like chemical etching and laser polishing those could be there, but those are not discussed in this lecture. So, there certain techniques which are being developed these days by various laboratories to improve the surface finish in the post processing step of rapid manufacturing.

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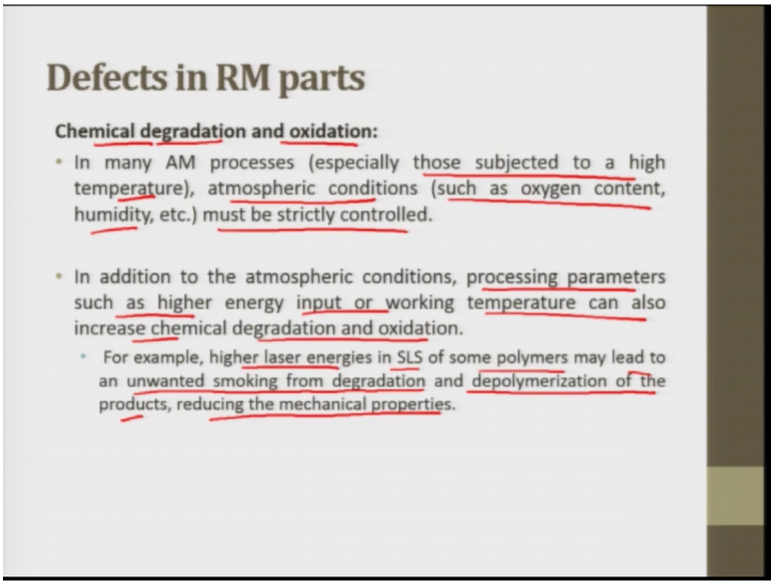

Next defect is chemical degradation and oxidation. In many additive manufacturing processes especially those subjected to a high temperature atmospheric conditions such as oxygen content, humidity etcetera must be strictly controlled. So, this is required to prevent or minimize degradation and oxidation.

So, degradation or oxidation may lead to depolymerization in additive manufacturing of polymers like polymerization happens, depolymerization could also happen that can have the physical or mechanical properties of the materials. So, this is important to be controlled. In addition to atmospheric conditions, processing parameters such as higher energy input or working temperature can also increase chemical degradation and oxidation.

For example higher laser energies in SLS of some polymers may lead to an unwanted smoking from degradation and depolymerization of the products reducing the mechanical properties. So, these are the common defects which are there in rapid manufacturing parts.

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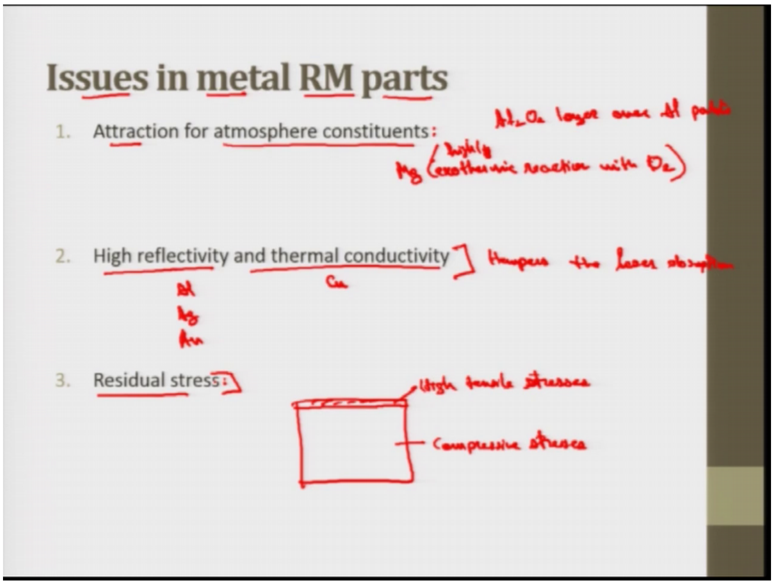

There are certain issues or challenges those come in specifically in metal rapid manufacturing parts. Number 1 is attraction for the atmospheric constituents, number 2 is high reflectivity and thermal conductivity, number 3 is residual stresses.

Now, attraction for atmospheric constituents, what happens in powder particles such as aluminuim or aluminuim alloys? They have a constants aluminuim oxide layer over aluminuim parts. Now what does this do? They enter the particles sintering or melt amalgamation. So, this has an adverse effect in electron beam melting specifically with a powdered bed needs to be presintered slightly bind the powder particles together before melting them. So, this needs to be avoided. So, this is the affinity to the atmospheric constituents, for instance oxidation is happening here so, in the case of materials for which reaction with oxygen is very exothermic. For example, magnesium exothermic reaction with oxygen or I could put highly exothermic.

What happens in this cases when the reaction is very exothermic it may be hazardous, it may be dangerous; if not carried out in an oxygen free atmosphere. So, the operators can also be hot with that is. So, these attractions or affinity to atmospheric constituents are important to be considered to be taken into account when we design the processing technique. So, this is one of the issue in metal rapid manufacturing parts.

Second is high reflectivity and thermal conductivity: high reflectivity we showed you in the laboratory demonstration on 3D scanning where aluminuim was highly reflective and it did not reflect back the laser that was to be taken by the reflector of the equipment. So, this high reflectivity and thermal conductivity both can be the challenges. Creating an effective melt pool is difficult for alloys that have high reflectivity this metals for instance aluminuim, silver, gold. This have high level of reflectivity high thermal conductivities also associated with them and this one copper is having high thermal conductivity.

So, this the high power lasers up to 1 kilowatt have been used to process these materials along with different wavelengths to increase the laser absorption, because they hampers the laser absorption. In this it is scanning case, we needed to get the signal back in we this case in manufacturing we needed the laser to be observed to transfer the laser energy to heat energy and to melt the material or to rise the temperature of the material to get it bonded with the other layer.

Residual stresses is the next concern in rapid manufacturing parts. In general, rapid manufacturing residual stresses distributions feature high tensile stresses at outer surfaces which are balanced by a large zone of compressive stresses in the center. So, at surface, we have high tensile stresses and we have compressive stresses here.

Now, here stress gradients also develop in the build direction depending upon the part geometry height and (Refer Time: 17:41) method to the base plate. So, does this quantification of residual stresses is also necessary and researchers are working on them to mitigate this defect, while deformations due to residual stresses is the general phenomena the occurrence of cracks and types of cracks are material dependent. So, this residual stresses can also lead to micro cracks, may be grain boundaries then embrittlement crack ignitions and sites are there at the high residual stresses point. So, this is also to be countered.

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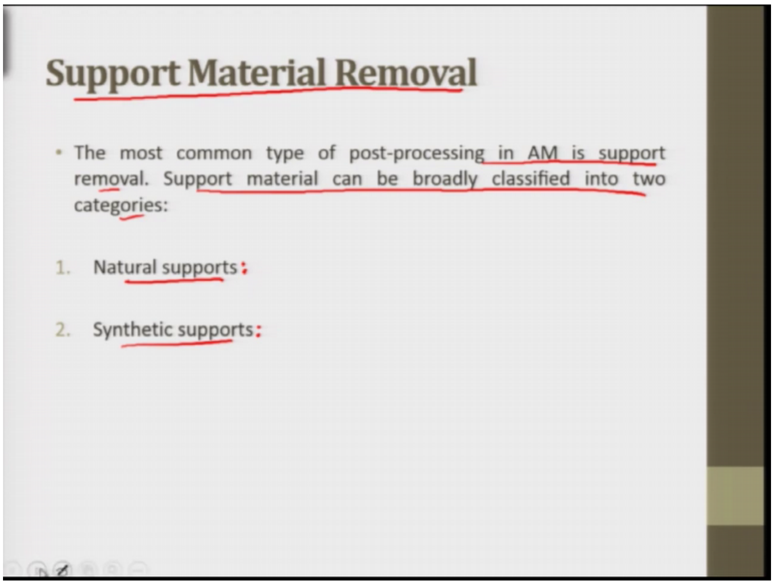

Next comes the post processing concerns; first concern is support material removal. The most common type of post processing and editing manufacturing is support material removal; support material removal can be broadly classified into two categories natural support and synthetic supports. Natural support is the material that surrounds the part, that is the surrounds a parts naturally because of the part will. And synthetic supports is the material that is designed to build the support, that is specifically put in to build the support and both is supports are to be removed.

Now, natural supports and synthetic supports are there which are to be removed. So, synthetic supports are those which restrain or they are attached to the part being built, to build a platform for them natural supports are those which are naturally occurring by the product built process. So, both these are to be countered.

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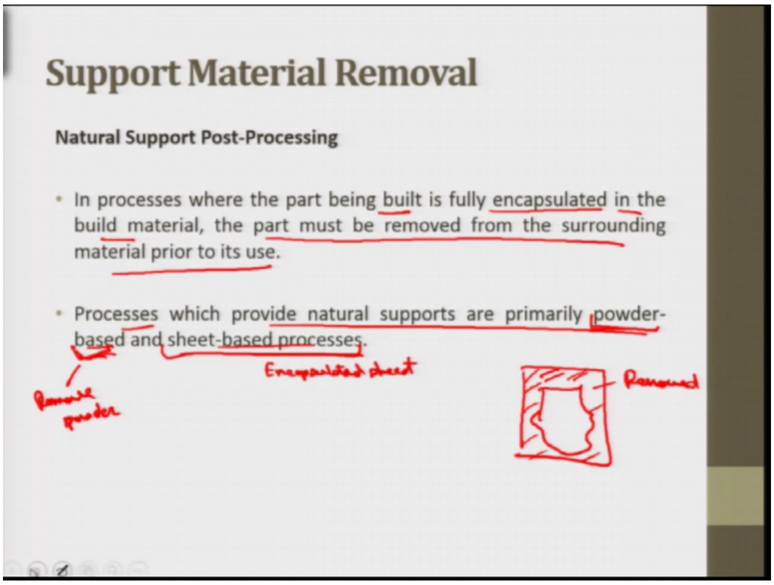

Now, natural support post processing in processes where the part is being built this fully encapsulated in the build material the part must be removed from the surrounding material prior to its use. The processes which provide natural supports are primarily powder based and sheet based processes.

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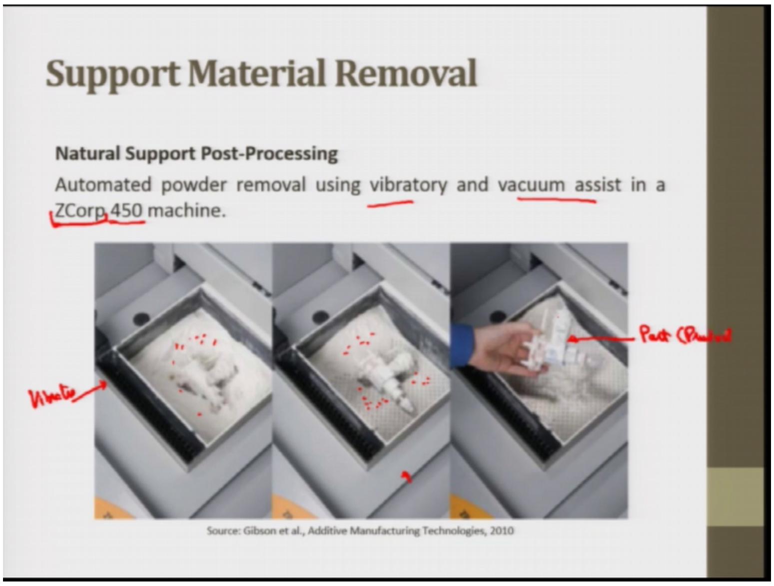

So, this powder this powder that is shown in this figure is a natural support. So, this is are mostly the powder based and sheet based as I said the material that is surrounding the build or the part that is being manufactured. So, this natural support in powder bed fusion and binder printing process it is required to remove the part from the loose powder surrounding the part and then form the sheet metal lamination process require removal of encapsulated sheet material.

So, in powder processes powder based and sheet based, here we need to remove powder and in this case we need to remove the encapsulated sheet. This is the sheet this is the part that is cut from it this material has to be removed.

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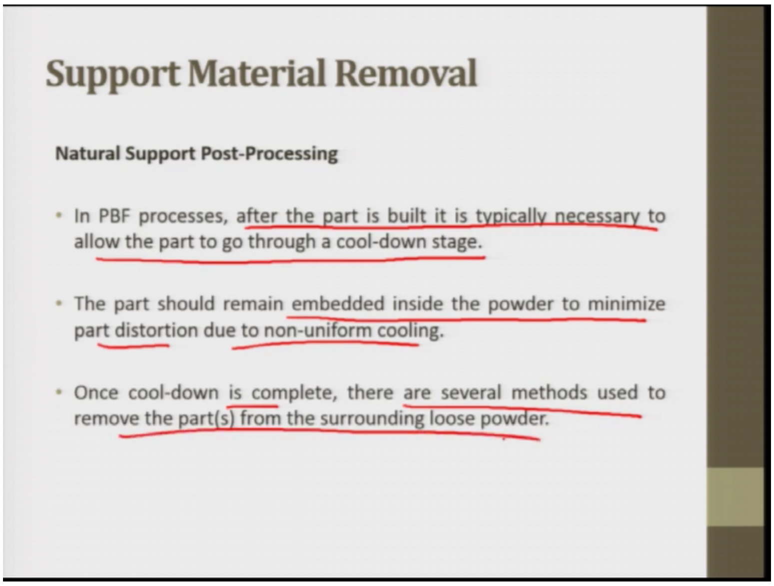

Now, in powder bed fusion process after the part is built it is typically necessary to allow the part to go through the cool down stage. The part should remain embedded inside the powder to minimize part distortion due to the non-uniform cooling the cool down time is dependent upon the built material and the size of the other parts. Once cool down is complete there are several methods used to remove the parts from surrounding loose powder.

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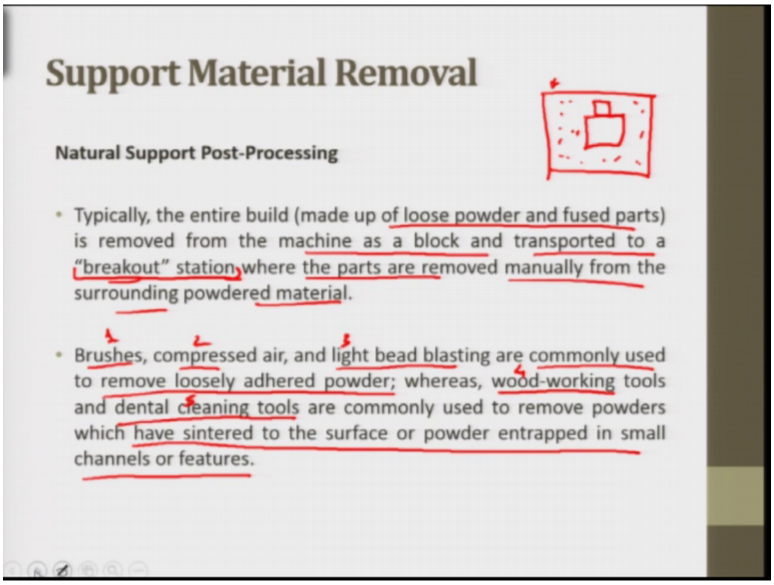

These methods can be all different they can be vibratory methods or the manual powder removal. So, typically entire built made up of loose powder fused parts is removed from the machine as the block and transport it to a break out station with the parts are removed manually from the surrounding powdered material. So, what happens this is this complete box, let me say this bottle is manufactured here this complete part is taken to the breakout station where they will remove this powder ok.

Now, brushes compressed air, light bead blasting are commonly used to remove loosely adult powder; 1 2 3 whereas, for powder that is not very loose woodworking tools and dental cleaning tools are commonly used. 4 and 5, 1 2 3 are for loosely added powder and 4 and 5 are for the powders that is not very loose. So, this powders which have sintered to the surface or powder entrapped in small channels or features these are removed by woodworking and dental cleaning tools. The internal cavities and hollow spaces can be difficult to clean and may require significant post processing time, even if we use these tools.

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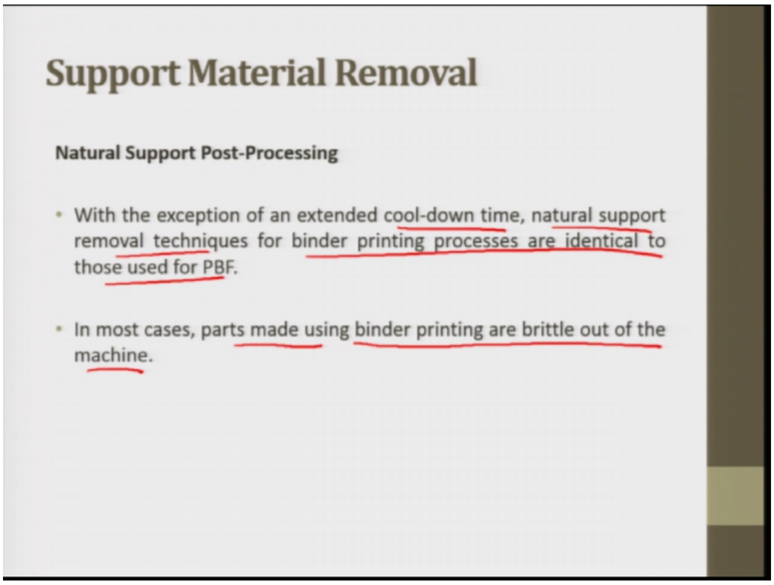

Now, with exception of an extended cool down time natural support removal technique for binder printing processer are identical to those used in powder bed fusion. In most cases parts made using binder printing are brittle out of the machine. Thus until the parts has been strengthened by infiltration. The parts must be handled with care because they are brittle.

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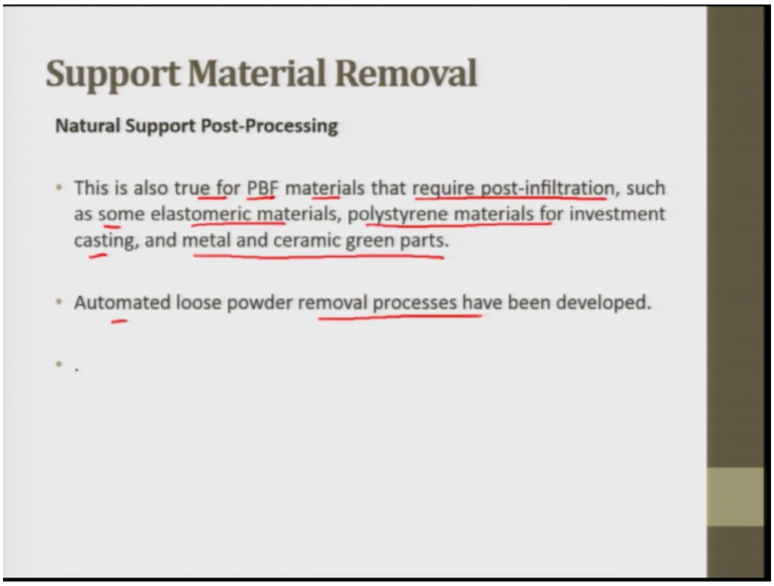

So this is also true for powder bed fusion material that required post infiltration such as some elastomeric materials polystyrene materials for investment casting and metal and ceramic green parts.

Automated loose powder removal processes have been developed. Now what are these processes these are standalone apprentices which are integrated into build chamber. Now this is one of the operators is that is developed by ZCorp manufacturers it is ZCorp 450 machine. It has a vibratory and vacuum assisted powder removal. Now when this vibrates this table vibrates and these pores are there that helps to remove the material and this is a vacuum down the table that takes this material this powder off and this is the build that is taken away part or I can even say product of this processing.

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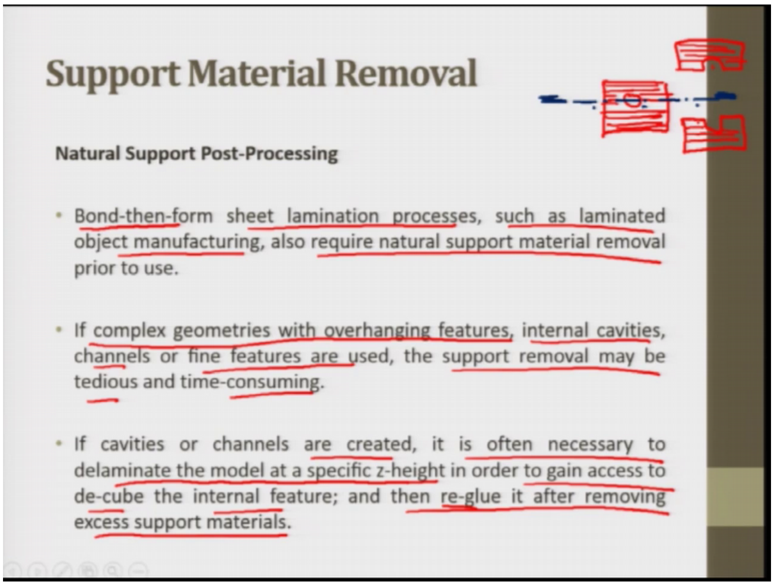

Now, then also bond then form sheet lamination processes such as laminated object manufacturing also require natural support material remover. If complex geometries with overhanging features internal cavities, channels and fine features are used the support material may be tedious and time consuming. If cavities or channels are created it is often necessary to delaminate the model at a specific z height in order to gain access to de cube the internal feature and then re-glue it after removing the excess support material.

So, what the point I am telling to make here is that, if there is some cavity that was for this is the component that is to be made and we have a cavity here and these are different sheets, they are different sheets these are different layers which are making this cavity. Now when these cavities encapsulated in between the layers can be removed, it can be taken off then this material can be taken removed and then that can be glue together that is they are telling re-glue.

So, I am putting the cutting plane here at the center of the cavity from here material can be taken off, sheets can be taken off and it will make two phases like this. And then this can be glued after material this material is taken off from this center. So, an example of de cubing operation of laminated additive manufacturing can be seen here.

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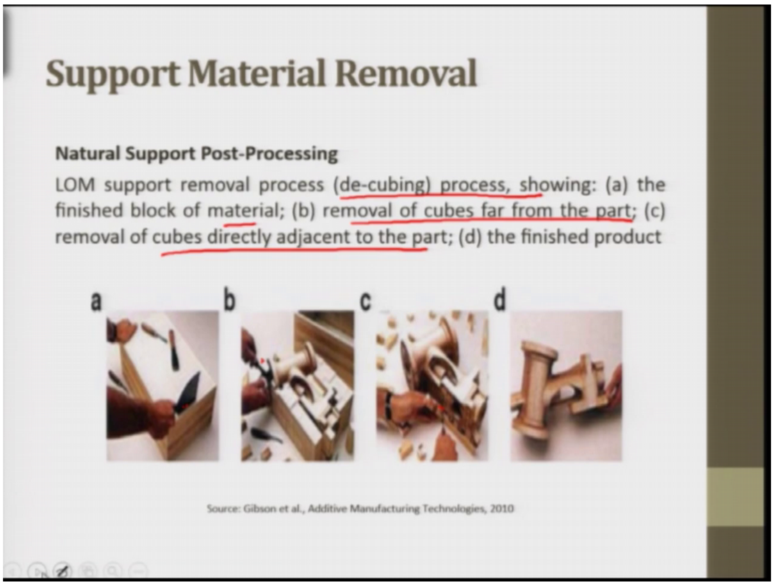

You can see the laminated object manufacturing support removal process that is de cubing process showing the finished block of material, then second part is b part is removal of the cubes far from the part this is the cube far from the part b a being removed. And these are the cube which are close to the part just adjacent to the part that is part c, then the finished product is taken. So, this is natural support post processing.

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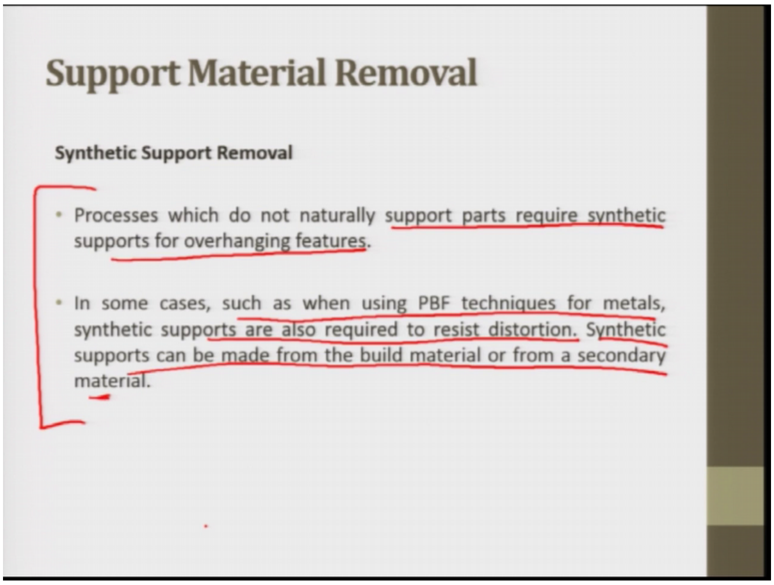

Next is synthetic support material removal, the processes which do not naturally support pass required synthetic support for overhanging features. In some cases such as when using powdered bed fusion techniques for metals synthetic supports are also required to resist distortion. Synthetic support can be made from build material or from a secondary material.

The development of secondary support materials was a key step in simplifying the removal of synthetic supports. These materials are either weaker or they are soluble in liquid solution or they melt at a lower temperature in the build like the material PVA which I discussed in the last lecture. So, they can be taken off, these are synthetic supports. So, they are easy to remove then the natural materials I could say.

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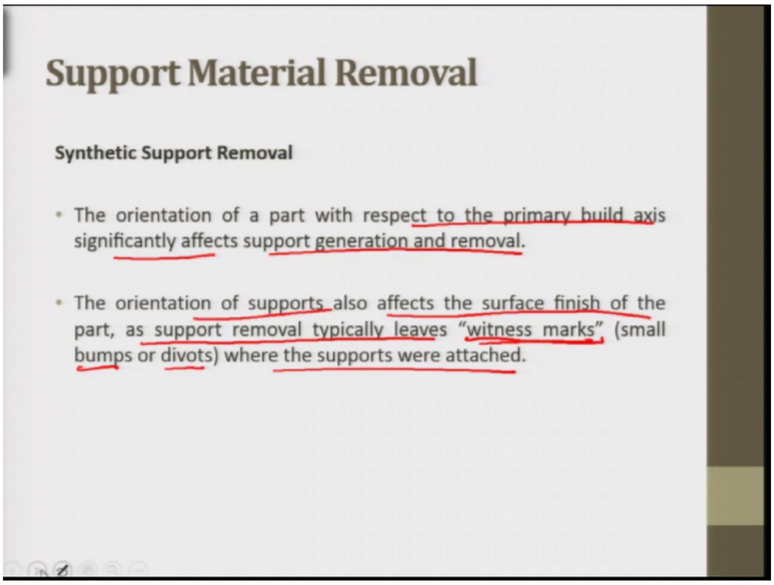

The orientation of a part with respect to the primary build axis significantly affects support generation and removal. Orientation of supports also effect the surface finish of the part as support removal typically leaves the witness marks that is small bumps or divots where the supports were attached. So, this is the build material this is supports material it is attached here it will leave some mark here. So, this witness marks that is small bumps and divots these can be there. So, these need to be countered. Now, if a thin part is laid flat for example, the amount of support material consumed may be significantly exceed the amount of build material.

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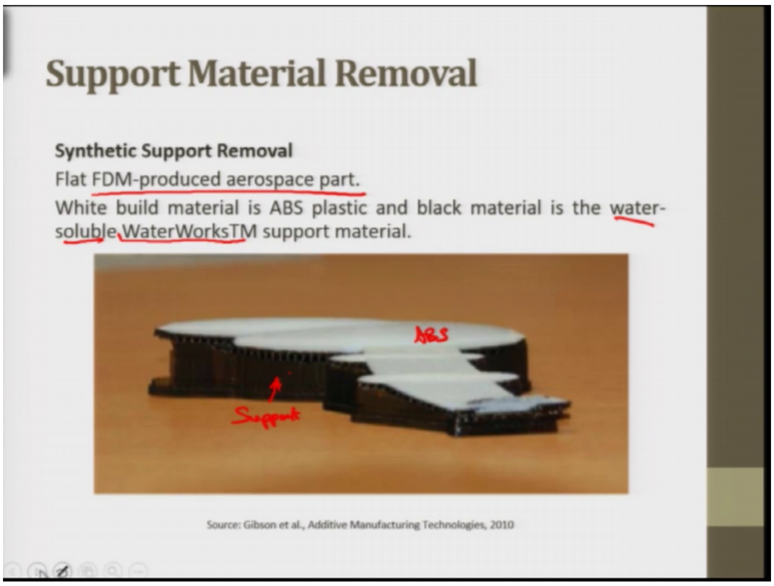

This can be the example for that the flat FDM produced aerospace part this white material is the ABS plastic, this is ABS and this is support ok, that is water soluble. This is a figure from water works, this can be removed, but you can see the part ABS component that is manufactured for the aerospace applications is too thin and the support material is too bulky here. So, this can also be the case sometimes. So, with this I like to have a break and I will come up with the other post processing concerns in the next lecture. That is the continuation with this lecture only where I will discuss surface texturing, machining enhancement of the properties etcetera.

Thank you.