Rapid Manufacturing
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Lecture - 34
Post-processing Concerns (Part 2 of 2)

Good morning. Welcome back to the next part of the lecture on Post-processing Concerns.

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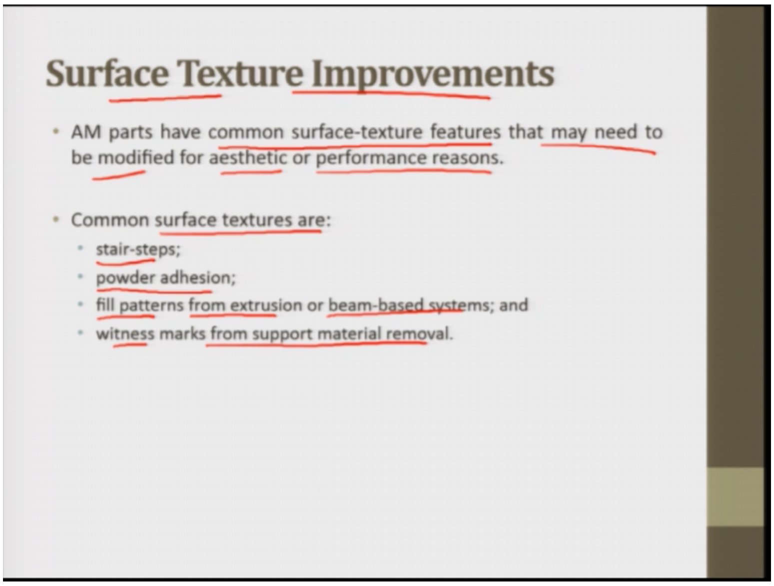

So, next concern is surface texture improvement. Surface texture or surface finish improvement. Additive manufacturing parts have common surface structure features that may need to be modified for a static or performance reasons. The common surface textures are stair-steps, powder adhesion, fill patterns from extrusion or beam-based systems, witness marks from support material removal. So these need to be addressed. Staircase effect that I discussed, this is a fundamental issue in a layered manufacturing and it is difficult to overcome sometimes although one can choose a thin layer thickness to minimize the error at the expense of build time. The thinner the layer is the more is the time, but will have a better finish in that case, but it is better to optimize the cost with respect to time and the quality.

Next is powder adhesion. Powder adhesion is also fundamental statistic of binder printing, powder by fusion and powder based beam deposition processes. Powder has an adhesion and that also creates a texture specifically on the surface.

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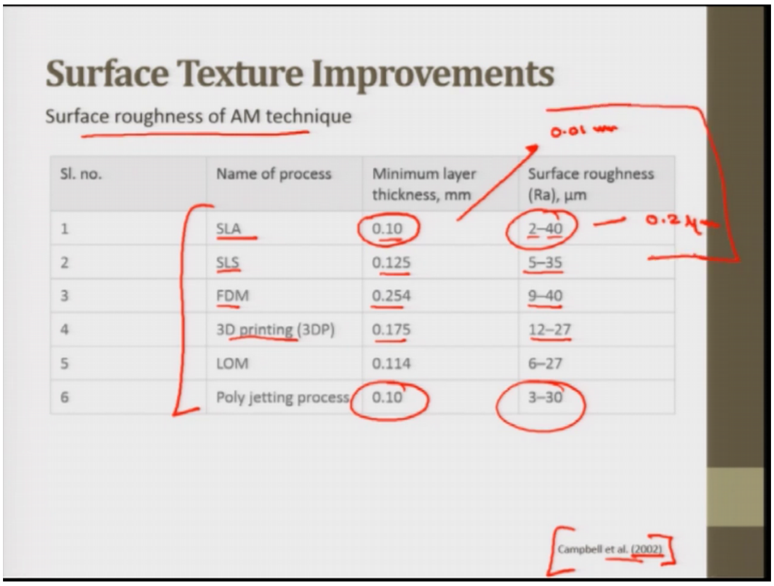

Typical surface roughness is which is taken from research are like these for SLA, this showed the minimum layer thickness as 0.1 millimeter roughness for a weight from 2 to 40 micrometers and for selective laser sintering it was 0.125 and this was from 5 to 35. And for FDM, it was the minimum layer thickness was 0.254 and surface roughness was 9 to 40 micrometers. For 3D printing, minimum thickness was 0.175 and the surface roughness was 12 to 27 micrometers.

We can see that in these processes, the minimum thickness that is obtained here is in SLA and poly jetting processes; and the minimum surface roughness that is possible here is for SLA and poly jetting again. So, this is a research way back in 2002, 15 years or 17 years later than this just certain material which are developed and which can take the rapid manufacturing, minimum layer thickness 2.01 millimeter and roughness that we can obtain is 0.2 micrometer. So, this is as present status of the technology.

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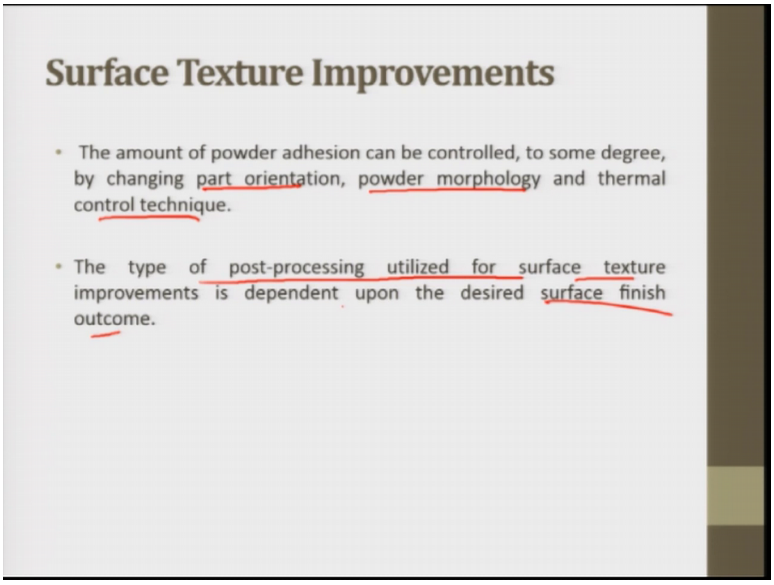

The amount of powder adhesion can be controlled to some degree by changing the part orientation, powder morphology and thermal control technique. The type of post-processing utilized for surface texture improvements is dependent upon the desired surface finish outcome. If metasurface finish is desired a simple bead blasting of surface can help even the surface structure removes a corners from the stair stepping and give an overall meta appearance that is, for meta appearance. But if polish or glossy appearance is required, then the smooth and polished finish has to be got then wet and dry standing and hand polishing are to be performed. So, it all depends to what extent do we need the surface finish.

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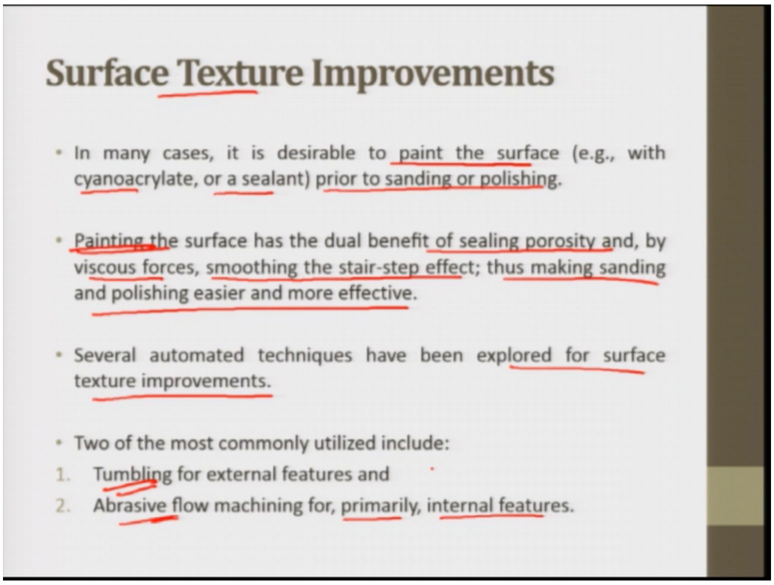

In many cases, it is desirable to paint the surface, to improve the surface texture for example, with cyanoacrylate or a sealant prior to sanding or polishing.

Painting the surface has the dual benefit of sealing the porosity by viscous forces, smoothing the stair-step effect and thus making sanding and polishing easier and more effective. So, this is the use of painting. Several automated techniques have been explored for surface texture improvement. Two of the most common utilized include the tumbling for external features, abrasive flow machining for primarily internal features. Abrasive flow is when internal features are to be finished, then abrasive flow machining can help to use abrasive to get the surface finish that is required. Tumbling when external feature is required the material is kept into a tumbler and that is rotated and the powder improves the surface texture. So, that is one of the ways.

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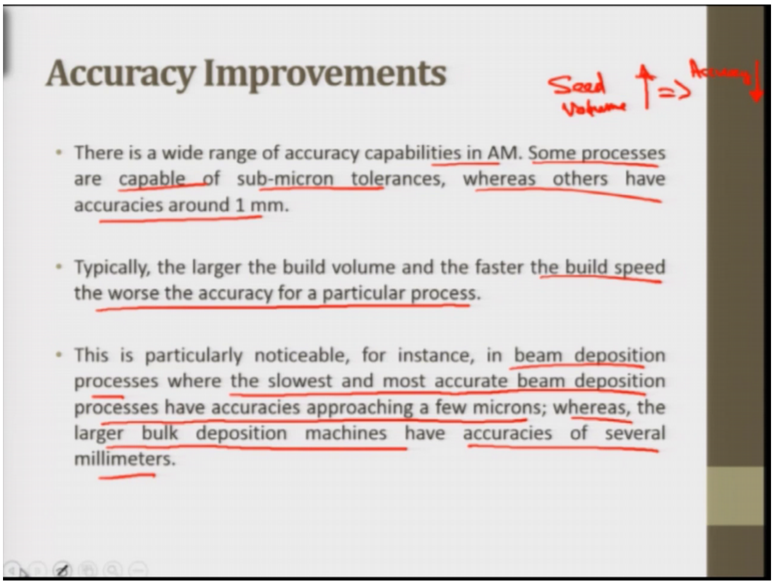

Next is accuracy improvements. There is a wide range of accuracy capabilities in additive manufacturing. Some processes are capable of sub micron tolerances, whereas, other have accuracies around 1 mm. Typically, larger the build volume and faster the build speed the worse the accuracy for a particular process. So bigger the volume and faster the speed; speed and volume; if they are high this implies accuracy is low. So, this is particularly noticeable for instance in beam deposition processes where the slowest and the most accurate beam deposition processes have accuracy is approaching a few microns whereas, the large bulk deposition machines have accuracies of several millimeters. So, these accuracies can also be seen here. The minimum layer thickness and surface roughness that is obtained; the minimum layer thickness implies the better surface roughness.

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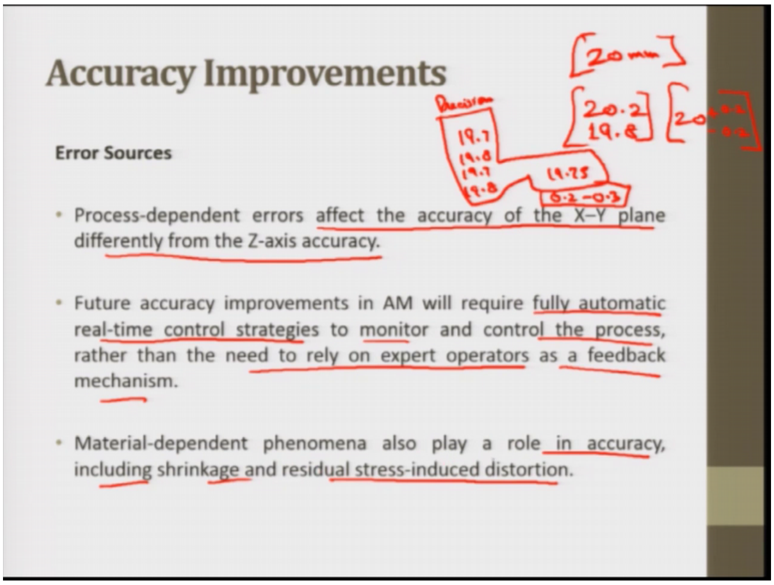

Now, for accuracy improvements we need to know what are the error sources. Process dependent errors affect the accuracy of X-Y plane differently from the Z-axis accuracy. These errors come from positioning and indexing limitations of the specific machine architectures. For instance, are we using 2.5D machines, 2.5 axis or 3 axis or 4 axis which kind of processing, which kind of stage are we using to get the rapid manufacture part. So, it all depends upon the orientation or on the indexing limitations of this specific machine stage or machine bed that is used. Then lack of closed loop process monitoring and control strategies, there can also lead to errors and issues fundamental to volumetric rate of material addition such as melt pool or droplet size are the other factors.

Future accuracy improvements in additive manufacturing will require fully automatic real time control strategies to monitor and control the process, rather than the need to rely on expert operators as a feedback mechanism. Fully automatic and real time accuracies as we will discuss in rapid product development module of this course. Now internet of things is also there. People can just order the product at their home and a product the specific customized product the shape and that can be printed and delivered to them. So, those things are there. So, we need not to have an expert to operators the computers would work by itself and the product would be manufactured. So, there are certain interfaces which are developed for this.

The material dependent phenomena also plays a role in accuracy including shrinkage and residual stress induced distortion. Now integration of additive plus subtractive processes is one of the ways. We do some additive and done some subtractive processes. Now this can be one of the ways to have better accuracy improvements. To recall, accuracy is the closeness to the original results. For instance, if I need this size as exactly 20 mm and I am exactly getting 20 mm that is accurate, but there are certain tolerances. For instance, 20 mm is my final build I required, the diameter and I am getting something like 20.2 or 19.8. So, this means it has 20 plus minus 0.2 and 0.2 tolerance. So, this is the closer to the final desired output the higher is the accuracy.

Generally, precision is there, but accuracy is not there. Precision is for instance, if I getting 19.7, 19.8, 19.7, 19.8, it is close to 19.75. So, this means the part is give us a precise reading which are close to 19.75, but there is always a difference of 0.2 to 0.3 mm in the negative direction. So, this is precision. So, accuracy material dependent phenomena also play role in accuracy including shrinkage and residual stresses.

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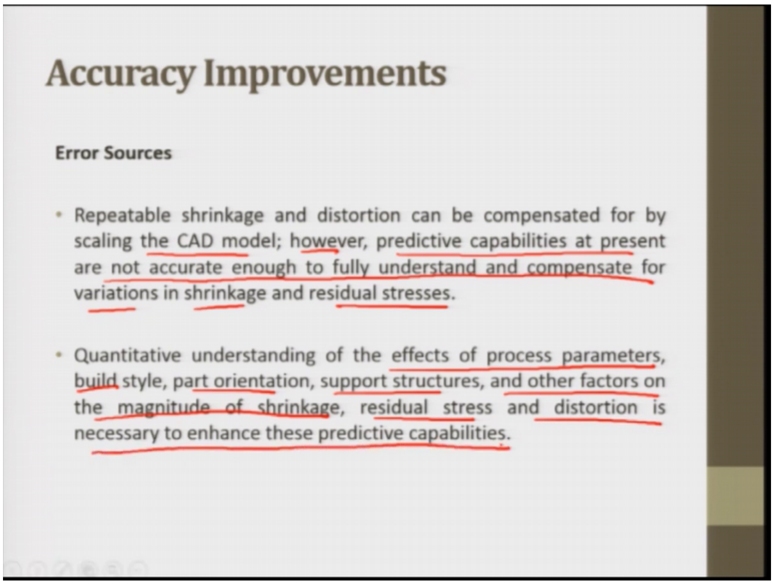

Repeatable shrinkage and distortion can be compensated by a scaling of the cad model; however, predictive capabilities at present are not accurate enough to fully understand and compensate for variation in shrinkage and residual stresses as in casting, we know there is certain alliances, shrinkage alliance, then we have draft alliance, though those alliances are also to be put here. Quantitative understanding of the effects of the process parameters build style, part orientation, support structures and other factors on the magnitude of shrinkage, residual stresses and distortion is necessary to enhance these predictive capabilities. For parts which require higher degree of accuracy, extra material must be added. This extra material can be a thin layer throughout the part or the portions where we know that higher shrinkage would happen. So, that extra material has to be added that can be machined again. That can be machined of the major build. This extra material must be added which is a critical feature which is then removed by other subtractive means to get a desired accuracy.

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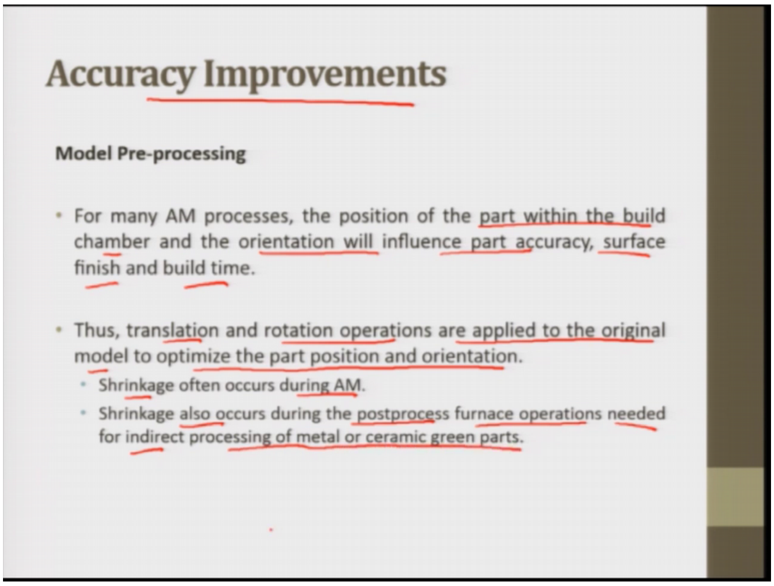

So, next after error sources you have model pre-processing as the way to accuracy improvement. Model pre-processing is for many additive manufacturing process is the position of the part within the build chamber and the orientation will influence the part accuracy, surface finish and build time. Thus, translation and rotation operations are applied to the original model to optimize the part position and orientation. So, shrinkage often occurs during additive manufacturing. Shrinkage also occurs during post process furnace preparations needed for indirect processing of metal or ceramic green parts.

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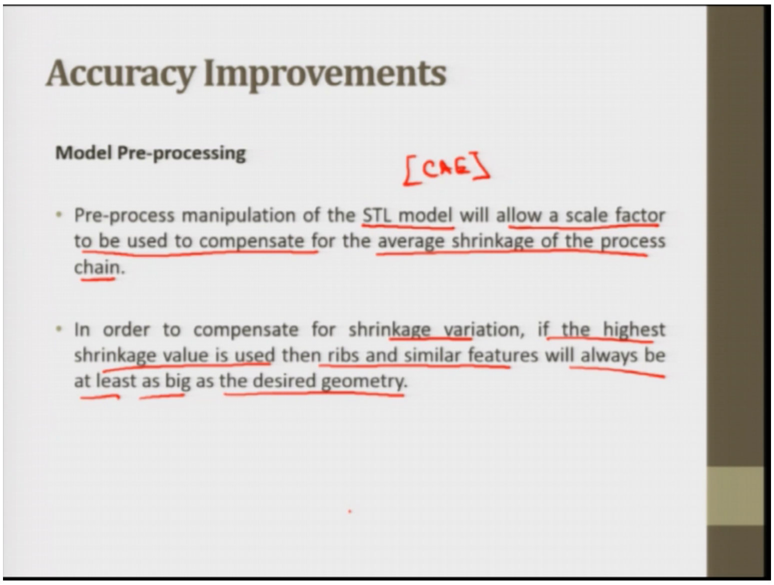

So, these need to be seen in the model pre-processing step only. The pre-process manipulation of the STL model will allow to scale a factor to be used to compensate the average shrinkage of the process.

So we are essentially talking here about CAE, computer aided engineering where we see what could be the shrinkage and when we need to compensate this shrinkage there would be always some features which will shrink slightly more or less than the average shrinkage. So we need to see where the shrinkage is larger and on the other hand, where the shrinkage is lower. I mean, we need to work according to that the specific factors can be taken what scale factor or what extra material should be billed accordingly. In order to compensate for shrinkage variation if the highest shrinkage value is used then ribs and similar features will always be at least as big as the desired geometry. So, this is important to have the segregated shrinkage factors.

For instance, if they are ribs like we say the bicycle wheel is there bicycle way the spokes. If we take the same shrinkage factor the spokes are made very big. For instance, if I take this shrinkage alliances 5 mm extra material; so, if the spoke sizes 2 mm and extra 5 mm diameter over that. That can make a spoke of 7 mm. So, the factors according to the size for instance the ribs and similar features should be determined and that can be put separately to the parts which are being manufactured to the portions of the part that is manufactured.

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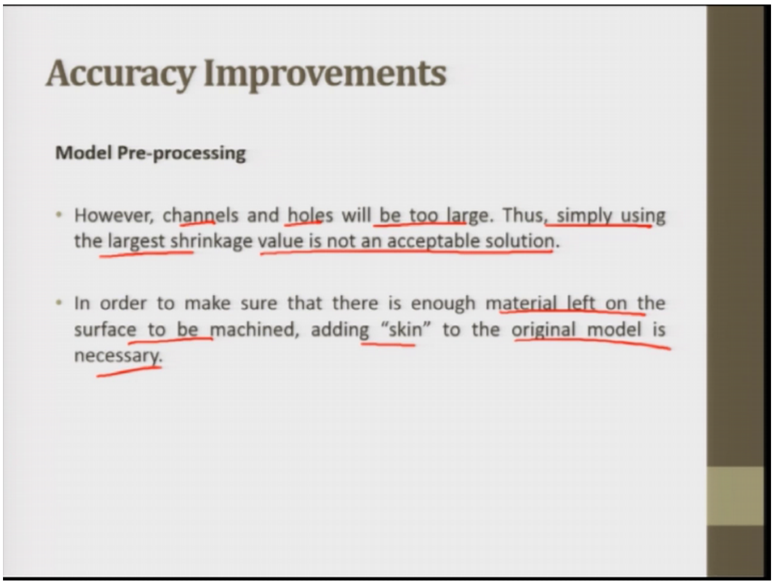

However, channels and holes will be too large. Thus, simply using largest shrinkage value is not an acceptable solution. So, this is connected ribs and similar features will always be at least a big as desired geometry and channels and holes will be too large right. So thus, simply using the largest shrinkage value is not an acceptable solution in order to make sure that there is enough material left on the surface to be machine adding a skin to the original model are also necessary. Adding the skin means there should be some material that is to be machined that material has to be left everywhere. Many studies have shown that shrinkage variations are geometry dependent even when using this same additive manufacturing or furnace process parameter settings. So, shrinkage alliance is similar to that in casting and in additive manufacturing.

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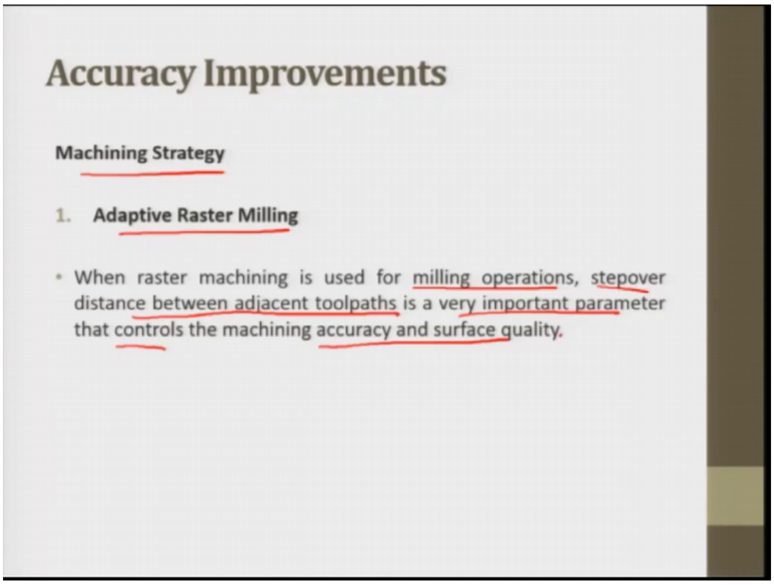

Next is machining strategy for accuracy improvement. Now machining strategy is very important for finishing, additive manufacturing parts and tools considering both accuracy and machine efficiency, adaptive raster milling of the surface plus hole drilling and sharp edge contour machining can fulfill the needs of the most parts. Adaptive raster milling when raster machining is used for milling operations step over distance between adjusting tool paths is very important parameter that controls the machining accuracy and surface quality it is known that higher accuracy and surface quality require a smaller step over distance and vice versa. So, step over distance becomes an important parameter here. So, this is adaptive raster milling.

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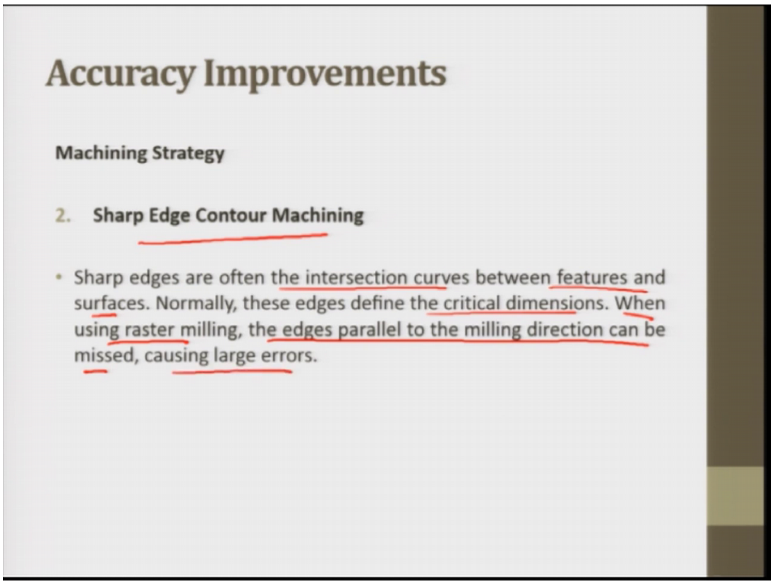

Next is, sharp edge contour machining sharp edges are obtained the intersection curves between features and surfaces. Normally, these edges define the critical dimensions when using raster milling the edges parallel to the milling direction can be missed causing large errors.

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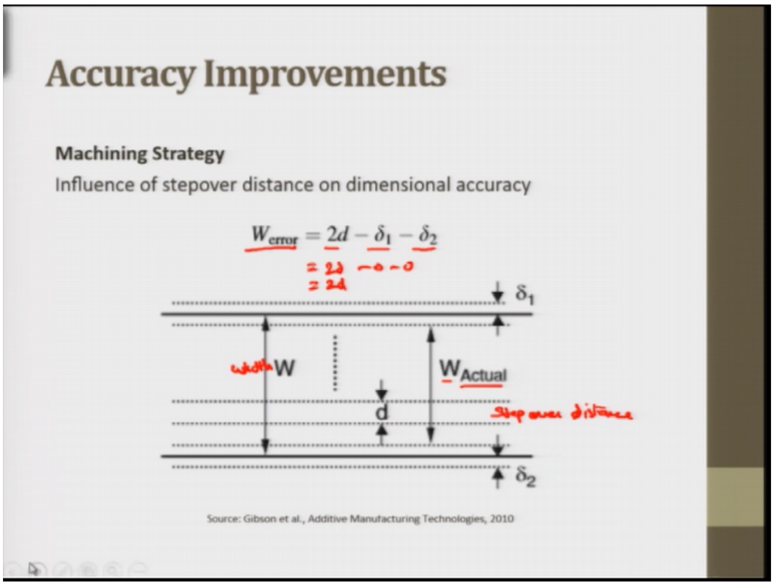

So these need to be countered. When step over distance is used. So, this d is the step over distance. This d step over distance and W is the slot width even when the CNC machine is perfectly aligned the slot width error will be at least. So, this is slot width error which is 2 d minus delta 1 minus delta 2. Delta 2 is on uppers delta 1 is on upper side delta 2 is in the lower side. So, this is W width it is actually obtained.

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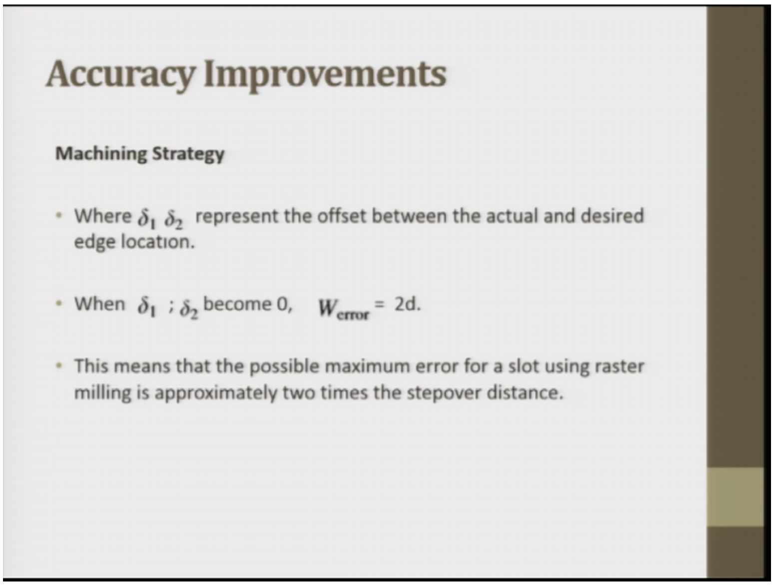

Here, delta 1 and delta 2 represent the offset between the actual and desired location. When delta 1 and delta 2 becomes 0 this W error becomes 2 d which means that the possible maximum error for the slot using raster milling is approximately two times the step over distance. This we can use here. This is 2 d minus 0; minus 0 is equal to 2 d. Now this is one of the models that determines this step or distance.

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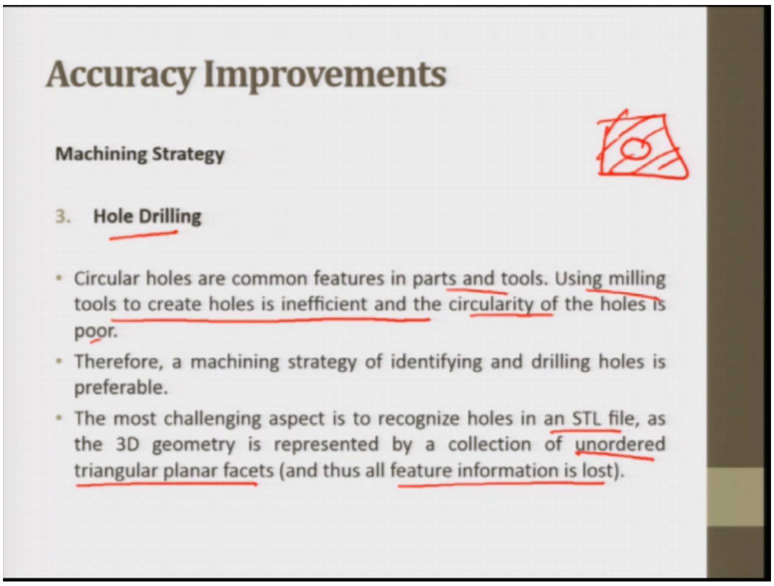

Now, third machining strategies hole drilling. Circular holes are common features in parts and tools using milling tools to create holes in inefficient and the circularity of the holes is poor therefore, a machining strategy of identifying and drilling holes is preferable. Most challenging aspect is to recognize holes in the STL file as 3D geometry is represented by a collection of unordered triangular planar facets and thus, feature information is lost.

Now, people have used algorithms in recognitions of the hole did better just based upon because the hole and the surface have a closed loop here. So, these algorithms which are made up of sharp edges from the model they are used to determine the holes. Now the closed loops may not be necessarily the intersection curves between the holes on surface. So, a series of hole checking rules are used to remove the loops they do not correspond to the drill holes. So, this is also one of the important machining strategy that needs to be cover.

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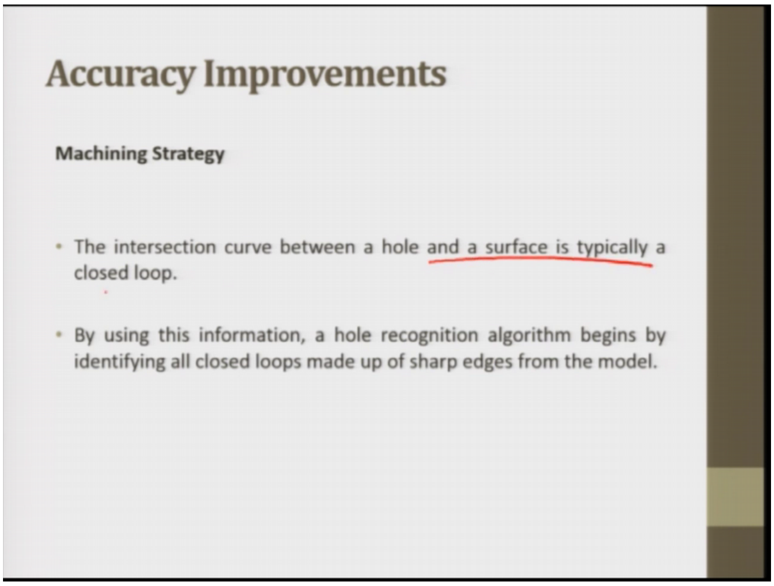

The intersection come between the hole and the surface is typically a closed loop by using this information. A hole recognition algorithm begins by identifying all closed loop made up with the sharp edges of the model. So, these are used by researchers to develop the algorithms and to develop the STL file only that has the hole drilling strategy in it.

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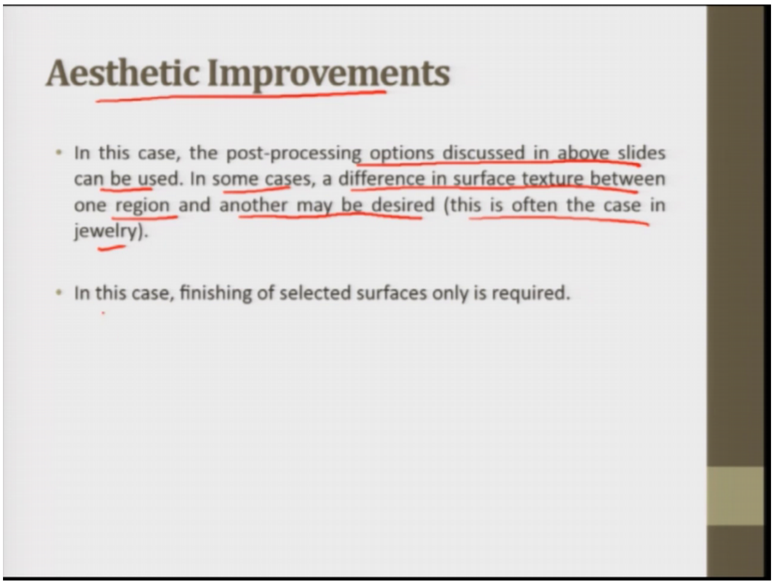

Next is a static improvement. So, many times additive manufacturing parts are manufactured just for displaying in the showroom or some marketing strategies; some marketing products are to be there. So, their aesthetic improvement is very important. So, highly aesthetic and appealing products are to be developed in additive manufacturing for that post-processing options discussed in the above slides can be used. In some cases, a difference in surface structure between one region and other may be desired this is often in the case of jewelry. So, the statics of the parts is of the critical importance for its end applications, often the desired aesthetic improvement is solely related to surface finish.

So in this case, finishing of the selected surfaces is only required.

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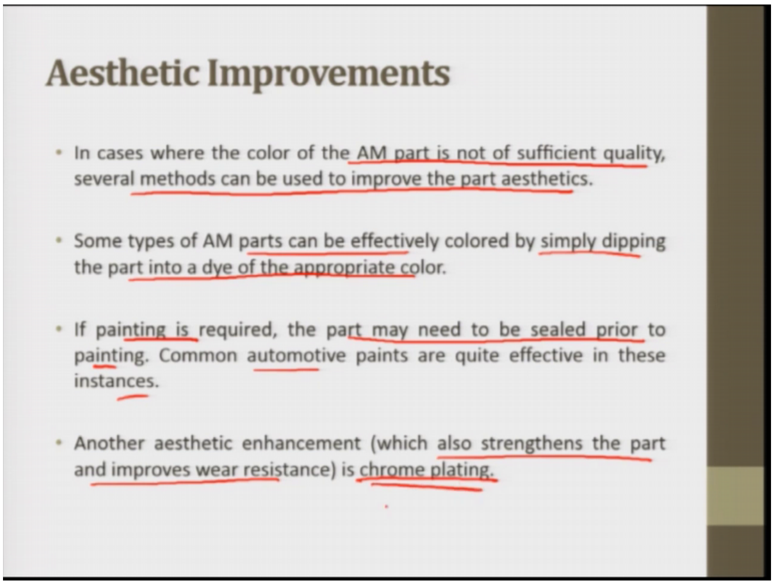

In cases, where the color of the additive manufacturing part is not of sufficient quality, several methods can be used to improve the part aesthetics. Some types of parts can be effectively colored by simply dipping the part into dye of the appropriate color. So, this method is particularly effective for the part created from powder beds as inherent porosity in these parts need to be effective absorption. So, if painting is required the part may need to be sealed prior to painting. Common automotive paints are quite effective in these instances.

Another aesthetic enhancement which also strengthens the part and improves wear resistance chrome plating.

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So, in this figure a SLA part that is, SLA part that is produced maybe using nylon; that is chrome plated and after chrome plating several materials have been coated for additive manufacturing parts including nickel, copper and other coatings. In some cases, these coatings are thick enough that in addition to aesthetic improvements. They also helped to get a robust enough to use as tools for injection molding or for ADM electrodes.

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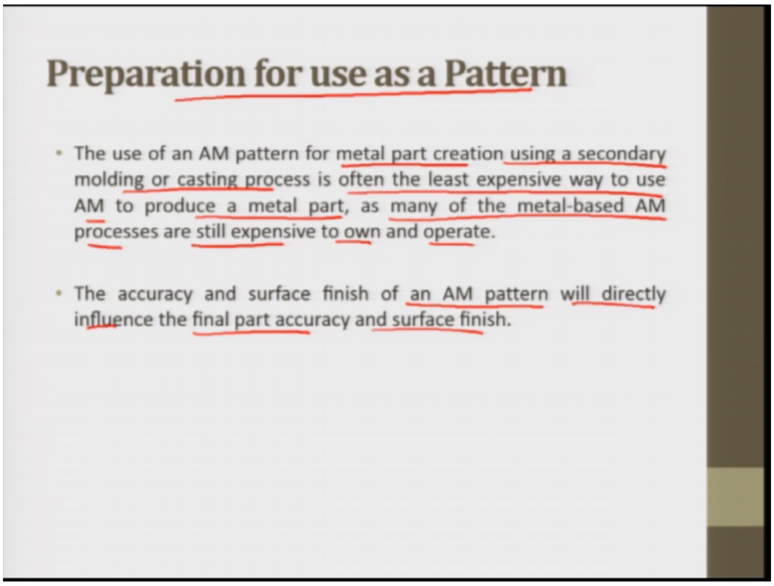

Next is, preparation for use as a pattern. This is also a post-processing concern here. Sometimes, the parts made using rapid manufacturing are intended to be use as patterns for investment casting, sand casting and other casting processes and the other replication processes may be. So, then the use of additive manufacturing pattern for metal part creation using a secondary molding or casting process is often the least expensive way to use additive manufacturing to produce a metal part as many of the metal based additive manufacturing processes are still expensive to own and to operate.

The accuracy and surface finish of an additive manufacturing pattern will directly influence the final part accuracy and surface finish. So, a special care must be taken to make sure that a pattern has desired accuracy and surface finish in the final part also. The pattern must be scaled to compensate for any shrinkage that take place in the pattern replication steps because we are talking about patterns, here again shrinkage would come into play.

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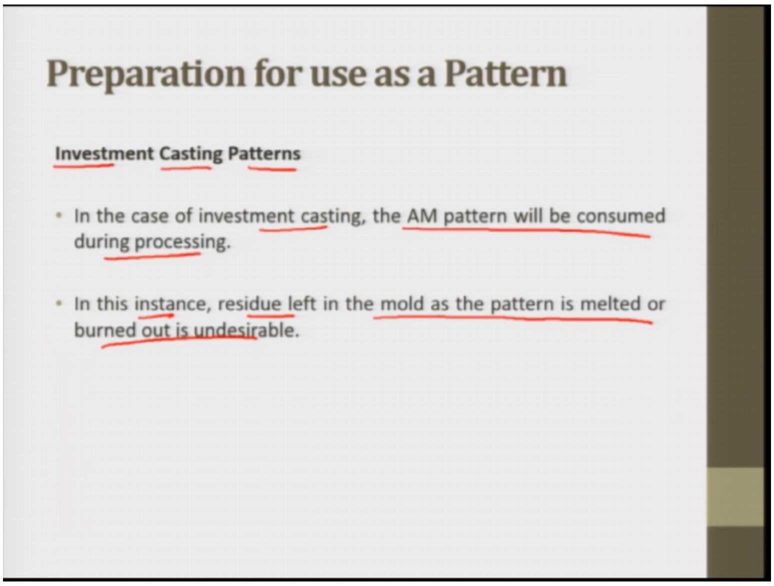

The certain patterns that needed to be prepared from the rapid manufacturing part, number one is investment casting patterns. In the case of investment casting the additive manufacturing pattern will be consumed during processing. For this instance, residue left in the mold as the pattern is melted or burned out is undesirable.

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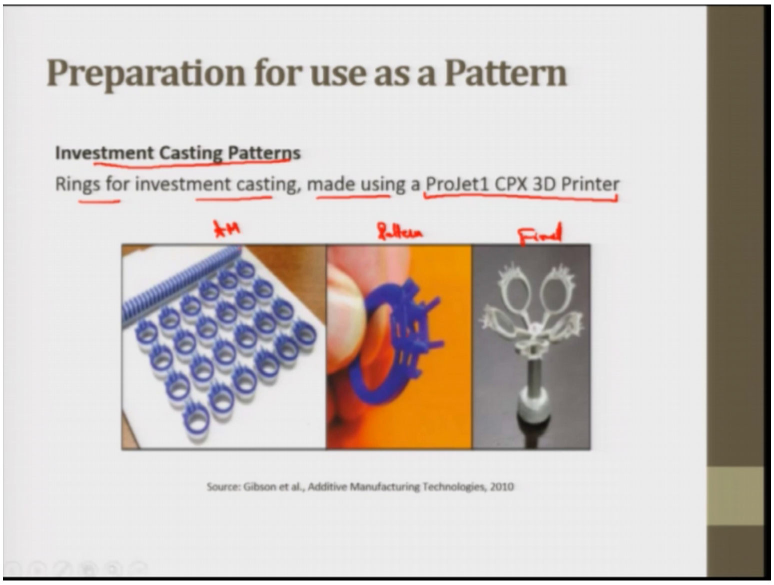

This is the example of investment casting patterns rings for investment casting made using this specific printer. Now these are rings which are developed for investment casting. So, these are the pattern those are used is a patterns made into the final rings, this is the final product and this is the pattern. This is additive manufacturing in the rings are made additive manufacturing or rapid manufacturing.

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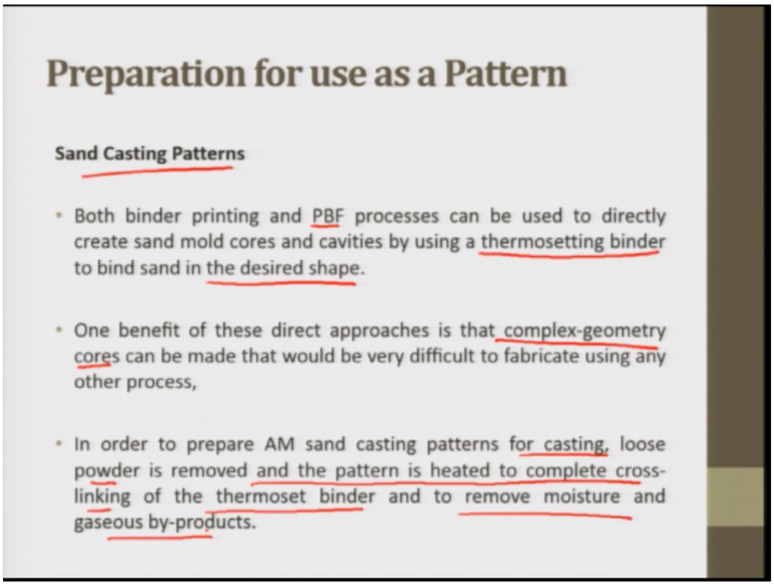

Next is sand casting patterns; both binder printing and border bed fusion processes can be used to directly create sand mold codes and cavities by using thermosetting binder to bind sand in that desired shape. One benefit of these direct approaches is that the complex geometry course can be made that would be very difficult to fabricate using any other process. In order to prepare additive manufacturing sand casting patterns for casting loose powder is removed and the pattern is heated to complete cross linking of the thermoset binder and to remove moisture and gaseous byproducts.

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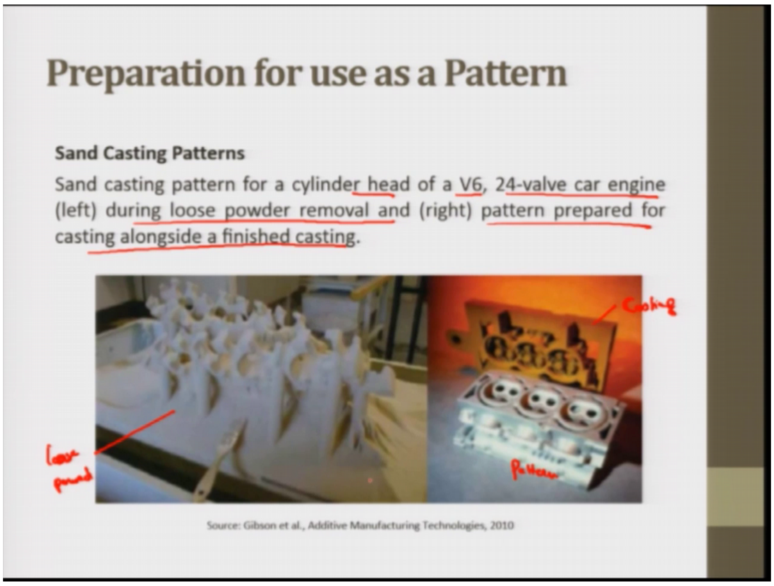

This is one of the sand casting patterns that is for a cylinder head of V6 24-valve car engine during loose powder removal and the right is the pattern prepared for the casting alongside a finished casting. So, this is the pattern, this is the casting that is obtained. So, this is loose powder and it is sand casting patterns which are prepared from rapid manufacturing.

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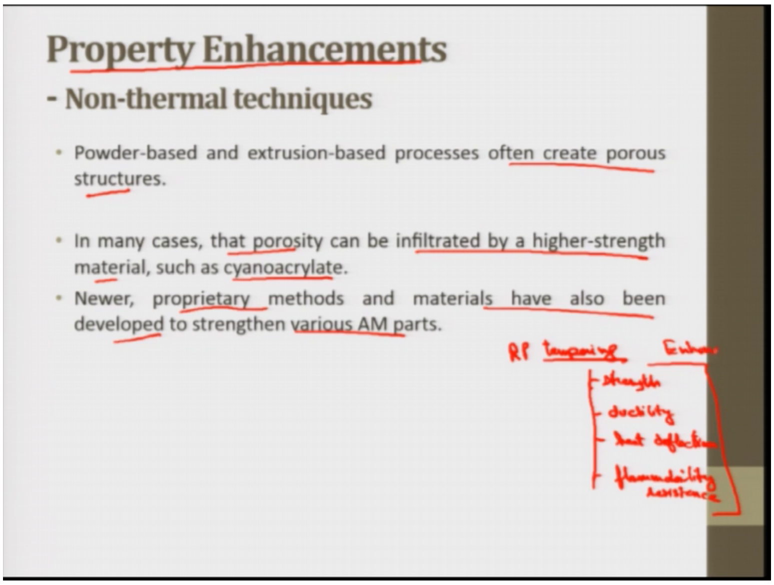

Property enhancement, the last post processing concern that we will discuss in this lecture, property enhancement non thermal techniques powder based and extrusion based processes often create porous structures. In many cases, that porosity can be infiltrated by higher strength material such as cyanoacrylate. Newer, proprietary methods and materials have also been developed to strengthen the various additive manufacturing parts.

So normal thermal techniques, one of the best known technique is tempering rapid prototyping tempering process. Rapid prototyping tempering is a collection of materials and treatment operations used to increase a strength, ductility, heat deflection and the other properties. This is rapid prototyping tempering. This is non thermal technique it helps to increase the strength, then ductility, then heat deflection, then flammability into resistance or resistance to flammability in other such properties. So, this actually induced the nano composite reinforcements that help to tamper the material and these properties are enhanced. This is non thermal technique.

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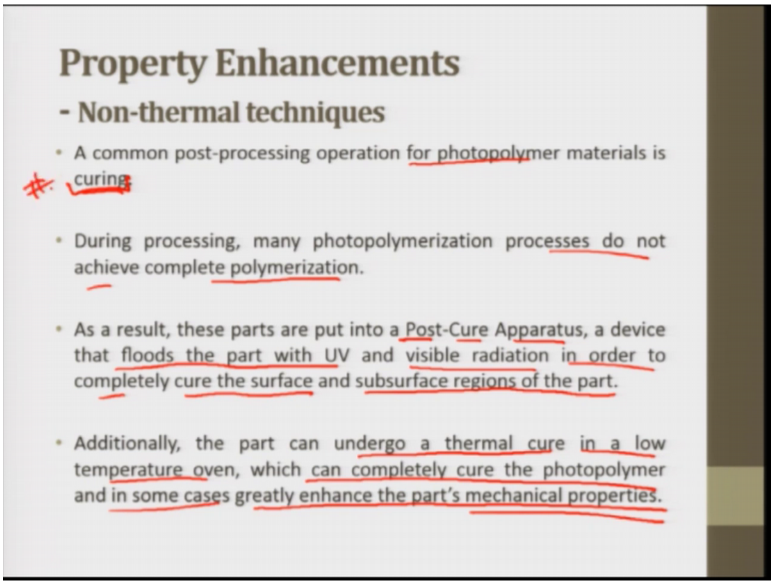

Now the common post-processing operation for the photopolymer materials is curing. After tempering we have curing here. During processing many photopolymerization processes, do not achieve complete polymerization. As a result, these parts are pulled into a post cure apparatus. That is a device that floods the part with ultraviolet and visible radiation in order to completely cure the surface and subsurface regions of the part.

Additionally, the part can undergo a thermal cure in a low temperature oven which can completely cure the photopolymer and in some cases greatly enhanced the parts mechanical properties that is, curing. This is important.

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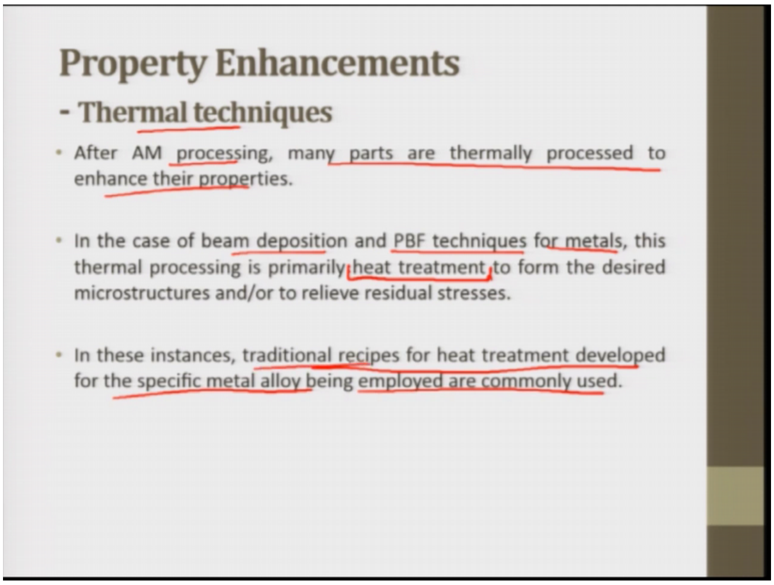

So there are certain thermal techniques as well after additive manufacturing processing many parts are thermally processed to enhance their properties. In the case of beam deposition in portable fusion techniques for metals; this thermal processing is primarily heat treatment. That is there to form the desired microstructure and to relieve the residual stresses. So, heat treatment is an important post processing technique that enhance the properties. Properties that is it develops the better micro structures which are specifically to the application that we need to apply then it also helps to relieve the residual stresses. So, this heat treatment is more prominent in the case of metals. Like we know in general casting and machining processes where we machine or take off the material, the material has some stresses developed in it. So, we do certain heat treatments like annealing, normalizing, spheroidizing. So, those kinds of heat treatment can also be done here.

So, in the instances when traditional recipes for heat treatment developed for specific metal alloy being employed are commonly used. So, traditional recipes as I said the common heat treatment processes are used. So, in some cases; however, special heat treatment methods are also developed to retain fine grain microstructure within the rapid manufacture part while still providing stress relief and ductility enhancement.

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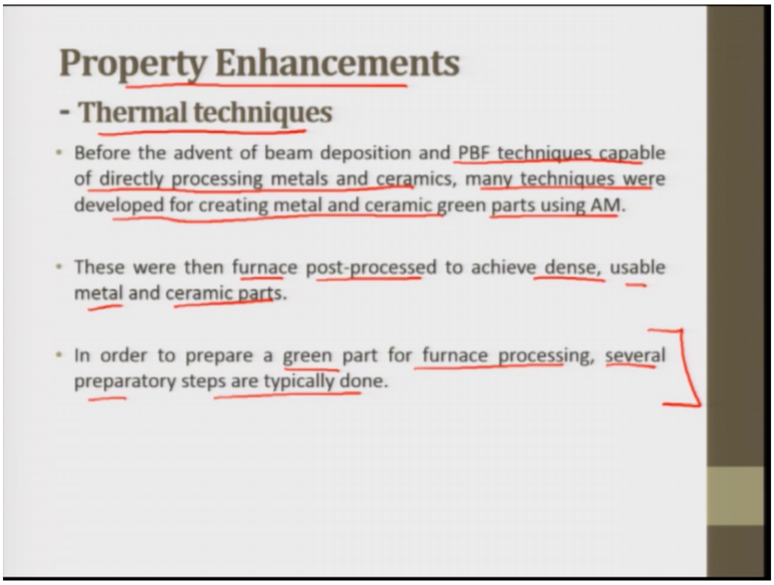

Before the advent of beam deposition in powdered bed fusion techniques capable of directly processing the metals and ceramics, many techniques were developed for creating metal and ceramic green parts using additive manufacturing. These were then furnace and post processed. So, heat treatment is one of the processes. Now next is furnaces post processing to achieve dense and usable metal and ceramic parts. In order to prepare a green part for a surface processing, several preparatory steps are typically done. There are certain steps involved in this furnace post processing we will not move into that direction, but yes furnace post processing and heat treatment are the major thermal techniques which are there to enhance the properties of the additive manufacture or rapid manufacture parts.

So with this, we have discussed the major post processing concerns in rapid manufacturing parts which were support material removal, then machining that is surface structure improvement, then we have the property enhancement. Certain people even say that methodological or inspection and testing is also the post processing, the testing of the material, quality testing, inspection all those things.

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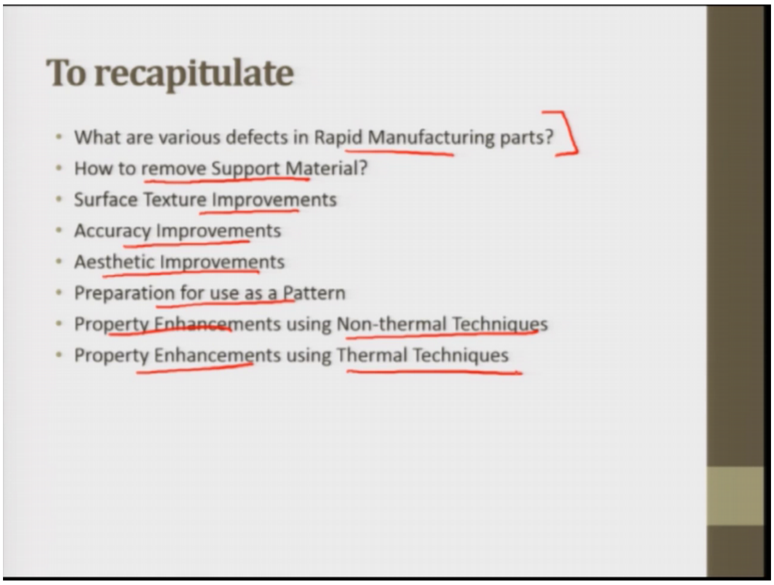

Then, to recapitulate we have seen what are the various defects in rapid manufacturing parts. How do we remove support material, then surface texture improvement concerns, then accuracy improvement concerns where we saw machining and other strategies. Then aesthetic improvement, where we saw surface texture improvement, then preparation of the parts to be used as a pattern; this we discussed. Then we saw the Property Enhancement using the Non-thermal Techniques and Thermal Techniques. So, with this, this lecture is over, we will meet again and discuss further on rapid manufacturing.

Thank you.