Rapid Manufacturing
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Lecture – 25
Sheet Stacking Processes

The next lecture will be on Sheet Staking Processes. So, why is that sheet stacking?

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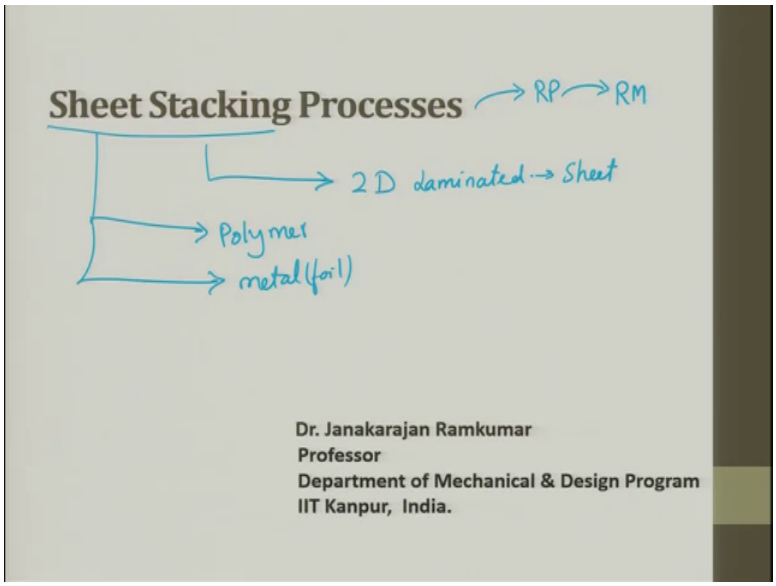

If you look at it, it is 2 D laminate itself is getting created. So, 2 D laminate is nothing, but a sheet. So, if I can made sheet thinner and thinner and thinner so then it will be equal to the laminate or I can give you an analogy here, if you can think of you have a certificate you laminate the certificate or top and bottom with a polymer sheet, that sheet is what you are talking about sheet.

So, you can think of sheet which is polymer, which you can think of sheet metal, metal foil ok; so all those things fall under sheet. So, now, we will see sheet stacking processes where in which are prime focus is first to make rapid prototyping and from there towards rapid manufacturing.

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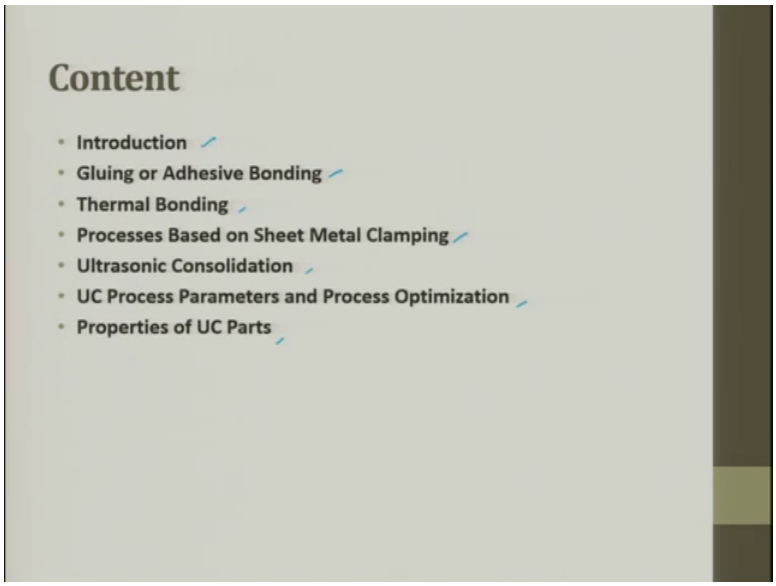

So, in this lecture the contents will be introduction, then gluing techniques or adhesive bonding, then thermal bonding then process based on sheet metal clamping, then ultrasonic consolidation, then UC process ultrasonic consolidation process parameters and process optimization and finally, the properties of ultrasonic consolidation parts.

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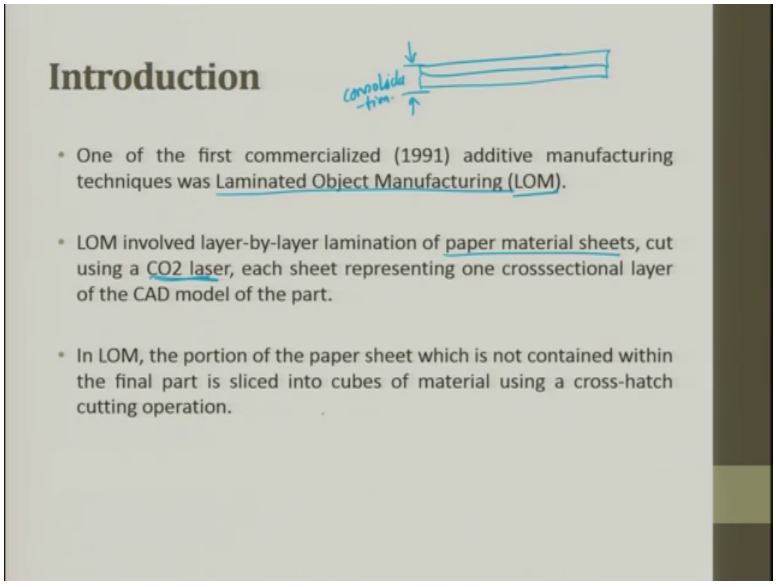

One of the first commercialized additive manufacturing technique was laminated object manufacturing, which is otherwise called as LOM. LOM involves layer by layer lamination of paper material sheet, cut using a CO2 laser, each sheet representing one

cross section layer of the CAD model of a part. So, single layer sheet, it is a single layer sheet, paper laminate sheet.

So, you this is one layer. So, you put this sheet and then you keep one more sheet at the bottom, then you make sure these two sheets glue together and form a consolidation ok. So, LOM involves layer by layer lamination of paper material sheet cut, using CO 2 laser. CO 2 laser is very important, because the wavelength of the laser plays a very important role when we, when we look into laser matter interaction. Each sheet represents one cross section layer of the CAD model of the part.

In LOM, the portion of the paper sheet which is not contained within the final part is sliced into cubes of material using a cross hatch cutting operation.

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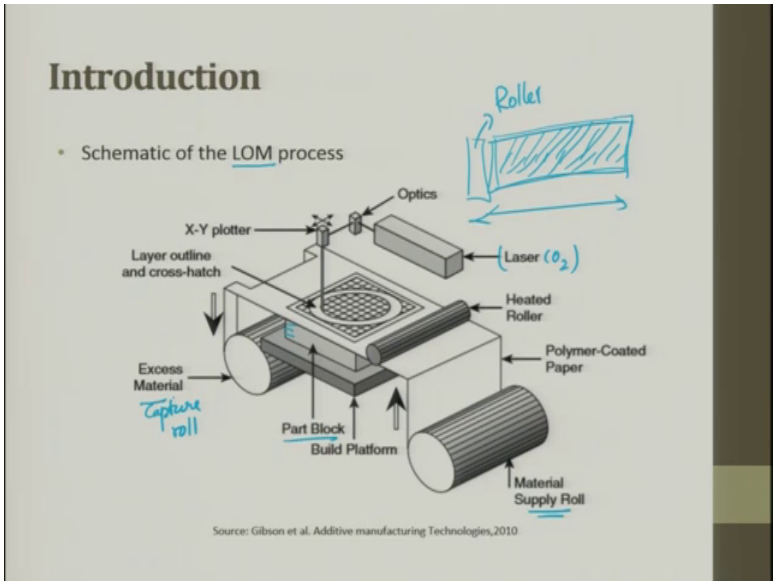

The schematic diagram of the LOM is shown here. So, look at it. So, you have a laser laser comes here, this is a CO2 laser and from here you have optics. This is, from this optics, it goes to a it goes to a galvo. So, from a galvo it is hit on the table. In the table you will have a laminate, you will have a laminate sheet that is what is laminate and here you now, you can think of like every time who is going to plays the sheet.

So, this sheet has to be continuously fed. So, we have reel that is a material supply role and the excess material role excess material capture role or acquire road ok. So, there will be a material, which is getting fed from here and when this material comes here, it is

exactly sliced, exactly sliced to the layer dimension, whatever it is and the rest of the material is left excess. So, once the laser engraves or laser hits, heats the material that the rest of the material will be rolled back into the excess material; so it is a continuous process.

So, you do not have to place stop the machine after placing every layer. So, this is fed here, it stops here, then a laser goes, it rise to draw the boundaries and cut the boundaries. So, it can do and engraving operation, it subtracts material. So, you have this and the rest of the reel will be rolled on the other side, fine; so now, what you do is you have this grids which are getting formed ok.

These grids and this is the information, which is to be engraved in this layer. So, if you go back and look into the grid in LOM, the portion of the paper sheet, which is not contained within the final part is sliced into cubes of material, using a cross hatch cutting operation ok.

So, what will happen after this one layer of information is done there? So, then either the spool can, the height of the spool can go high or the table can sink down so you create layer by layer. So, this is the part block, which is created where in which you have all sorts of layers ok. This is the platform, the platform we will move down as and when you keep the layers and see after finishing one layer, this layer has to stick to the other layer the next layer which comes here.

So, for that to make sure, what we do is we have a heated roller, this heated roller smears over the surface smears over the surface and then wherever there is a laminate polymer, laminate and temperature is rose and then it becomes in a semi solid state or in a viscous state, where that is used to glue with a next layer coming.

So, first layer you have, then here you have this roller, this roller reciprocates and here what happens? All these things are now, heat and then it becomes sticky and when the next layer come, this is the roller and when the next layer comes, this will just stick on top of it and then you form the other layer ok. So, this is why we use a heated roller; the entire process is called as laminated object manufacturing.

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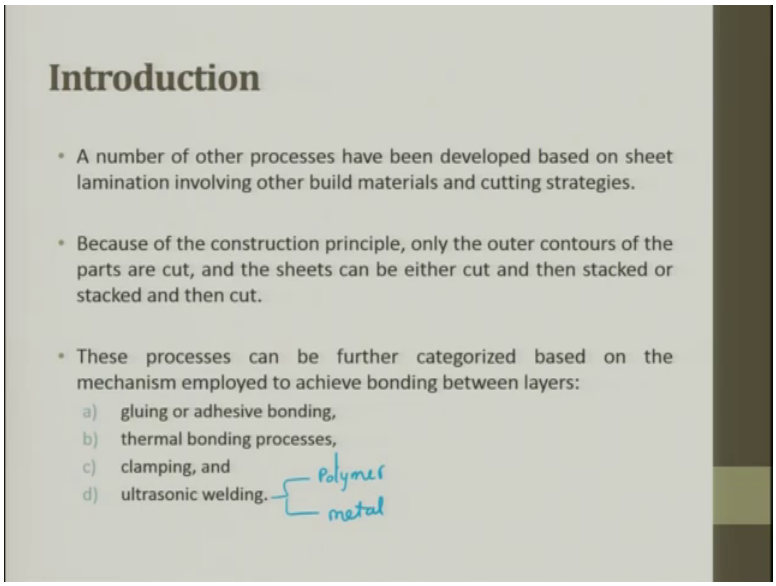

A number of other processes have been developed based on the sheet laminate involving other building material and cutting strategy. So, here we do not you supporting structure, because the supporting structure that sheet whatever is there which is placed. So, you have the sheet and then on wherever there is an extra material required. So, this will be stacking layer by layer by layer and finally, once the object is done, you chill out all the squares and you take the product out.

Because of the construction principle only the outer contour of the parts are cut and the sheet can either be cut and then start or the start and then cut. So, both options are there you can do it. These processes can be further categorized based on the mechanism employed to achieve the bonding between the layers. Gluing and adhesive bonding, thermal bonding processes can be done; that means, to say only heat you apply, you apply a glue to join, then we can do clamping and then you can also do ultrasonic welding, ultrasonic welding as such you know it is used for polymer process.

Polymer if you want to join we use ultrasonic welding process, you can also use metals to do it. Basically, when you do metals the oxide layer is removed and the nascent, nascent layer comes in contact it glues. So, between layer to layer you can use the ultrasonic welding and start gluing it.

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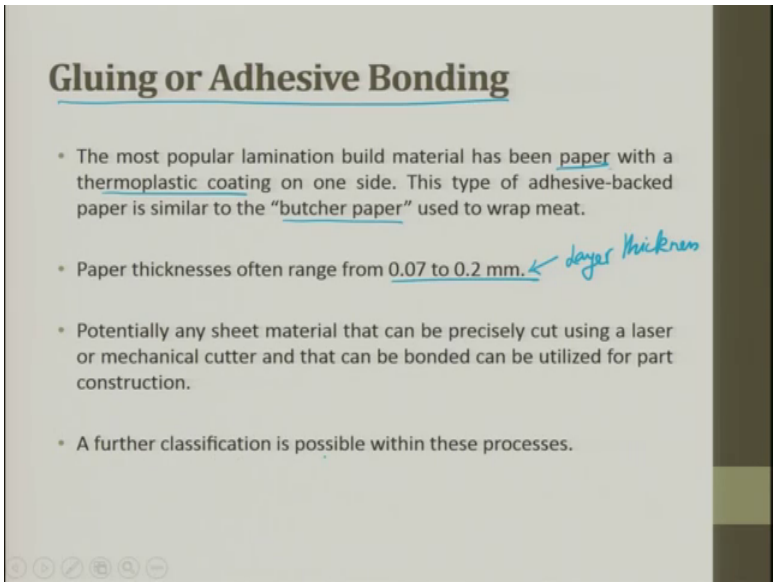

Gluing or adhesive bonding the most popular lamination build material has been the paper with a thermoplastic coating, this is what I said lamination, which you do for certificates paper, with a thermoplastic coating on one side. This type of adhesive backed paper is similar to the butchers paper used in wrapping meet.

The paper thickness is varying; so this will be the layer thickness. So, this thickness will be less than the FDM, if you see, if you want to play around, you can do it. Potentially any sheet material that can be precisely cut using a laser or a mechanical cutter and that can be bonded can be utilized for the part construction. A further classification is possible within these processes.

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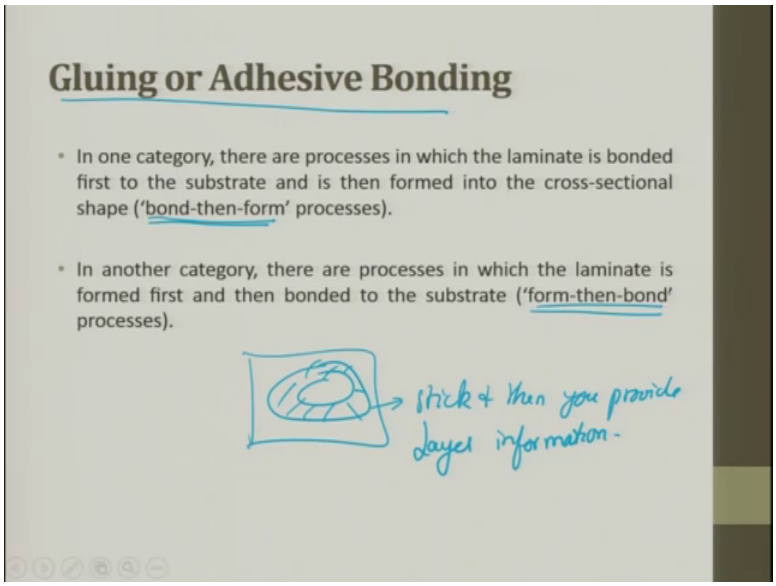

In one category, there are processes in which the laminate is bonded first to the substrate and is then formed into cross section shapes; so bond then form. The other category is form and then bond. So, bond means first you stick and then you give a shape, then you provide layer thickness layer information provide layer information; this one ok.

The other one is you form, give all the information and then you stick both categories are allowed. So, gluing or adhesion this is very important please note, it need not be bond and then form it can also be form and then bond; so both categories are possible.

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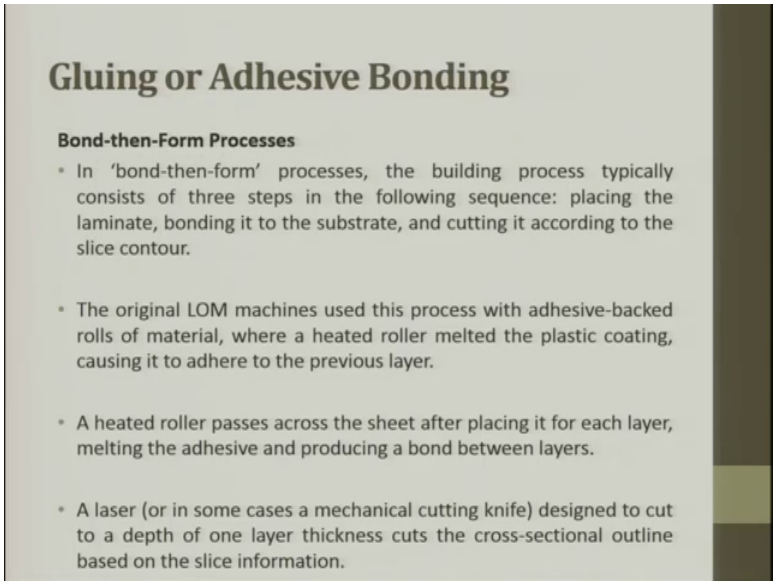

So, bond and then form process, in bond then form process, the building process typically consists of three steps in the following sequence: placing the laminate, bonding it to the substrate where the part is getting developed and cutting it according to the slice contour.

The original LOM machine used in this process with adhesive backed roller on material, where a heated roller melts the plastic coating causes it to adhere to the previous layer. That is why we use a hot and it is not red hot it tries to slightly increase a temperature as I told you earlier, polymer to viscoelastic material it glues and goes, heated roller passes across the sheet after placing it for each layer, melting the adhesive and preceding a bond between them ok.

So, adhesive and preceding, a laser designed to cut to a depth of one layer thickness cuts the cross section outline based on the slice information. The laser here is predominantly used like a knife. So, assume that you have a paper, a very thin paper you wanted to cut a profile, on in the current state of then you use scissor and cut ok.

So, if you want to automated you use it by a laser that is what is a difference and I am giving lot a analogy please try to use this analogy for your understanding and in this course where it is a primitive course. So, what we are trying to do is I am trying to explain and give you all short possible technologies which are available ok. And these are only the base. To get into rapid manufacturing you can be more creative than whatever is available.

Please, do not think this is the ultimate, it is a technology course, the technology keeps on be evolving. But if you understand two three technologies in fullest possible way, then for you to extrapolate the data and develop a new process, it is easy.

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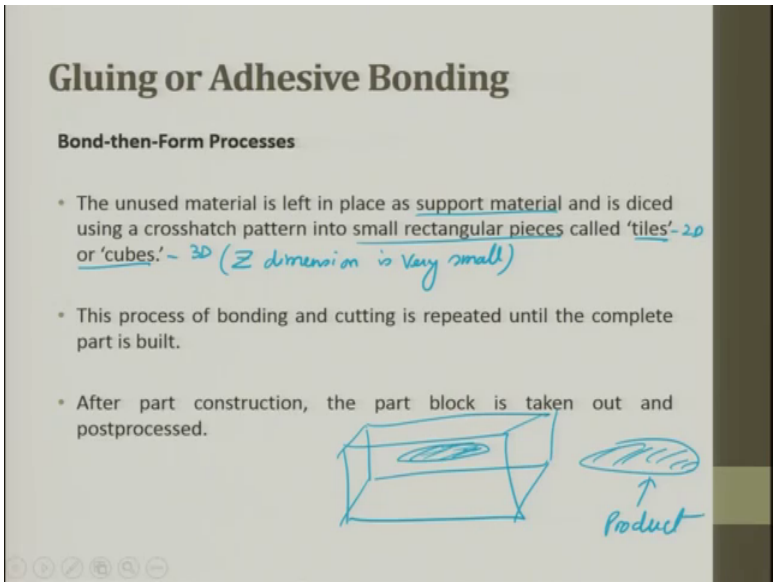

So, bond then form process the unused material is left in place as supporting material. This what I say, there is no supporting structure as we use in fdm process is used here and is diced using a cross hatch pattern into small rectangular pieces called as tiles or cubes. Tile is a 2 D, cube is a 3 D and here the Z dimension is very small ok.

This process of bonding and cutting is repeated until the complete part is built. After part construction is over, the part block is taken out and post process. Post processes now, what will happen? You will have a complete cube, will have a complete cube, in this you might have some information. So, now, what you do is you remove all these things and take the information out; so this is your product.

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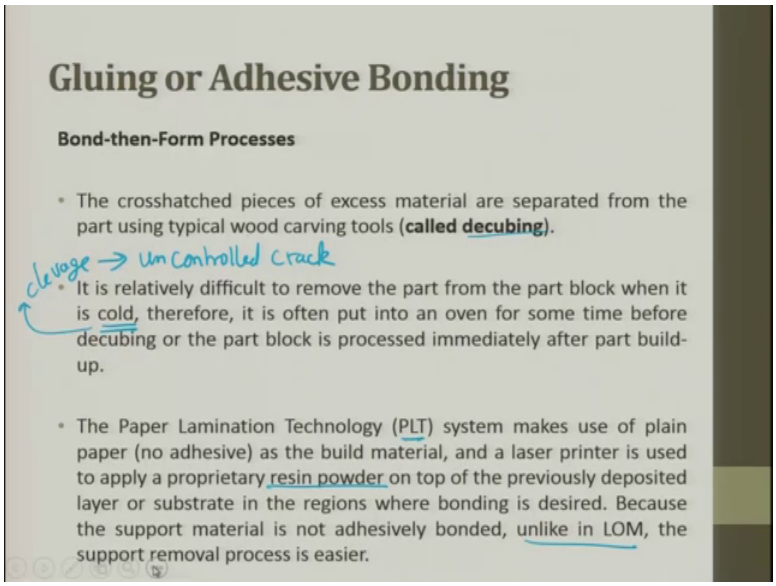

The cross hatched piece of the excess material are separated from the part using typical wood carving tool are called decubing. Straight away trying to break, sisil it out and remove. It is relatively difficult to remove the part from the part block when it is cold, therefore, it is often put into a woven for sometime before decubing or part block is processed immediately after the part building happens.

So, in the cold state there is a possibility you can generate cleavage. Cleavage means uncontrolled crack. So, in order to avoid this uncontrolled crack, we try to take it to a slightly higher temperature, maintain the temperature and then we try to remove it from the part whatever is the extra material available.

The paper laminated technology system PLT makes use of plain paper no adhesion as a building material, and a laser printer is used to apply a proprietary resin powder on top of the previous deposited layer or substance in the region where bonding is desired.

So, you see wherever laser was used now, you use a resin powder, because the supporting metal is not adhesively bonded unlike in LOM the support removal process is easier here.

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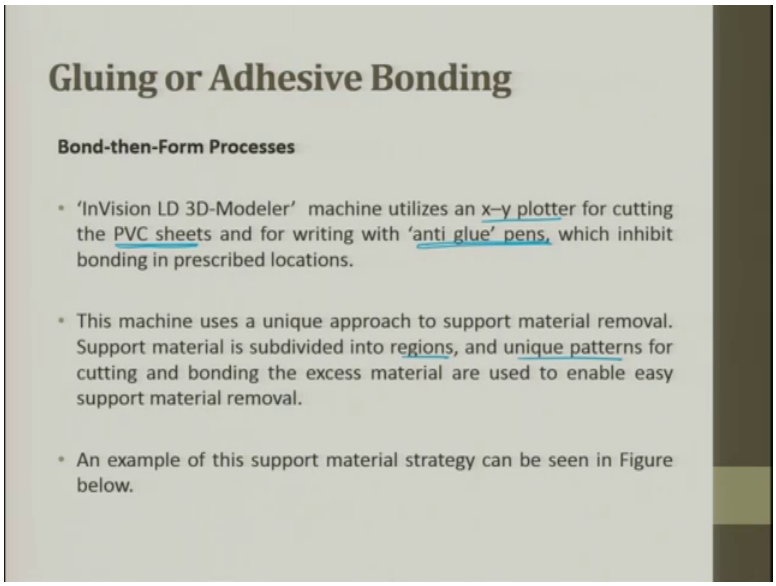

This is a next one; so a small of shift of the regular process in vision LD 3 D Modeler machines utilize a x-y plotter for cutting PVC sheets and for writing way with anti glue pens, which inhibits bonding in prescribed locations. So, PS PVC sheets, anti glue pens are used drop and then you get the information.

This machine uses a unique approach to support material removal. Support material is subdivided into regions and unique patterns for cutting and bonding the excess material are used to enable easy support material. An example of this supporting material strategy can be explained in then figure.

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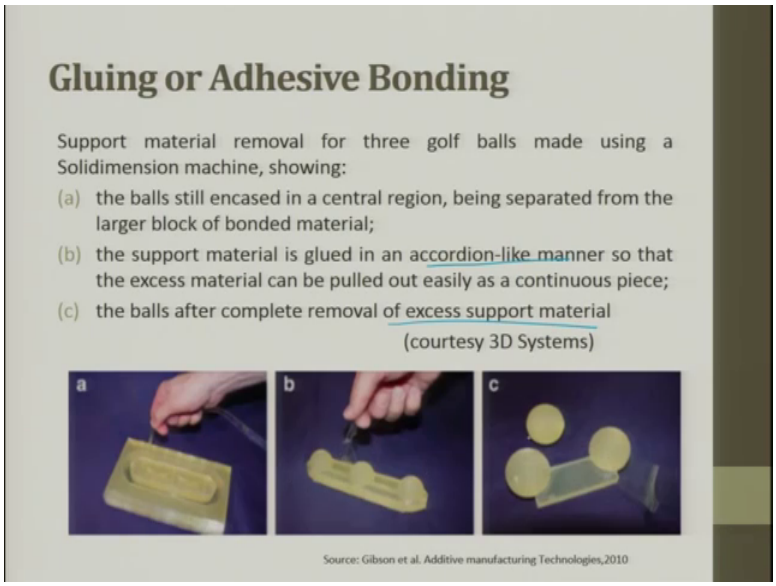

So, you can see, look at it; supporting material removal for three golf balls made using a solid dimension machine, showing. So, the ball still, the ball still encased in a certain region, being separated from the large block of bonded material.

Then in the second one see that if you remove, the supporting material is glued in a manner. So, that the excess material can be pulled out easily as a continuous piece; the ball after completely removing from excess material, you get three distinct golf balls. So, you remove from here, then you remove from here, then you get three different balls.

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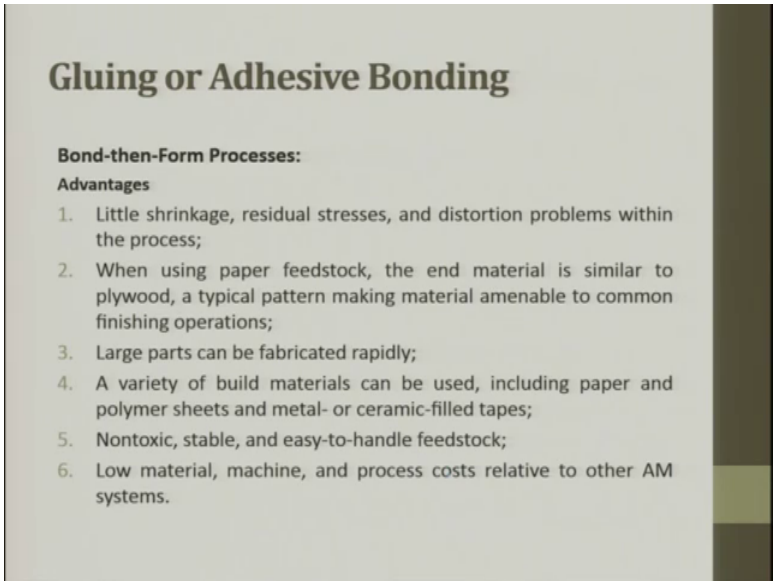

So, the advantages little shrinkage, residual stress and distortion problems within the process; when using a paper feedstock the end material is similar to plywood a typical pattern making material amenable to common finishing operations. Large parts can be fabricated very rapidly a variety of building material can be used including paper poly sheet metal or ceramic filled tapes. The non toxic and stable and easy to handle feed stocks can be used. No material machines and process cost relative to other am system can be done.

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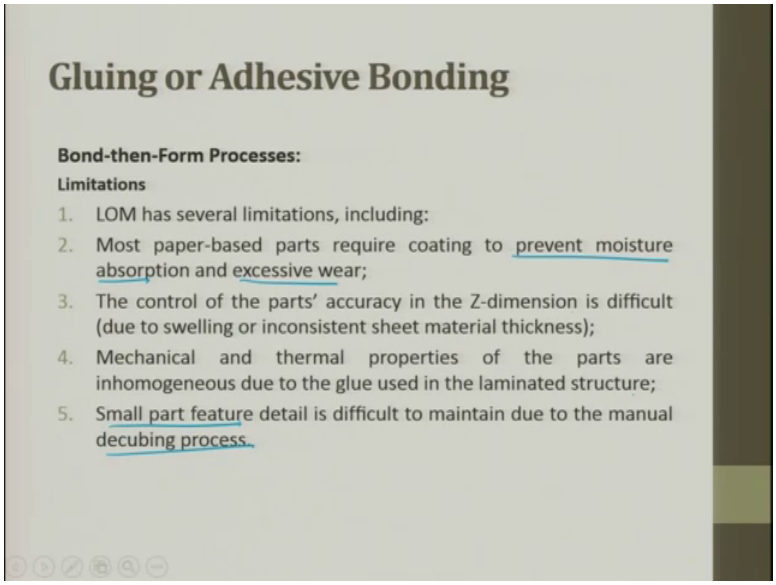

The limitation is; LOM has several limitations, including; most paper based parts require coating to prevent moisture absorption and excessive wear. This is very important, because even in the delamination certificates you can see sometimes air bubble go sticks in between, second thing is if the delamination starts at a corner it keeps propagating very fast and it propagates very fast not, because of pulling, but because the oh group which is a freely and available in the atmosphere enters inside and that starts weakening the bond.

So, it starts releasing; the control of the part accuracy in easer direction is difficult mechanical and thermal properties of the parts are in homogenous due to glue used in laminate structure. Small part feature detail is difficult to maintain due to manual decubing process small parts cannot be done, because small parts when you do and when you do decubing around, it will start breaking.

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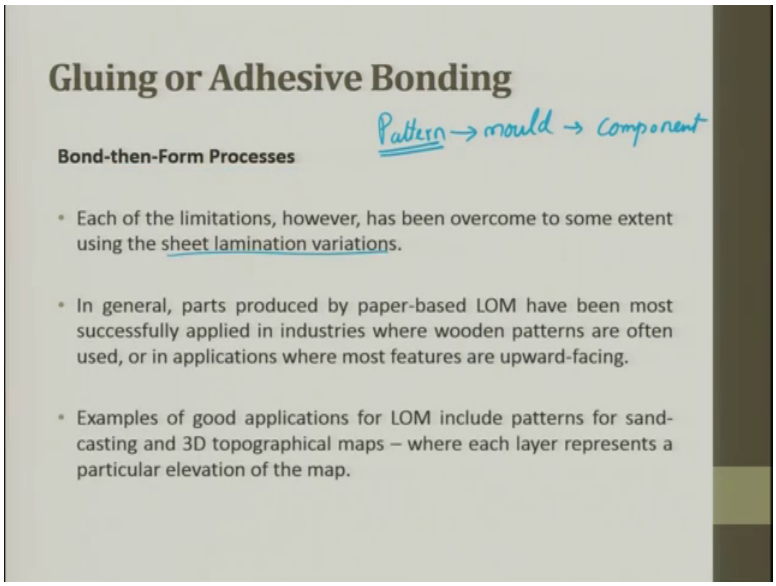

Each of the limitation; however, has been overcome to some extent using a sheet laminate variations. In general, parts produced by paper based LOM have been most successfully applied in industries where would patterns are often used.

So, now we are talking about patterns. So, pattern makes a mould, mould makes a component ok. These patterns which are initially made out of wood, are made out of this LOM. Example of good application for LOM includes patterns for sand casting and 3 D topological maps, where each layer represents a particular elevation of the map. So pattern, pattern live into mould, mould live into component.

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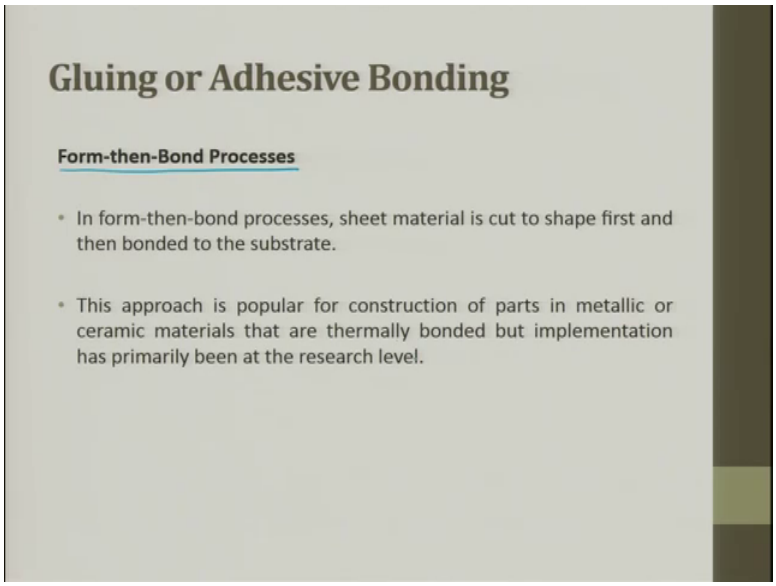

Form and then bond; so, till now what we are seeing? We were seeing bond then form. So, it is form then bond process. In form then bond process, sheet material is cut to shape first and then bonded to the substrate. So, first gluing happens and then shaping happens. Now, here shaping happens and then gluing happens; that is the difference. This approach is popular for construction of parts in metallic or ceramic materials that are thermally bonded, but implementation has primarily been at the research level only.

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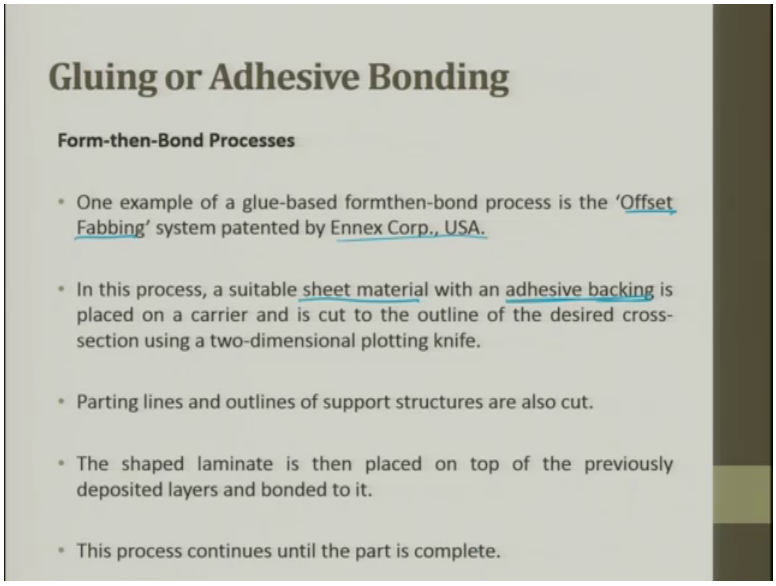

One example of the glue based form, then bond process is the 'Offset Fabbing' system pattern by Ennex Corp, USA. In this process, a suitable sheet material with an adhesive backing, a suitable sheet material with adhesive backing is placed on a career and is cut to the outline of the desired cross section using two dimensional plotting knife.

First, you cut it, parting line and outlines of supporting structure are also cut. The shaped laminate is then placed on top of the previous deposited layer and the bonding happens on it. This process continues until the part is complete. So, first you make the layer information and then glue it.

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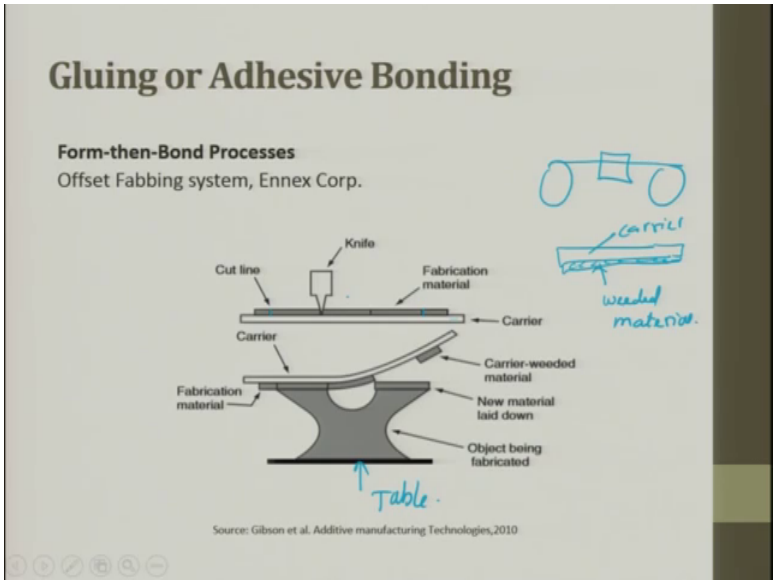

So, this is how it is. So, you can see here this is a part being fabricated, this is a table ok. Here, is the new material getting laid, this is a career weeded material this is a career ok. Career is a ok, if you want to put an analogy, you have a roller, you have a roller, there is a tape, which is going on and if I take the cross section of the tape tape plus this.

So, this is the carrier which is again running end to end and this is the weeded material. So, this is placed on top of it. So, you can see here, first the career layer. So, fabricated material is here, there is a knife, which goes around or you can use a laser which goes around and then this is a cutting line which is used. So, this cuts and we place it on top of the offset.

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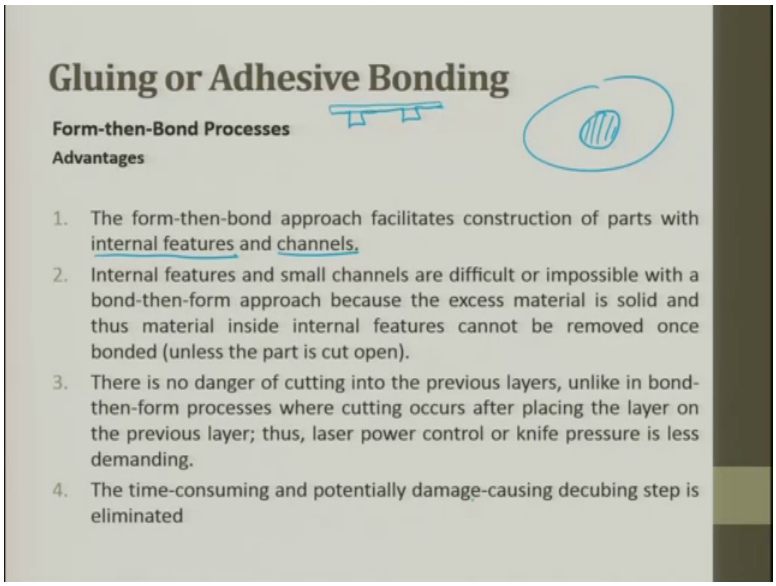

The form then bond approach facilitates construction of parts with internal features and channels ok. The form then bond approach facilitates construction of parts with internal features; that means, to say a egg yo albumin yolk right.

So, you have, if you want to have a internal structure or if you want to have a porous structure here, you can possibly have it and a channel, if you want to have you can do it. The internal features and the small channels are difficult or impossible with bond, then form approach look at it how beautifully they have. I have developed a process for internal features and channels, because the excess material is solid and these material inside the internal features cannot be removed once bonded so; that means, to say some one layer information, then the next layer information will be done.

So, now you cannot remove this. There is no danger of cutting into the previous layer, unlike in the bond then form process where cutting occurs after placing the layer on the previous layer; thus, laser power control or knife pressure is less demanding the time consuming and potential damage causing decubing step is eliminated permanently here.

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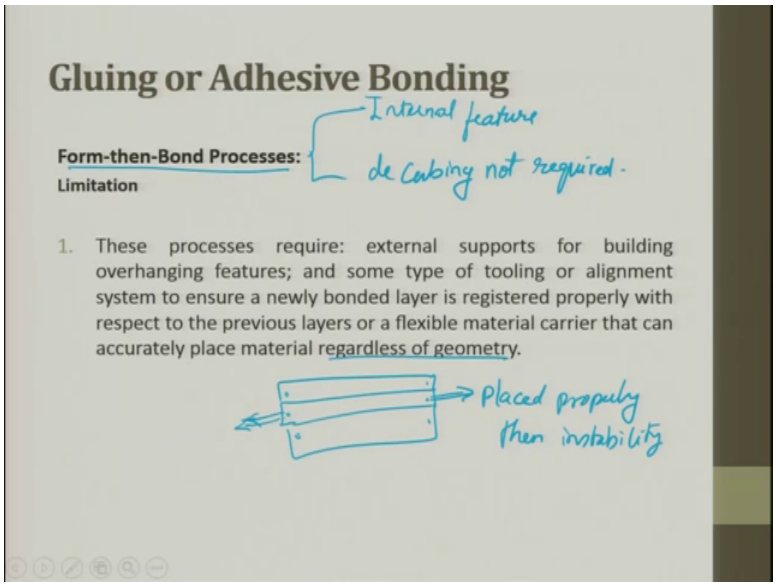

So, that is the advantage of form. So, form has internal features, internal features and decubing not required. The limitation is these process is required external support for building overhanging features; but this was not there in the LOM process and some type of tooling or alignment system to ensure a newly bonded layer is registered properly with respect to the previous layers or a flexible material career that can accurately be placed material regardless of the geometry.

Say for example, that is a big challenge, when you have material building up layer by layer so many a times this layers, what will happen? These layers if they are not placed properly placed, then not place properly then there will be instability or, where the layer can get delaminated if this is pulled or it is offseted. So, placing this one above each other at the exact points will try to help.

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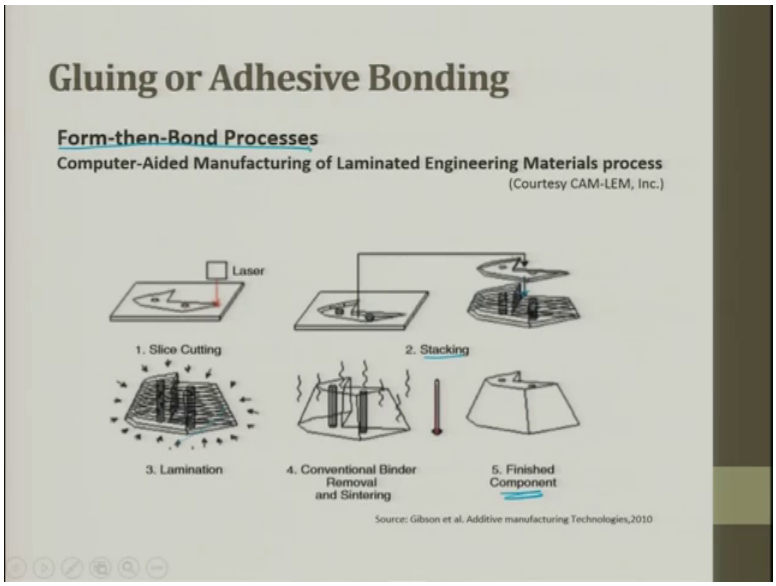

So, this is form then bond, first we use a laser. So, slice cutting is done then what we do is; we try to cut then stacking, then stacking is placing them on above each other.

Then what we do is we try to lamination is done and then conventional binder removal is done. So, all the binders are removed and the entrance and then finally, we get a finish talk. So, cutting and then what we do is, we try to cut and then keep the slice, stacking and this alone is removed and it is placed. All these things are consolidation happing, this lamination is consolidation then de binding and then finishing part. So, this is form then bond, which is different from bond then form.

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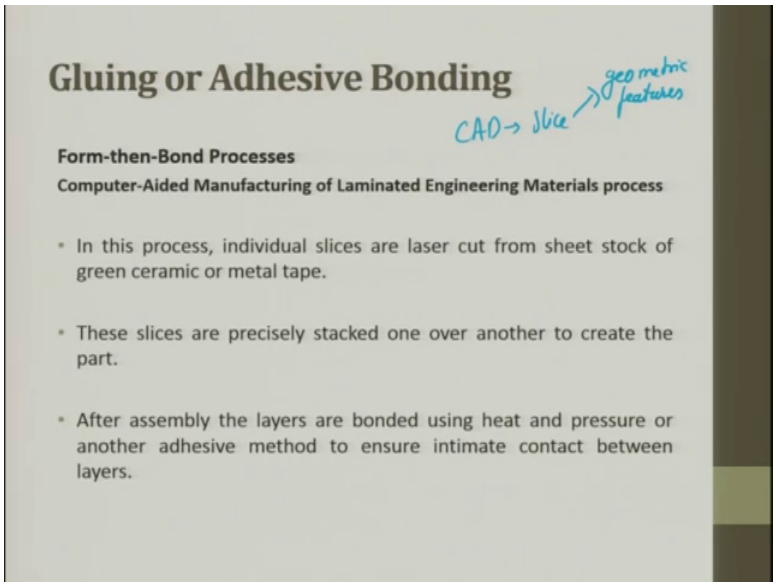

Computer aided manufacturing of laminated engineering material process; in this process individual sizes are laser cut from sheet stock of green ceramic or metal tape. These slices are precisely start to one over each, this is what I said is a limitation.

Placing it is a challenge. So, what we do is when we try to make a CAD and when we try to slice it itself we have some geometric features. These features what it will do is; this will try to orient and align properly such that when the next layer is formed it exactly sits there. After assembly these layers are bonded using heat and pressure or another adhesive method to ensure intimate contact between the layers.

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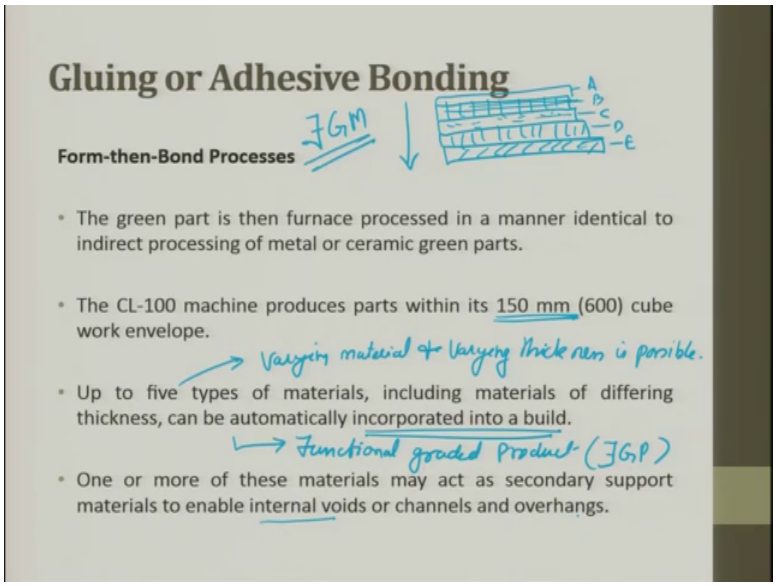

The green part is then furnace processed in a manner identical to indirect processing of metal and ceramic green parts. The CL 100 machine produces part within it is 150 millimeter cube work envelope. Up to five types of material include material of different thickness, can be automatically incorporated into the build.

So, this means that varying material and varying thickness is possible and the other thing is you can also make functionally graded products; that means, to say when you have five different types of materials. You can have one layer with whatever a material, two layer we can have this, three layer we can have this, four layer we can have this material and five layer we can have empty.

So, this is A B C D and E; so the functionally graded functionally graded material FGM's you can try to have through this process. So, these are nothing, but functionally graded products. One or more of these material may act as a secondary support material to enable internal voids or channels and overhangs.

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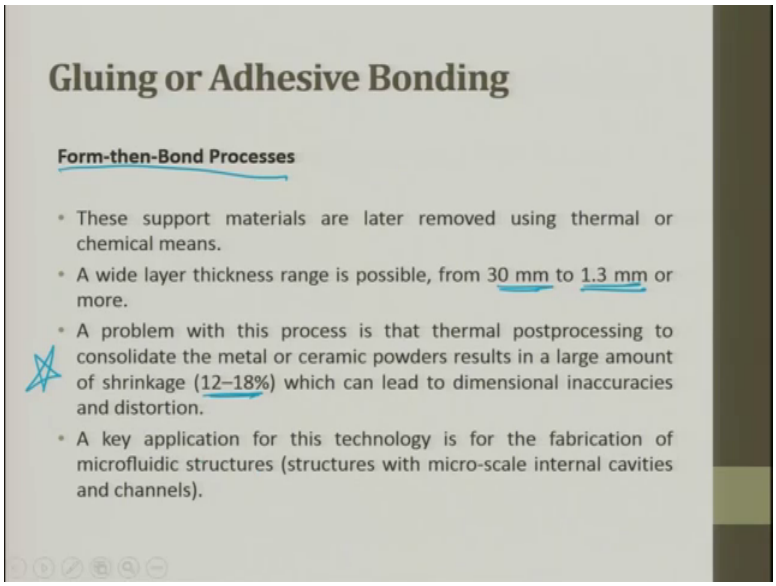

These supporting materials are later removed using thermal and chemical means. the wide layer thickness range is possible from 30 millimeter to 1.3 millimeters it can be done. A problem with this process is that thermal post processing to consolidate the metal or ceramic powder results in a large amount of shrinkage 12 to 18 percent, which can lead to dimensional inaccuracies and distortion.

We have to be careful; this is a very-very important point ok. So, moment it shrinks, it need not shrink uniformly, it will warp and shrink. So, there is a distortion, there is a delamination happening, be very careful. Form then glue; this is very important that there is a shrinkage coming a key application of this technology is for the fabrication of micro fluidic structures we can use form then bond processes.

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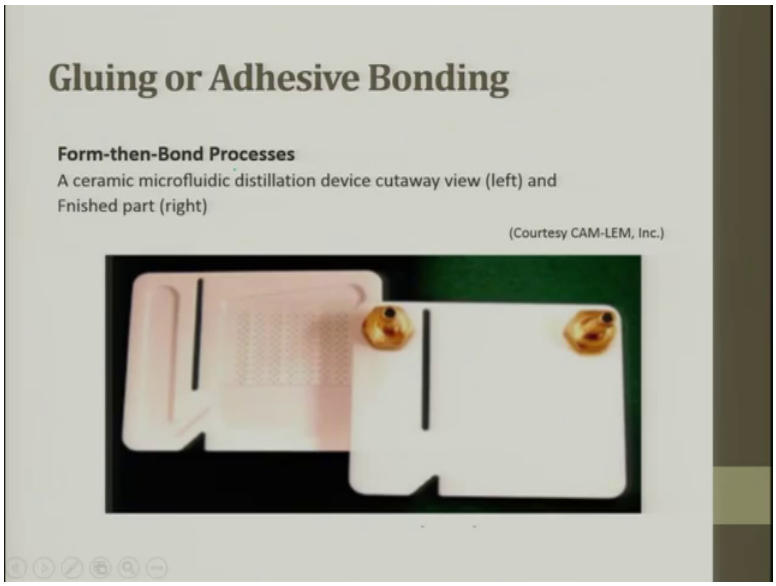

So, a ceramic micro fluidic distillation device cut away view left and the finished product is shown here, so that this can be used for micro fluidic application.

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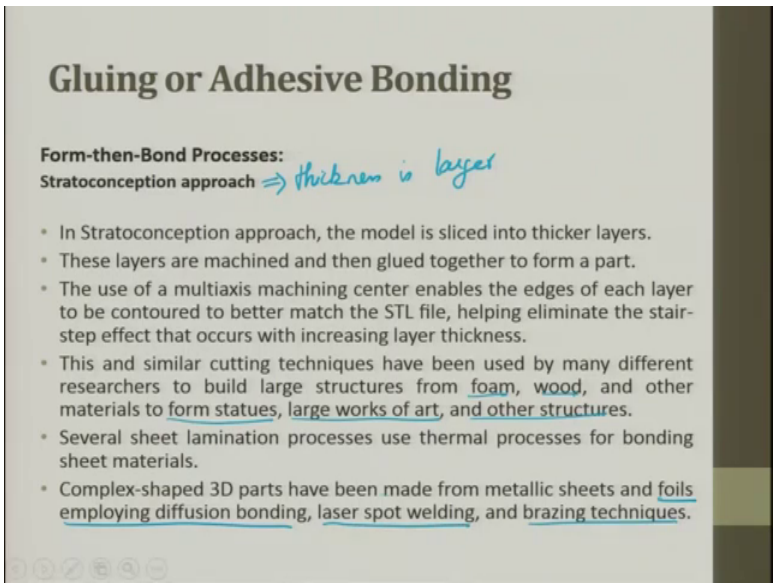

Stratoconception approach, in stratoconception approach, the model is sliced into thicker layers. These layers are machined and then glue together to form a part. For example, you take a bread loaf, take individual bread slice, this bread slice thickness is there, cut whatever information you want in each slice, than stack it together, the layers are machined and then glue together to form a part.

The use of multiax machining centre enables the edges of each layer to be contour to better match the STL file, helping eliminate the staircase effect that occurs with increasing layer thickness. This and similar cutting techniques have been used by many different researchers to build a large structures from foam, wood, and other materials to form statues, large work of arts, and other structures.

So, here we the biggest advantages, thickness is larger ok. So, that you can get, so you can use plywoods also to make. Several sheet laminated lamination process used thermal processes for bonding sheet material. Complex shaped 3 D parts have been made from metallic sheets and foils employing diffusion bonding, laser spot welding, and brazing techniques.

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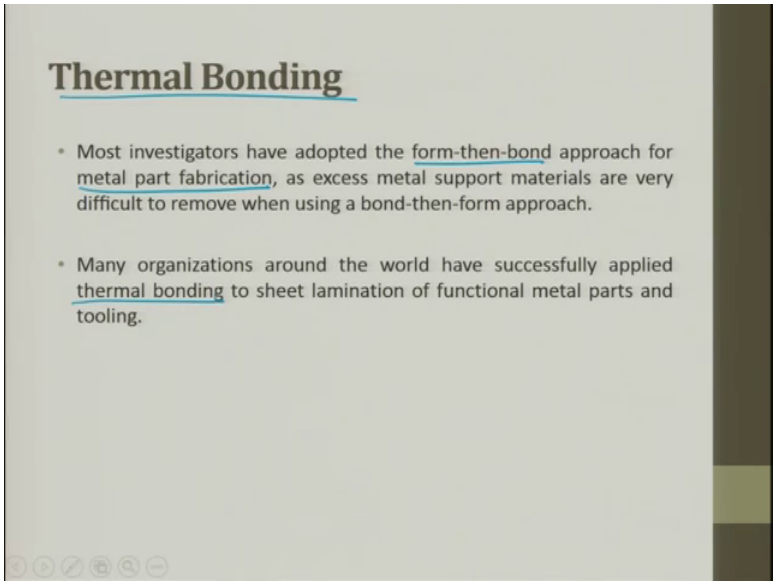

The most investigators have adopted the form then bond approach for metal part fabrication, as excess metal supports materials are very difficult to remove when using a bond, then form approach. Thermal bonding, metal parts, form and then bond approach, three important points.

Many organizations around the world have successfully applied thermal bonding to sheet laminate of functional material parts and toolings; so thermal bonding; thermal means temperature applied bonding.

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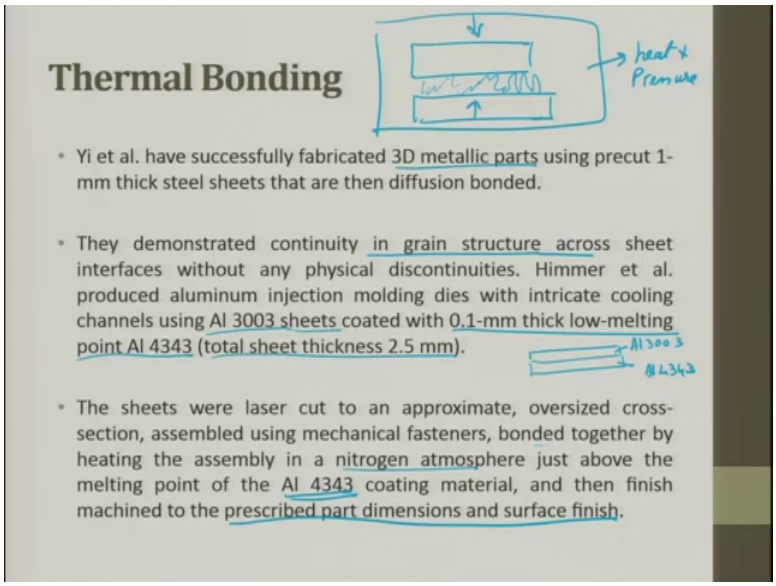

Yi et al. have successfully fabricated a 3 D metallic part using precut 1 millimeter thick sheet that are then diffusion bonded. They demonstrate diffusion bonding is, diffusion bonding is you have two materials you heat them, you apply heat as well as you apply pressure. So, when you apply heats these two and pressure also there is a diffusion happening between these two structures; so there will be joining happening here. They demonstrated continuity in grain structure across heat interface without any physical discontinuity.

So, you get a better green consolidation. Himmer produced aluminium injection molding die with intricate cooling channels using Al 3003 sheet coated with 0.1 millimeter thickness of low melting point Al 4343 material. So, the total thickness is 2.5 so; that means, to say like cladding you can do take one sheet of higher melting point, other sheet of low and then you can do.

So, it is Al 3003, this is Al 4343 ok. The sheets for laser cut to an approximate, oversize to cross section, assembled using mechanical fasteners, bonded together by heating the assembly in a nitrogen atmosphere, because it should not get oxidized just above the melting point of Al 4343 coated material, and then finished machine to the prescribed part dimension and surface finish.

So, this is what is very important; so between these two, you will always have the lower melting point material we will melt and in the nitrogen atmospheric it will join.

Assembly using mechanical fasteners bond, mechanical fasteners we do not use, we always go for bonding together by heating. So, this is easier to do and the process can be automated.

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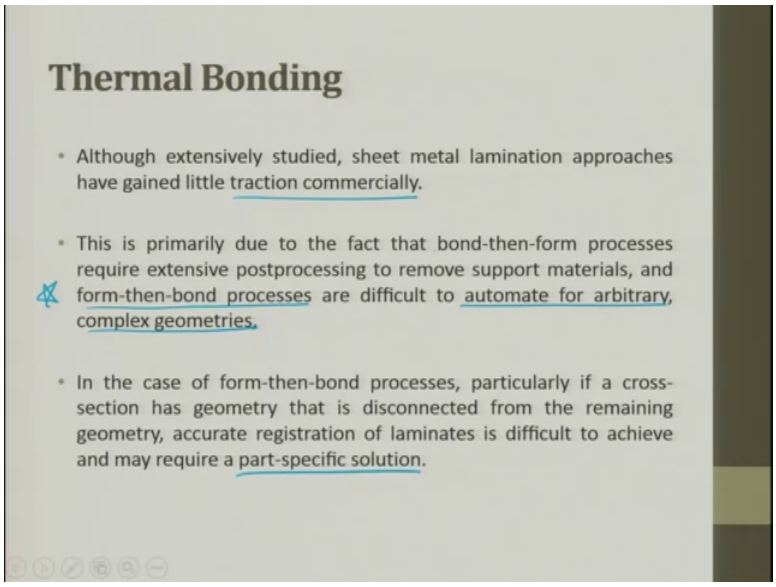

Although extensively studied, sheet metal laminated, lamination approaches have gained little traction commercially, because the final output was not a solid part, which can be a directly taken for rapid manufacturing.

So, when you start making the ceramic part and the when you are ceramic part and the metal, you saw the example of micro fluidic channel made, that is direct rapid manufacturing. So, there is nothing in between, you have made it using ceramics, we have consolidate, got the output whatever you want ok. So, that is what this process is directly thought of in many a times for rapid manufacturing.

This is primarily due to the fact that bond then form process require extensive post processing to remove supporting material, and form then bond process are difficult to automate for arbitrary, complex geometries important. In the case of form then bond process, particularly if a cross section has geometry that is disconnected from the remaining geometry, accurate registration of laminates is difficult to achieve and may require a part specific solution.

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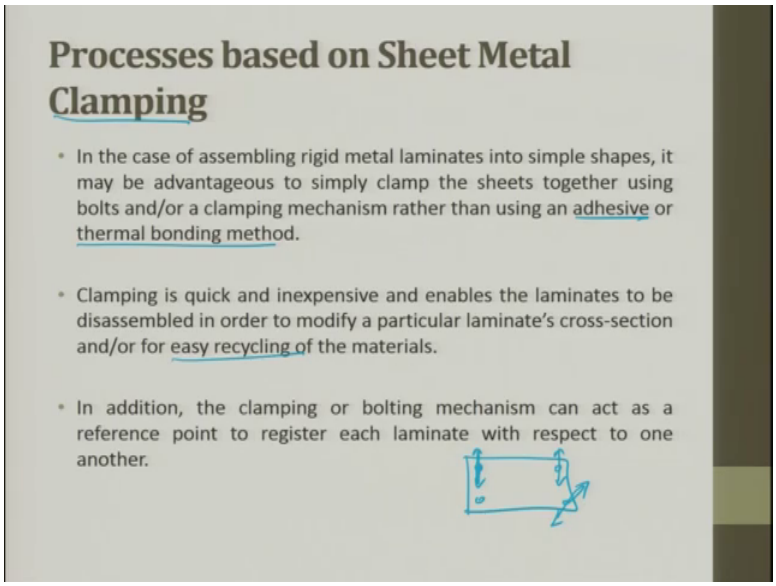

In case of assembling rigid metal laminates into simple shapes, it may be advantages to simply clamp the sheets together using bolt and a clamping mechanism rather than using an adhesive thermal bonding method. Clamping ok, camping is quick and inexpensive and enables the laminates to be disassembled in order to modify a particular laminate cross section for easy recycling on the material. So, you here you put a clamp nut and a bold or something rather and then you start unscrewing, removing, dismantling, change the layer, whatever you want and then you can now, you can reuse the same material.

For easy recycling on the material we go for clamping also; adhesive, thermal, then clamping. In addition, the clamping or the bolting mechanism can act as a reference point to register each laminate with respect to one another. So, every laminate what will happen is you will have four holds. So, these holds will be used as a locating point you push here nut or a screw here and then you start tightening it and then you get the consolidation.

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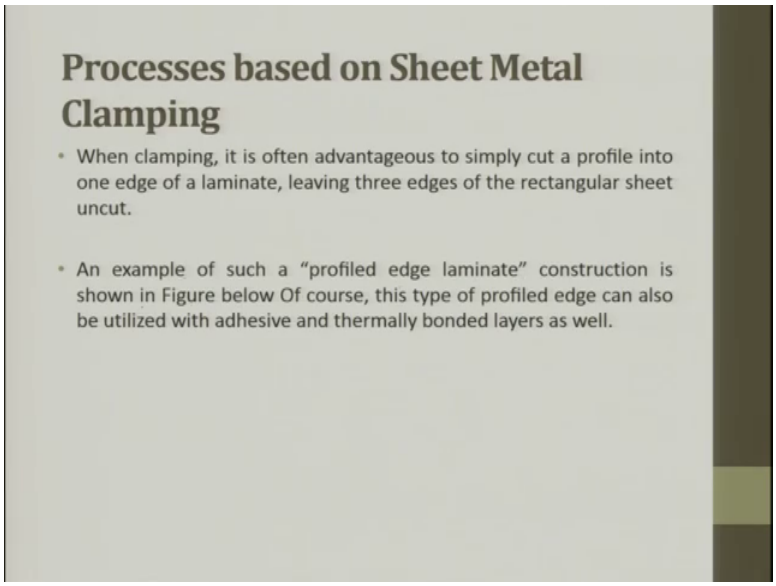

When clamping, it is often advantages to simply cut a profile into one edge of a laminate, leaving three edges of the rectangular sheet uncut ok. An example of such profile edge laminate construction is shown in the next figure.

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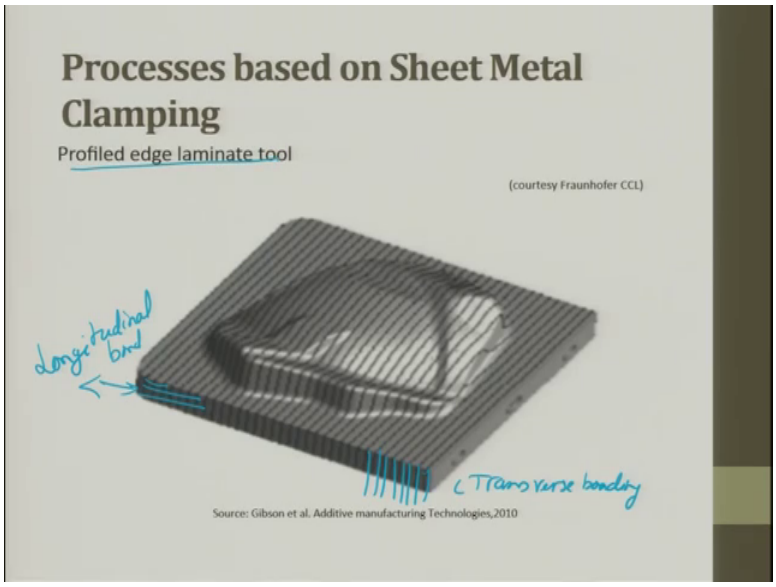

So, this is what it is. You can see here, these are layers and interestingly you should also know, it is not necessary every time the layer can be formed in this way. The layer can also be formed this way, depending upon your product. You can try to have either

longitudinal bonding or you can have transfers bonding ok, that depends whatever you want. So, this is profile edge laminated tool is used for making it.

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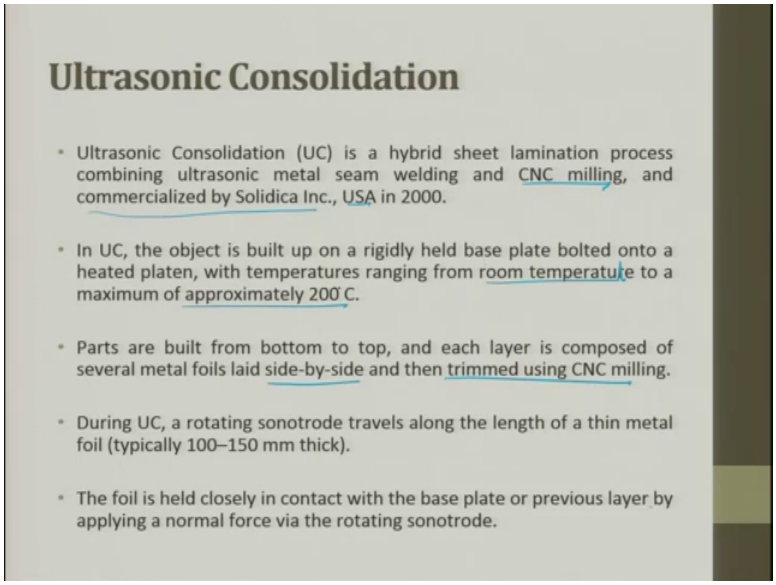

The ultrasonic consolidation is a hybrid sheet lamination process combining ultrasonic metals seam welding and CNC milling. So, metal seam welding and CNC milling and commercialized by Solidica Inc, USA in 2000.

In ultrasonic consolidation, the object is built up on a rigidly held base plate bolted on to a heated platen, with temperatures ranging from room temperature to approximately 200 degree Celsius. Parts are build from bottom to top, and each layer is composed of several metal foils laid side by side and trimmed using a CNC milling machine. During UC, ultrasonic consolidation a rotating sonotrode travels along the length of a thin sheet foil. This foil is held closely in contact with these base plate or previous layers by applying a normal force by other rotating sonotrode.

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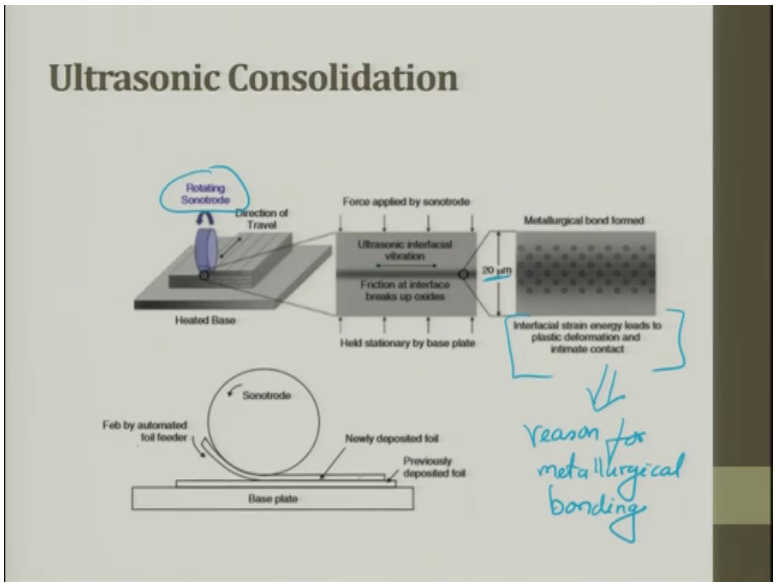

So, this is what is the rotating sonotrode;. so here if you see, this is a heated base, this is how the object is getting built, and here is a rotating sonotrode, it is a drum, which goes from this to this.

So, it tries to consolidate and try to make it. So, when you see the side view a sonotrode goes feed by automatic foil feeder; so this is fed. So, these two are cladded together by the sonotrode. So, if you look at it, the force applied by sonotrode, this will be the force which is getting applied. So, this will be one layer, this will be the other layer, the vibration is given in this direction. So, that what happened the friction at the interface breaks the outside layer. So, two nascent nascent layer comes in contact and that is done by the force whatever you apply it glues.

So, the metallurgical bond which is getting formed I have written it very clearly, 20 microns only, the interfacial strain energy leads to plastic deformation and intimate contact. So, this is what is the reason for metallurgical bonding ok; so the interfacial strain energy is lead to plastic formation and intimate contact between these two.

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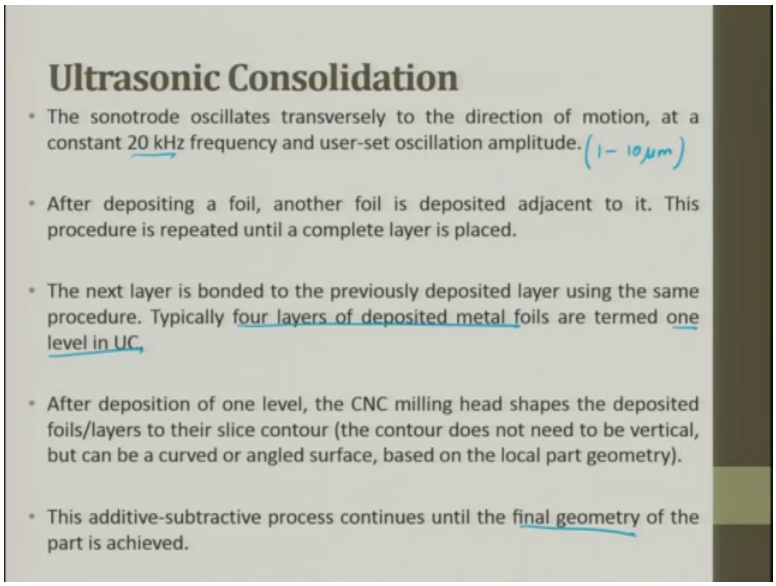

The sonotrode, moment you say ultrasonic with we use 21 kilo hertz. Yes, sonotrode oscillates transversely to the direction of motion, at a constant frequency of 20 kilohertz and the user set oscillation amplitude.

This will be from 1 micron to 10 micron or 20 micron maximum. After depositing a foil, another foil is deposited adjacent to it next to it. This procedure is repeated until the complete layer is placed. The next layer is bonded to the previous deposited layer using the same procedure. Typically four layers of deposited materials, metal foils are termed one level in UC, four layers so that you get a considerable amount of thickness.

After deposition of one level, the CNC milling head shapes the deposited foil layer to their slice contour and then it slice, it around and then you try to get it. This additive subtractive process continuous until the final geometry of the part is achieved.

So, you make four you machine, it then you make four, then you machine it and finally, what you get is a metal consolidated using ultrasonic for building up a rapid manufactured 3 D part 3 D metal part.

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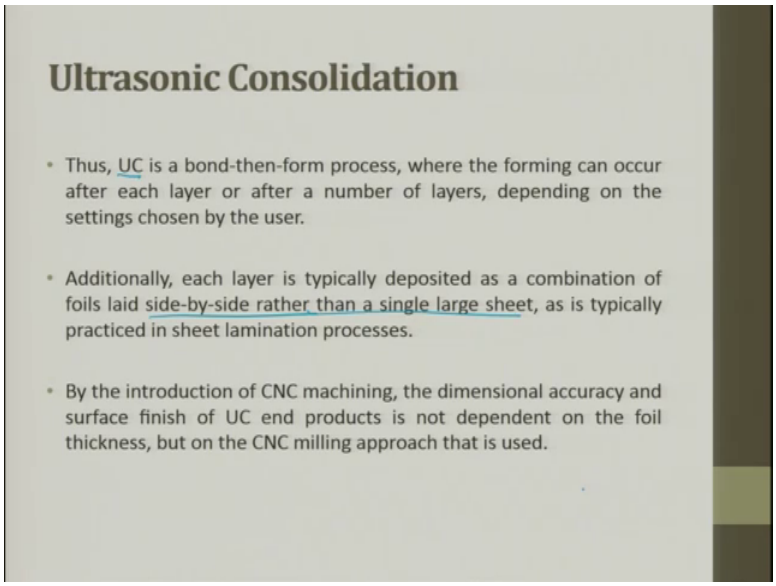

Thus, UC is a bond then form bond then form correct no, earlier if you cut this slice and then make it is form and then bond. So, you see falls in the bond then form process, where the forming can occur after each layer or after a number of layers, depending on the setting chosen by the user. Additionally, each layer is typically deposited as a combination of foil laid side by side rather than a single layer, where it will be done side by side rather than a single layer as is typical practice in sheet laminated process.

By the introduction of CNC machining, the dimensional accuracy and the surface finish of UC end products is not dependent on the foil thickness, but on the a CNC milling approach.

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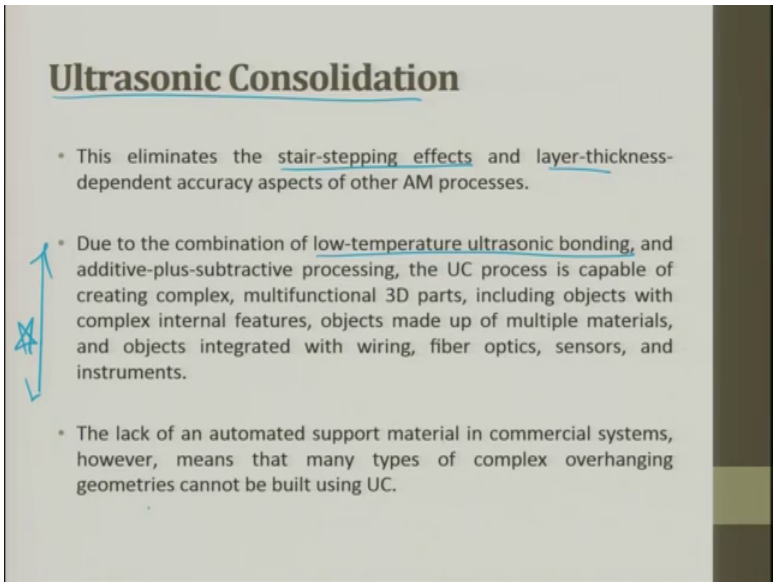

This eliminates the staircase effect, whatever is getting formed when to do layer by layer approach, we have this staircase that is removed by ultrasonic consolidation method and layer thickness depends accuracy aspect of other AM processes.

Due to the combination of low temperature ultrasonic bonding, and additive plus subtractive processes the UC process is capable of creating complex, multifunctional 3 D part, including objects with complex internal features, object made from multiple material, and the objects integrated with wiring, fiber optics, sensors and instruments. So, this is a very important take over a message of this process of ultrasonic consolidation.

The lack of an automated support material in commercial systems, however, means that many types of complex overhanging geometries cannot be built using UC.

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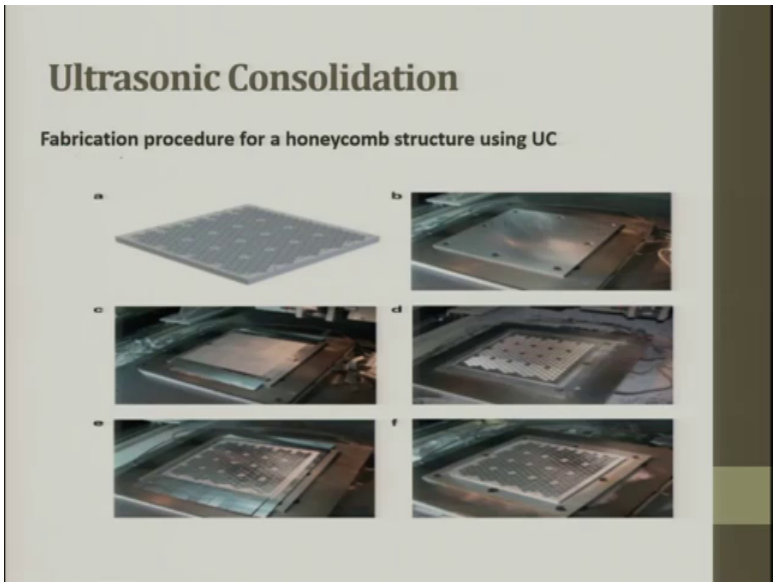

So, this is what it is. So, you have the fabrication procedure for a honeycomb structure using UC. So, honeycomb structure, so this is b. So, you keep, you keep the other layer, then you see that layer which is placed here, then honeycomb, whatever it is we have done here then e and then f. So, ultrasonification happens consolidation happens and then you get the layer.

Thank you.