# Rapid Manufacturing

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## Lecture – 24
## Extrusion and Liquid based processes (Part 2 of 2)

Welcome back to the lecture which we were discussing about Extrusion and Liquid based processing.

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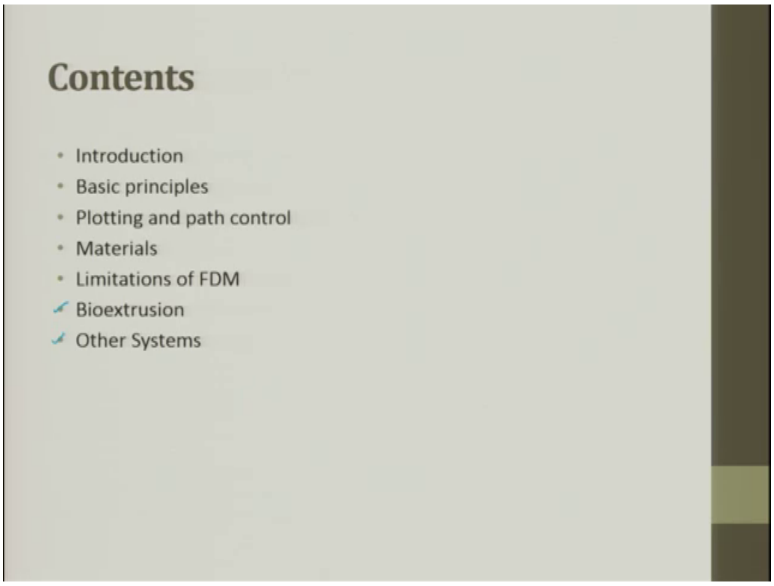


In the previous lecture we were more focused towards Extrusion process in this lecture we will be focus towards Liquid based processes. So, we will start looking into Bio Extrusion and other processes here.

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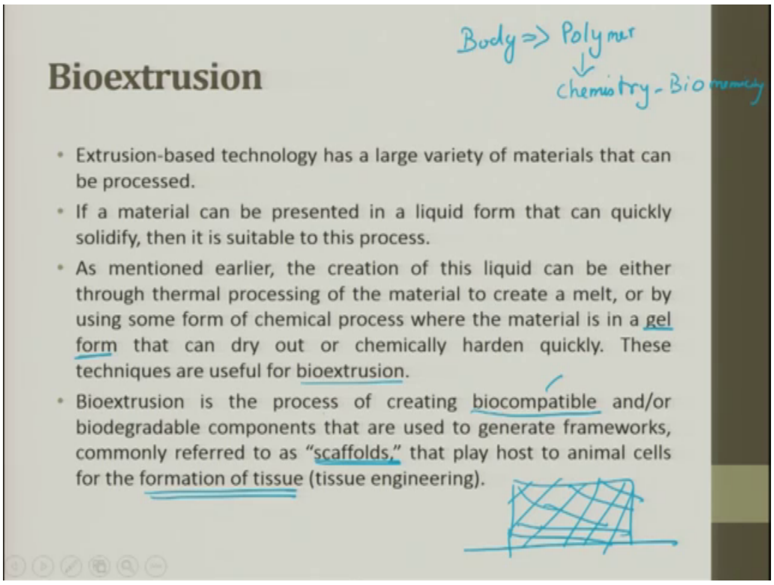


Bio Extrusion process this is an extrusion based technology has a large variety of material that can be processed, if a material can be presented in a liquid form that can quickly solidify then it is suitable for this process. As mentioned earlier the creation of this liquid can be either through thermal processing of material to create a melt or by using some form of chemical process where the material is in a gel form that can dry out or chemically hard and quickly, these techniques are useful for bio extrusion.

So, the analogy for this is if you keep the fevicol exposed to the free atmosphere it reacts and it solidifies, so that is what it is so or by using some form of chemical process where the material is in a gel form semi solid form that can dry out or chemically hard and quickly. For example the glow whatever we use for sticking the tyre puncture; fevicol all these things undergo this process, so this techniques are useful for bio extrusion bio extrusion is the process of creating biocompatible very interesting.

So, if you see our body if you see our skin, tissue they are all made out of polymers body is made out of polymers of course the skeleton is there, but the covering layer will be polymers these polymers today people have understood the chemistry and then they have started mimicking it, so they call it as Biomimicking. So, they call it as biomimicking, in biomimicking what happens understand the chemistry redevelop the material to artificially to match the natural one.

So, this material is fabricated that is in a gel form and it is extruded and when you say it is in a gel form if you go back and think in the extrusion process we had a wire, the diameter of the wire the nozzle diameter always had a restriction on it. So, if we can reduce the nozzle diameter and control the flow of the material then you can get very high resolutions or the features whatever you make will be very close to reality, so that is why they use liquid as a starting metal or a gel as a starting material.

So, bio extrusion is a process of creating biocompatible and or biodegradable components ok, why do we call it as biodegradable? Suppose you integrated into your body and it is there for some time and then it should be biodegradable for example today they have staplers.

So these staplers for example, if you have a surgery in your skin it is cut and earlier we do sutures stitches and initially these stitches the threads where not biodegradable then came biodegradables sutures that means to say threads. Now what is happening we have biocompatible or biodegradable staplers, so they just pull out the skin and stapler it and leave it there.

So, over a period of time the stapler also dissolves the skin also joints and you do not see any scar mark there. So, biodegradable components are there that are used to generate framework commonly referred to as scaffold, that play host to animal cells for the formation of tissues.

So, either you can make you can make a scaffold or you can make a compound like this and where and which you can put it inside and ambiance and in that ambiance you will allow the bacteria to grow or whatever cells to grow. Then the cells are taken out and then it is integrated into the body so or the cells form the tissues.

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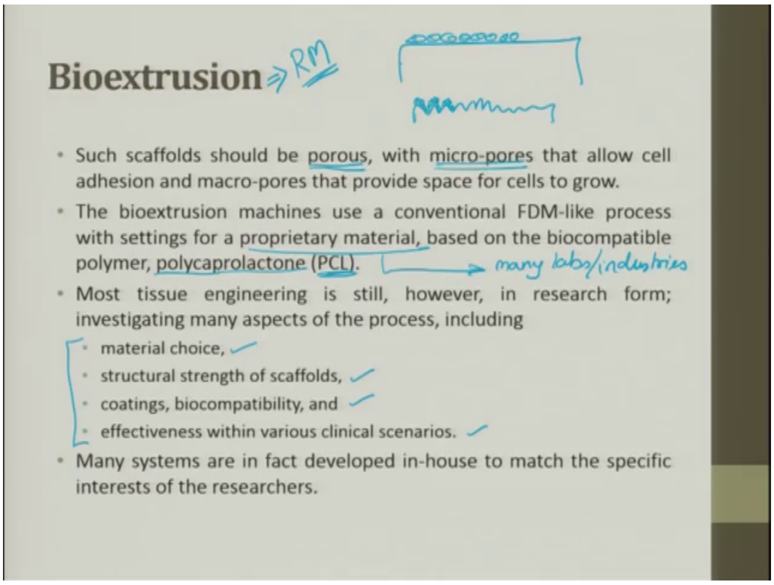


Such scaffolds should be porous, so we do not need we do not need completely densed material we need porous, so that through this porous material the flow can happen, the cell can grow and it can get attached to the body with micro pores that allow cell adhesion. See if you have a flat body cell to sit on top of it is very difficult, but if you have a undo related surface the cells can sit and get locked very fast.

So, this is what we are talking about the pores if you see that it this can I have just put on the surface you can have across the surface if you want to do you can do. Bio extrusion machine use a conventional FDM like process with setting for a proprietary material, this is a challenge where many labs many labs and industries are working; it is completely preparatory ok. You can use light to solidify you can allow free atmosphere to solidify you can allow oxidation to happen.

So, many materials are getting integrated based on the biocompatible polymer polycaprolactone PCL is a material which is generally used, most tissue engineering is still however in the research form. Investigating many aspects of this process includes material choice; depending upon the customer requirement the material choice the material adding and deleting can be done, today the technology of the process engineering has gone to such an extent they decide what to add what not to add.

They can functionalize they can coat whatever they want they can do, next is structural strength of the scaffold then coating and biocompatibility can be done, effectiveness with various clinical scenarios, so these are some of the aspects which are done. See what happens in engineering products engineering products? We just make a product do a mechanical test and you certify that is, but whereas when you want to integrate this product whatever is getting developed through rapid prototyping as a replacement for the existing technology.

So, then what we will do is we will have to do the trial on animal, then see that see the performance then put it on man wait for 10 years or 8 years whatever it is and then we say now it is worthwhile trying in the human body. So, it takes a long time so that is what we are talking about effectiveness with various clinical scenario. Clinical scenarios, if you make bio product or if you make a bio mechanic product and if you integrated outside the body it is easy to get clinical clearance, if it is a inside it needs a stringent testing ok.

So, these are some of the investigation even now people are executing it the challenge here is not the machine, the challenge here is the proprietary material. Many systems are in fact, developed in house to match the specific interest of the researcher. So when bio extrusion comes into fullest extent we will talk more of rapid manufacturing only, the prototyping is gone the product what gets develop from this process bio extrusion process.

Let it be FDM or any other route whatever gets it is directly called as rapid manufacturing, why because you have made the live product which gets into the real time application directly. So, here bio extrusion people are now talking about only polymers slowly slowly people are started going towards ceramics that is hydroxyapatite they have started talking and then they are also now talking about can we directly put metals and can we extrude metals, so that is the other thing which people are talking about.

So, here these are some of the challenges and when we talk about the product the product feature size feature size not the products size a feature size is very important. Next one is the roughness on the surface, the roughness on the surface can be selectively made for a cell to adhere cell not to adhere. So, you can selectively roughen the surface or make a porous structure in the surface, such that the cell goes sticks there and starts growing there. So, bio extrusion is one of the major process which leads towards rapid manufacturing.

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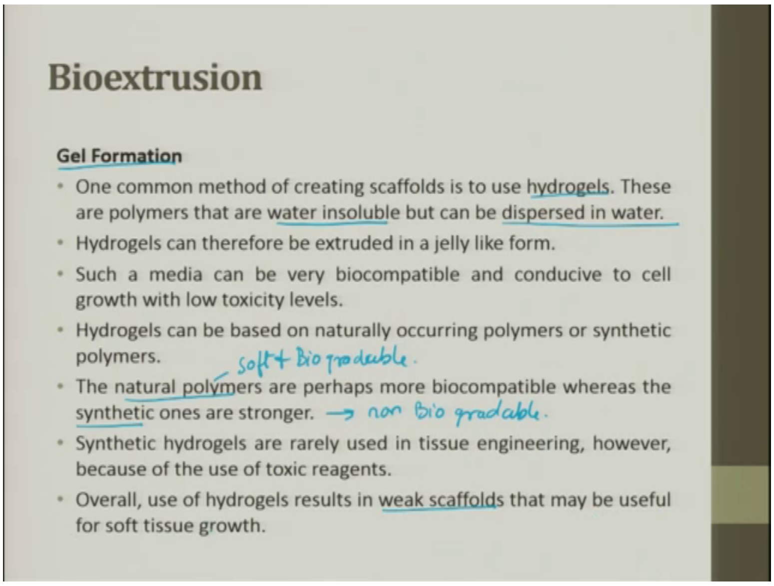


Gel formation one common method of creating scaffold the output product is to use hydrogels this is a material hydrogels. These are polymers that are water insoluble but can be dispersed in water insoluble but dispersed in water. You see that you can cook the material to your requirements, of course there is a huge intellectual challenge there.

But people are slowly getting out of that simulation some come up in a big way molecule dynamics simulation which we talk about it has come up in a very large way. So, that can give you lot of understanding of the formation of polymers, hydrogels can therefore be excluded in a jelly form such a media can be very biocompatible and conducive to cell growth with low toxicity level.

Hydrogels can be based on naturally occurring polymers or synthetic polymers, the natural polymers are perhaps more biocompatible whereas the synthetic ones are stronger. So, you see natural polymer and synthetic polymer natural is soft and biodegradable easily, synthetic are strong and it is many a times you add elements to it which is non biodegradable many a times some of the elements not all the elements. Synthetic hydrogel are rally used in tissue engineering, however because of the use of the toxicity reagents overall the use of hydrogel results in weak scaffolds that may be useful to soft tissues.

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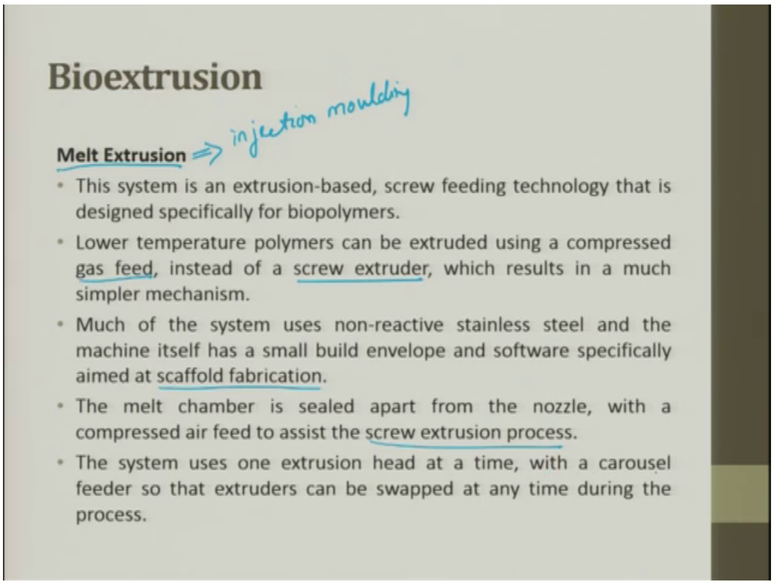


Melt extrusion is a process which is done this system is an extrusion based, screw feeding technology that is designed specifically for biopolymers. Melt extrusion, if you understand the process of injection moulding melt extrusion you can understand, lower temperature polymers can be extruded using a compressed gas feed instead of screw extrusion.

So, screw extrusion see what is happening is the challenge and all these injection moulding machine says you have a largest charge you need a large charge. That means, to say the raw material minimum required will be in few 10 kilos. So, if you want to make small components then we have to make a small hopper and we also try to avoid the screw.

So, there we use a compressed gas feed which results in a much simpler mechanism much of a system use non reactive stainless steel and machine itself has a small built envelope and software specifically aim into aiming at the Scaffold fabrication. The melt chamber which we saw in FDM is sealed apart from the nozzle with the compressed air feed to assist the screw extrusion process. Whatever screw did earlier now the screw is replaced by the air; the system uses one extrusion head at a time so that means to say you can have multiple extrusions.

So, multiple extrusions is you can have multiple materials coming out from different different nozzles, depending upon your requirement, depending upon your colour, you can blend it you can get; with a carousel feeder, so that extruder can be swapped at any time during the process.

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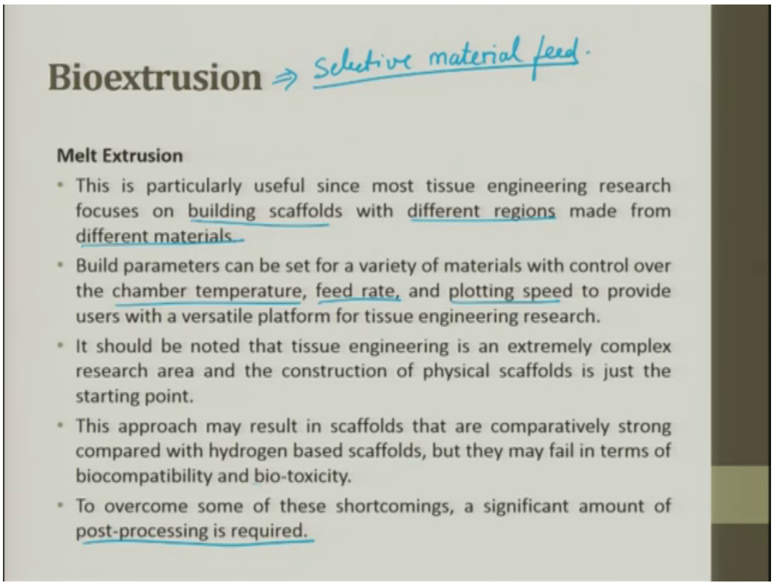


This is particularly useful since most tissue engineering research focuses on building scaffold with different regions made from different materials, this is what I was talking to about in bio extrusion we do selective selective material feed. Build parameters can be set for a variety of materials with control over the chamber temperature feed rates plotting speed to provide user with a versatile platform for tissue engineering research; this we have already discussed the chamber temperature.

So, that the glowing can happen properly feed rate and then plotting speed; it should be noted that the tissue engineering is an extremely complex research area and the construction of physical scaffold is just a starting point.

This approach may result in scaffolds that are compared with hydrogen based scaffolds, but they may fail in terms of biocompatibility and bio toxicity. So, when you replace it if we have this problem to overcome some of the shortcomings significant amount of post processing is required. So, what we do is we talk about coating the scaffold whatever is manufactured.

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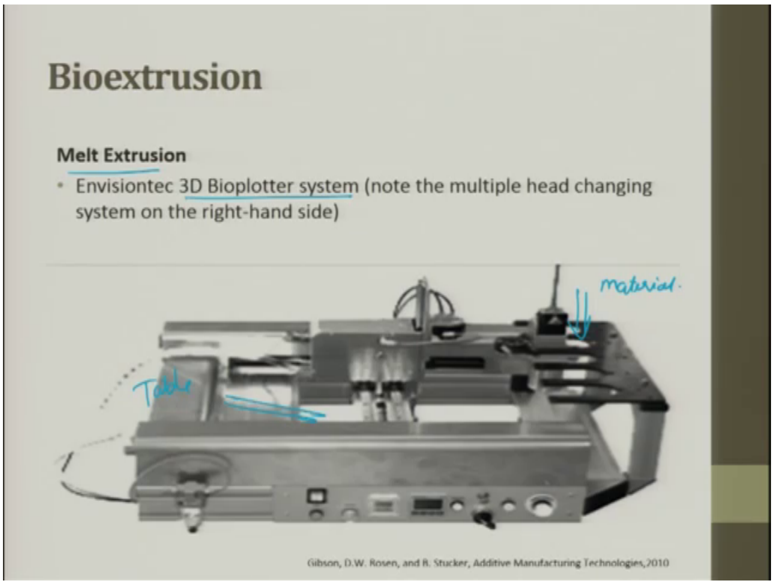


So, this is one of the bio plotter which is used, so you can see here these are the place where you keep the cartage material and this is the table which is used the machine looks to be a desktop machine. So, here are the cartridges which we keep for multiple material selectively you want to do you can use it.

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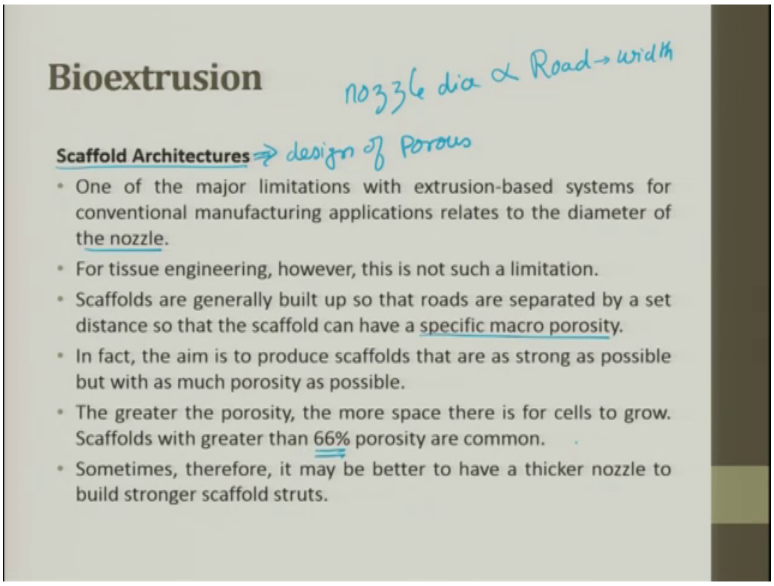


Scaffold architecture so scaffold architecture is another big challenge, when we talk about rapid manufacturing using this process in biologies scaffold architecture is a big challenge, one of the major limitation with extrusion based system for conventional manufacturing application relates to the diameter of the nozzle. So, scaffold because the nozzle diameter; nozzle dia is directly proportion to the road which is made ok.

So now since it is visco elastic then it is directly proportional to width of the road ok, for tissue engineering; however, this is not such a limitation. Scaffold are generally built up; so that the roads are separated by a set distance, so that the scaffold can have a specific porosity. So, that is what is a challenge here architecture is you decide and design your porous; design of porous for cell to grow that is a challenge.

In fact, the aim is to produce scaffold that are strong as possible but with a much porosity as possible, the greater the porosity the more space there is for cell to grow. Scaffold with greater than 66 percent porosity are common today. Now look at the weight already it is polymer based and then you will have you make it which 66 porosity it will be very light.

But now the challenges how do you strengthen a 66 percent porous material therefore, it may be better to have a sticker nozzle to build a stronger scaffold. So, designing of the pore this leads to nozzle design nozzle design leads to road width.

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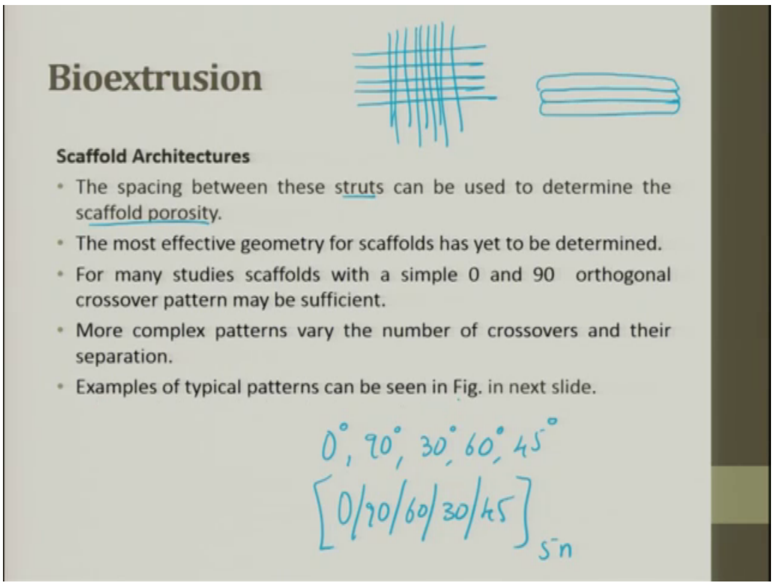


The spacing between the struts can be used to determine the scaffold porosity; the most effective geometry of scaffold has yet to be determined for many studies scaffold with a simple 0 and 90 orthogonal crossover pattern may be sufficient. So, what they say is they say you will first layer put like this, next layer you will put like this and the third layer may be you will put like this ok.

So, if you see that first layer second layer third layer, so what have you done you have change the orientation such that you strengthen the material. The more complex pattern may have vary in crossover patterns why? It can have 0 degrees it can have 90 degrees, it can have 30 degrees it can have 60 degrees it can have 45 degrees, it can have a combination 0 slash 90 slash 90 slash 30 slash 45 and then you can do it like 5 times. So, this pattern will be repeated so about the axis you will repeat it, so why do we do this? Because we try to distribute the strength.

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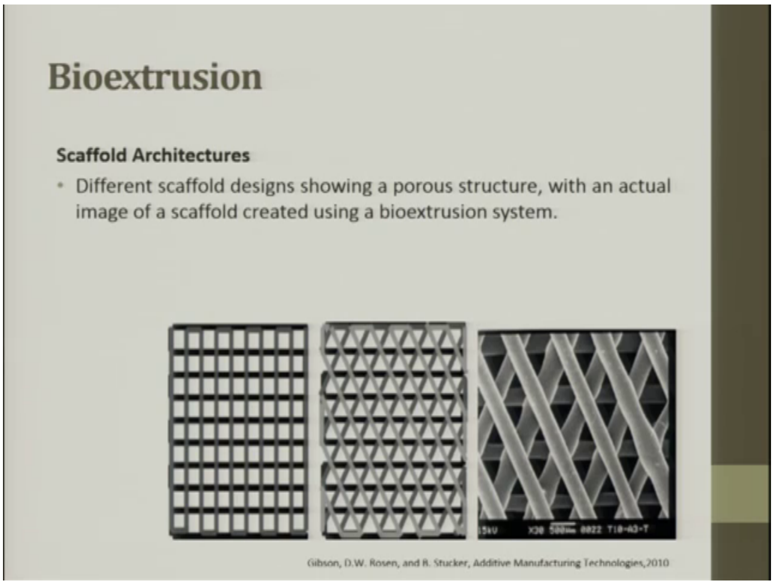


Example of typical figures are given in the next 2 figures. So, you can see these are the scaffold architectures, so this is what it is you can see 0 degrees may be 45 degrees, this is may be minus 45 degrees you can have. So, different scaffolds each scaffold has different strength build time varies and you can also the density of the material varies of the product varies.

So, we have all these important points and then when you also try to do when you have these structures the heat shrinkage is controlled ok. Heat shrinkage is controlled so these are very important factors when we start working on this porous structure and when you want to make scaffolds for real time application.

So, this leads directly towards rapid manufacturing, so what you print gets integrated into your body and still it is in the research stage. There are few labs abroad where started making testing's and then they have started implementing in the body, but still a long way to go..

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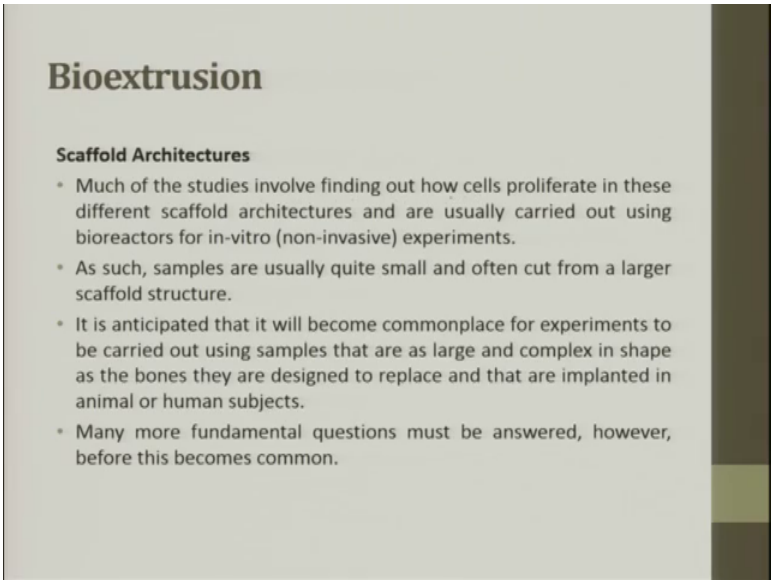


Much of the study involves finding out how cell proliferates in these different scaffold architecture and are usually carried out using bioreactors for in vitro experiments. As such samples are usually quite small and often cut from a large scaffold structure it is anticipated that it will become common place of for experiments to be carried out using samples that are as large and complex in shape as the bones they are trying to replace the bones ok.

if you see bones bones are not dense bones are there are dense outside it is dense inner it is hollow. So, we are trying to mimic that they are designed to replace and they are implanted in the animal or the human subjects many more fundamental questions must be answered, however before this becomes into common.

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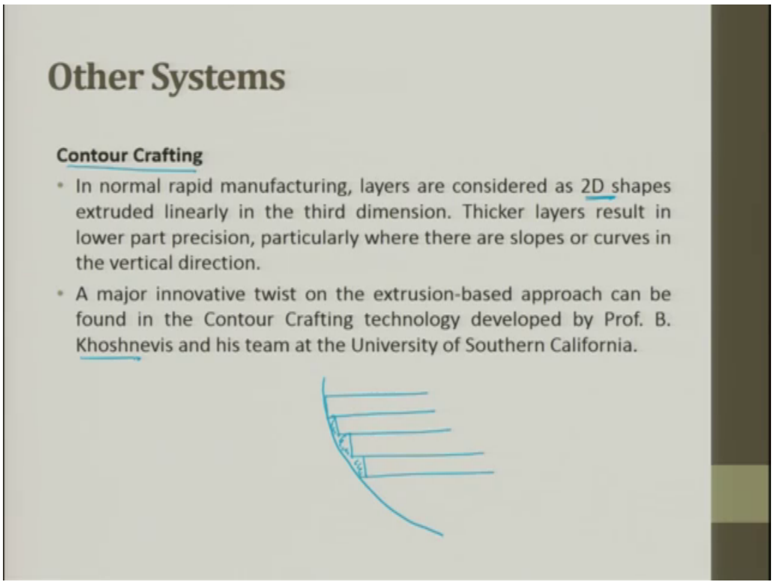


The contour crafting in normal rapid manufacturing layers are considered as 2 D shapes extruded linearly in the third dimension, thicker layers result in lower part precision particularly where there are slopes or curves in a vertical direction. So, what you are trying to say is the if there is a slope change like this if you want to make multiple layers you will make layers like this.

So, you look at it so this is what they talk about is the error. The thicker layer results in the lower part dimension because there is a huge error resulting where the slopes or curves are in vertical direction, a major innovative twist on the extrusion based approach can be found in the contour crafting technology developed by professor B Khoshnevis and his steam in University of Southern California.

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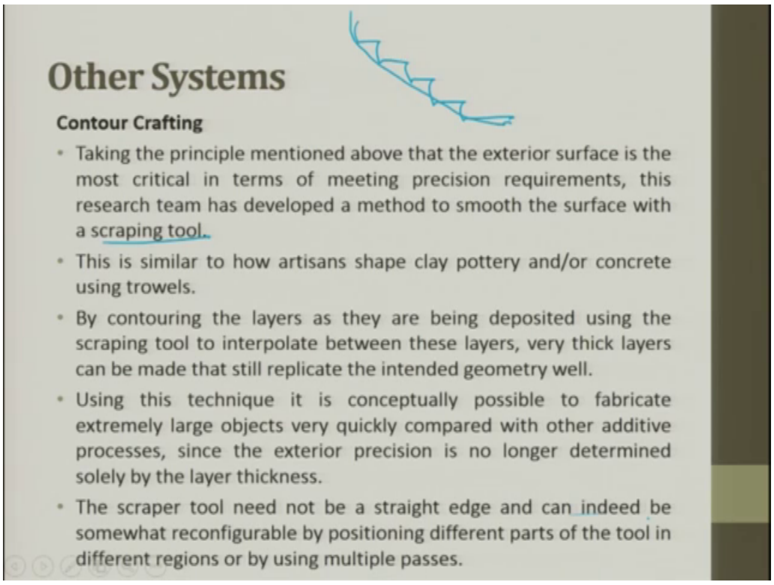


The contour crafting taking the principal mentioned above the exterior surface is most critical in terms of meeting precision requirements. This research team has developed a method to smoothen the surface with a scraping tool. So, what we can do a suppose you have a pattern like this, so what you do if you try to smoothen it by giving a by using a tool why because, it is a polymer material if I can play with a temperature I the material the product or the scaffold whatever is made is not is not rigid or solid.

So, I just use a blade or a hot wire and then sweep it around try to smoothen the surface, so that is what is talked about the scraping tool. This is similar to use a partition shape clay pottery and the concrete using travels, by contouring the layer as they are being deposited using the scrapping tool to interpolate between these layers very thick layers can be made that still replicates the intended geometry well.

Using this technique is conceptually possible to fabricate extremely large bodies very quickly compared with the other additive processes, since the exterior precision is no longer determines only by the layer thickness. The scraper tool need not be straight edged and can impact be somewhat reconfigurable by positioning different parts of the tool in different regions or by multiple passes basically you are trying to smoothen the surface.

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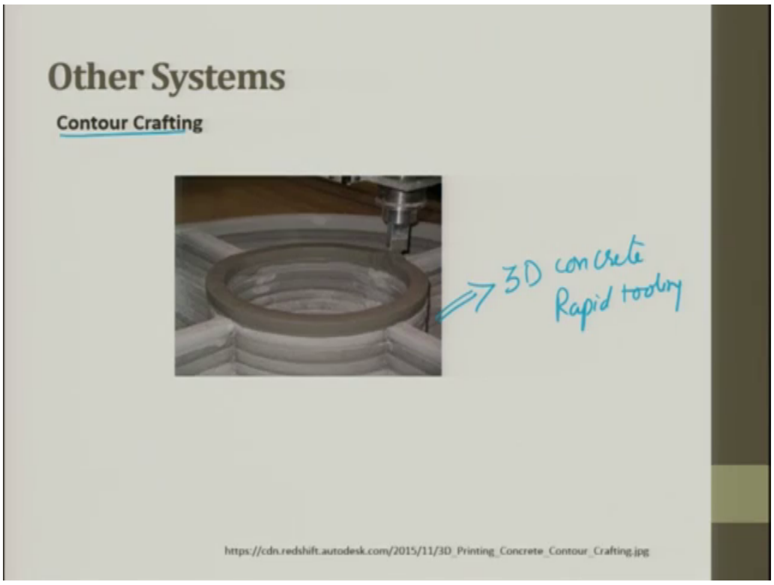


So, this is what is contour crafting and today what people talk about they also talk about something called as 3D concrete rapid tooling. So, almost the same technique is used in contour crafting, so you get the required output in the required state.

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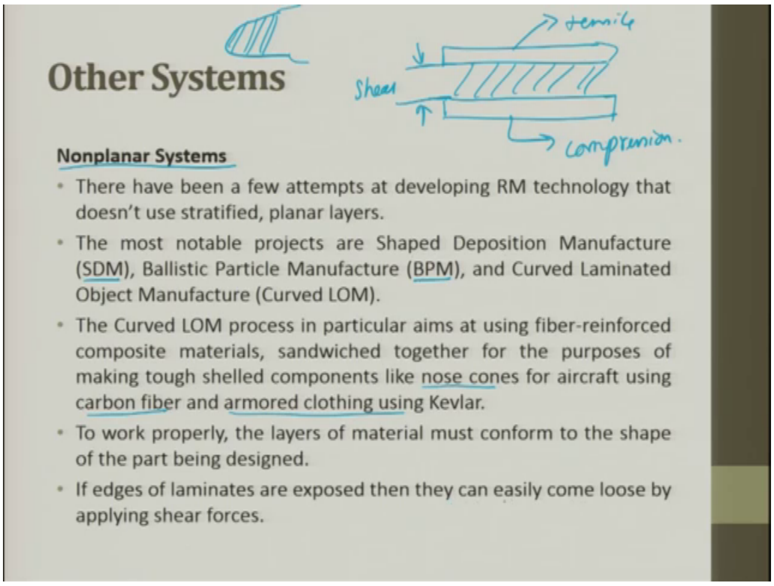


There are other systems like non planar systems there have been a few atoms to develop RM technology that does not use stratified planar layers, the most notable project are shaped deposition manufacturing which is otherwise called as SDM or ballistic particle manufacturing which is called as BPM or curved laminate object manufacturing curved LOM.

The curved LOM process is particularly aimed at using different using fibre reinforced composite material sandwich together for the purpose of making tough shelled components like nose cones for aircrafts using carbon fibers and armored clothes using Kevlar. So, what is sandwich this is you have a top layer you have a bottom layer whatever you want and in between you do feeling of some other layer, so this and this we will try to take care of the tensile maybe compression or it can go vice versa and the shear is taken care by the core.

So, this is used for making Kevlar in the nose cone, so what is nose cone nose cone is when you have a flight this is the front part and then you have a flight. So, this is the nose code to work properly. The layer of the material must confirm to the shape of the part being designed, if edges of the laminates are exposed then they can easily come lose by applying shear force.

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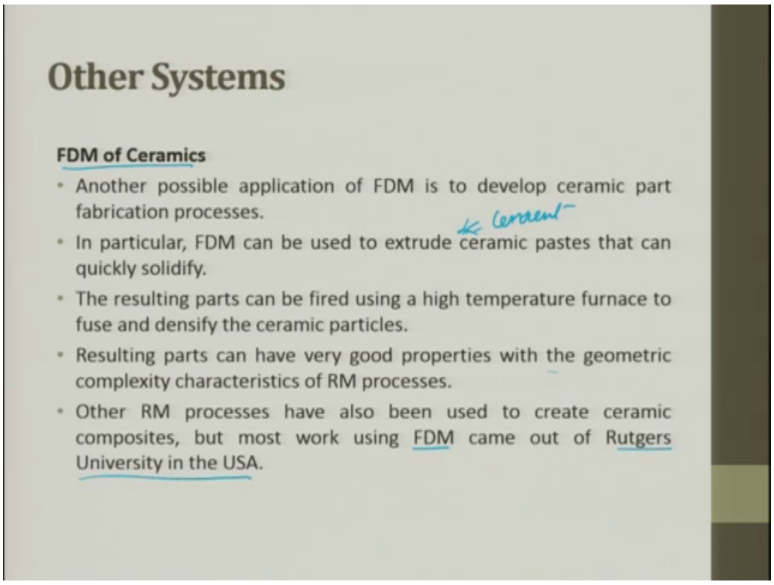


So, FDM of ceramics are also tried today, another possible application of FDM is to or extrusion process is to develop ceramic parts fabrication process in particular FDM can be used to extrude ceramic pastes that can be quickly solidify. Ceramic paste is nothing but cement cement is a ceramic paste, the resulting part can be fired using a high temperature furnace to fuse and densify the ceramic material resulting part can have very good properties with geometric complexity characteristics of RM process other RM processes have also been used for creating ceramic composites. But most of the work in FDM came out from Rutgers University in USA.

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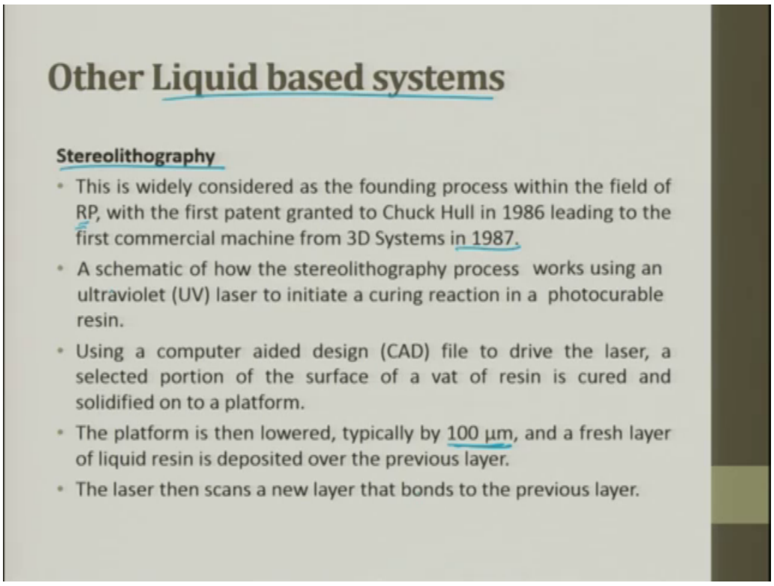


The next process which is liquid based process the process most commonly named as Stereolithography this is widely considered as a founding process within the field of rapid prototyping with the first patent granted to chuck hull in 1986, leading to the first commercial machine from 3D systems in 1987.

A schematic diagram of how the stereolithography process works using a UV laser to initiate a curing reaction in a photocurable resin was discussed earlier. We will also see now using a cad file to drive the laser is a selector portion of the surface of a vat of resin is cured and solidified on a platform the platform is then lower typically by 100 microns and a fresh layer of the resin is deposited over a previous layer.

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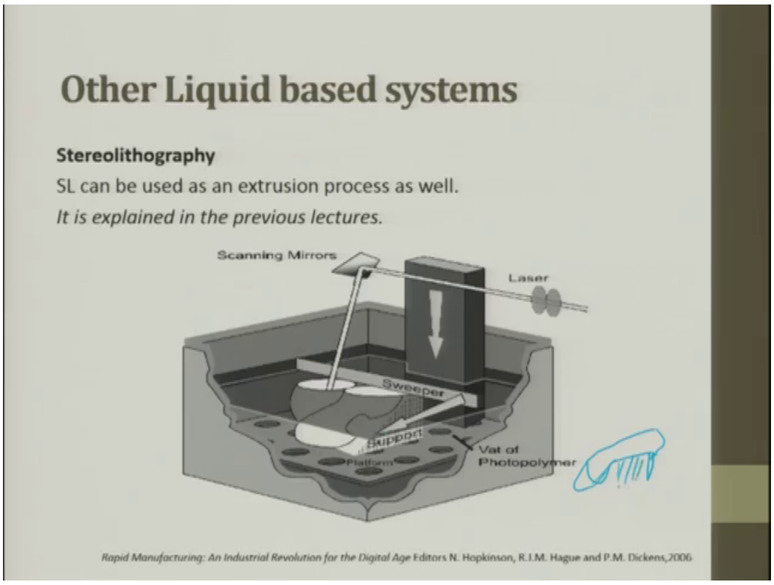


This laser then scans a new layer that bonds to the previous layer. So, this is what it is we saw more in details when we were discussing about the photopolymerization. So, here is a lens this is a table and here is a supporting structure, so you see that this is a supporting structure this is the part. So, maybe if you are trying to make a shoe ladies shoe so here you need supporting, so that is what is the supporting layer used.

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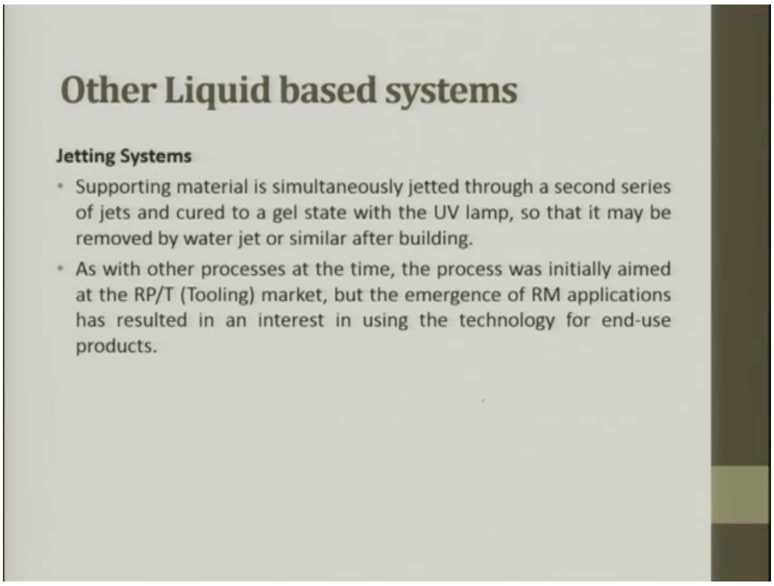

Jetting system is another system supporting material is simultaneously jetted through a secondary series of jet and cured to a gel state with the UV lamp, so that it may be removed by water jet or similarly after building.

So, it can also you can also use reaction based, for example you can use some solvents which can dissolve the material. As with the other processes at time the process was initially aimed at they are rapid prototyping or rapid tooling market. But the emergence of RM application has resulted in an interest in using technologies for using in the end products.

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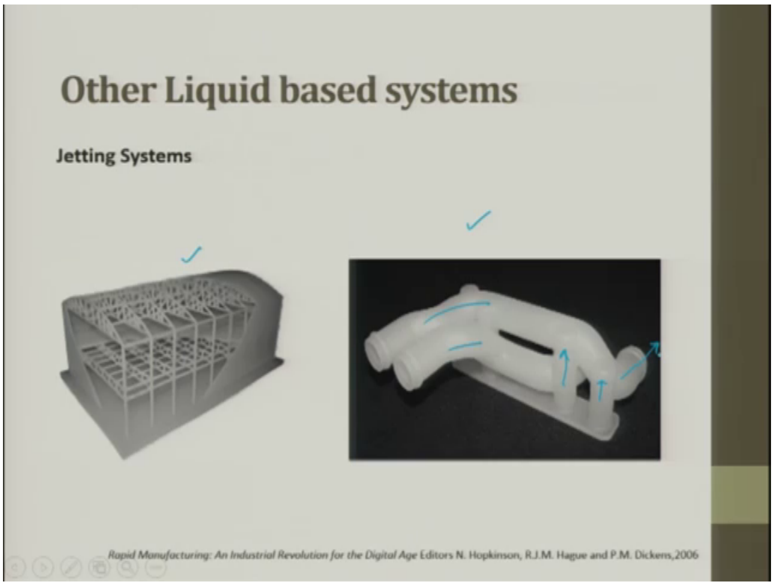


So, this is done by the jetting system this product and this product are done by Jetting system, it is really a complex product it is an engine valve if you want to make it in a single product by metals it is you can do it by casting. But designing a mould for it is also a challenge. Injection moulding also can be tried, but before doing it rapid prototyping is used for making such complex shapes. So, you can see here there is there is a pipe which flows and then here and here.

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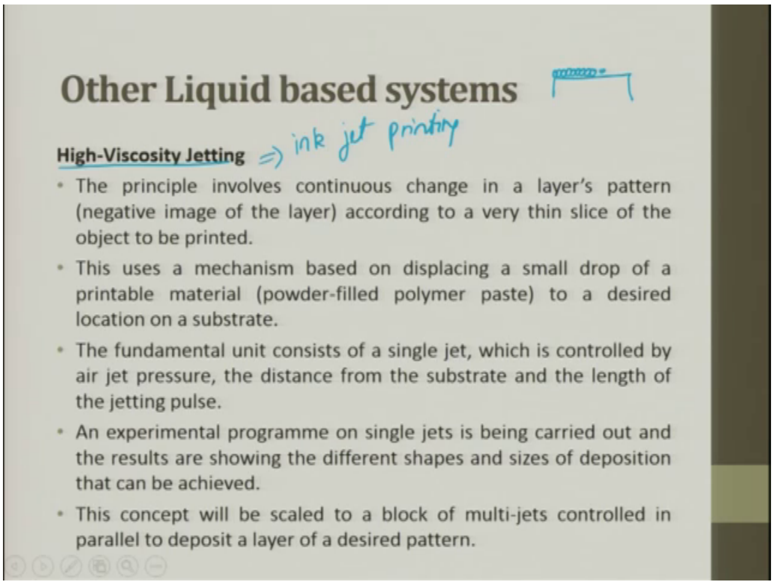


High viscosity jetting process, the principle involves continuous the same in layer pattern according to a very thin slice of object to be printed, this uses a mechanism based on displaying a small droplet of printable material to a desired location on the substrate ok. You have a substrate so you put droplets so this is droplets come out of the jet, the fundamental unit consists of a of a single jet which is controlled by R jet pressure the distance from the substrate and the length of the jet pulse is very very important.

And experimental program on single jet is being carried out and the results are showing the different shapes and size of deposition can be achieved still this is in the nation stage, this concept will be scaled to a block of multiple jet control in parallel to deposit of layers of a desired partner.

If you are looking for an analogy this process you should look at ink jet printing it is almost like that. So, you have a cartridge through there is a liquid then through this liquid is allow to open and then it you try to create multiple outputs, the high viscosity jetting principal what is a challenge is the high viscosity.

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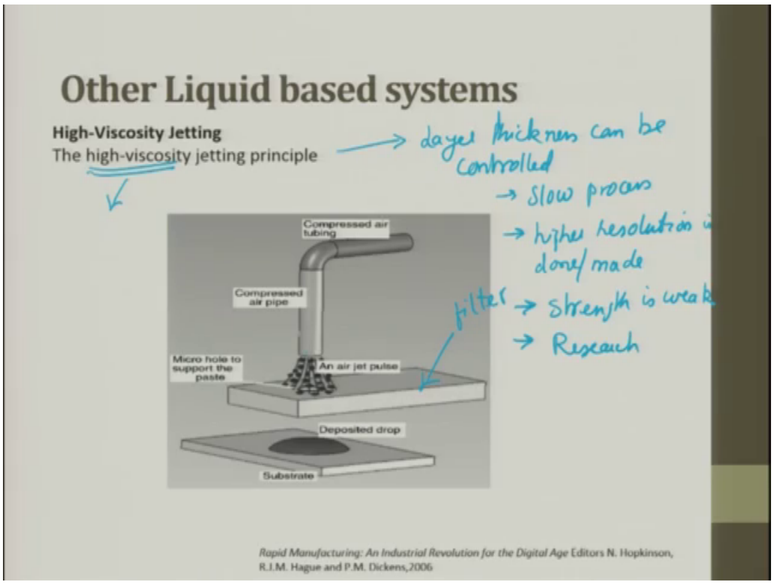


The viscosity is a challenge where in which you have to apply compressed air and this fellow compressed air the through the tubing it comes the compressed air pipe it comes and then you see and air jet pulse is given.

So, micro holes to support the plates, so you see that there are these are the holes through which the jet falls down and then this gets deposited. So, this is like your filter so the compressed air comes here and then you have the liquid also through this an R jet is pulsed here. So, there are lot of holes though this holes the material falls on top of the substrate and you get deposited.

So, what is the big advantage, the advantages is layer thickness can be controlled it is a slow process it is a slow process layer thickness can be controlled, so high higher resolutions can be done higher resolutions is done or is made. The strength is week strength of the component is weak and it is still in research these are the points you should understand.

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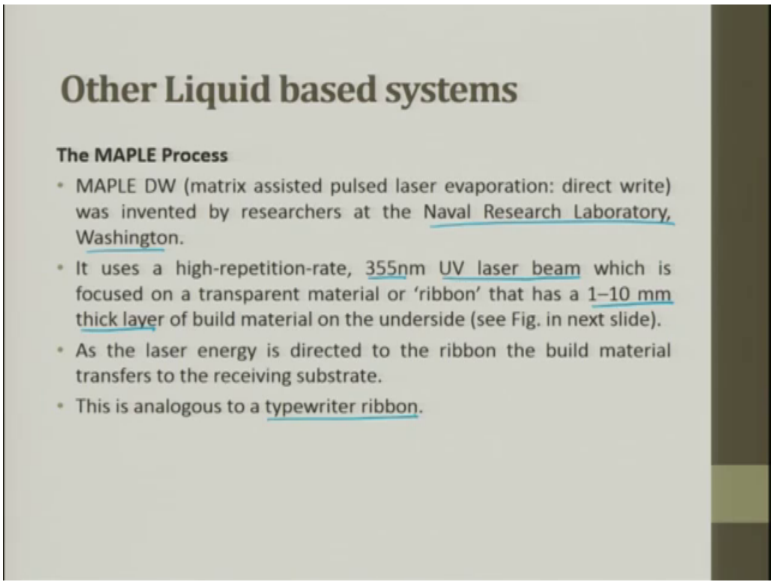


Maple process maple DW matrix assisted pulsed laser evaporation direct right was invented by researchers at the naval research laboratory Washington, it uses a high repetition rate 355 nanometer UV laser beam which is focused on a transparent material or ribbon that has 1 to 10 millimeter thick layer of build material on the underside. As the laser energy is directed to the ribbon the build material transfers to the receiving substrate.

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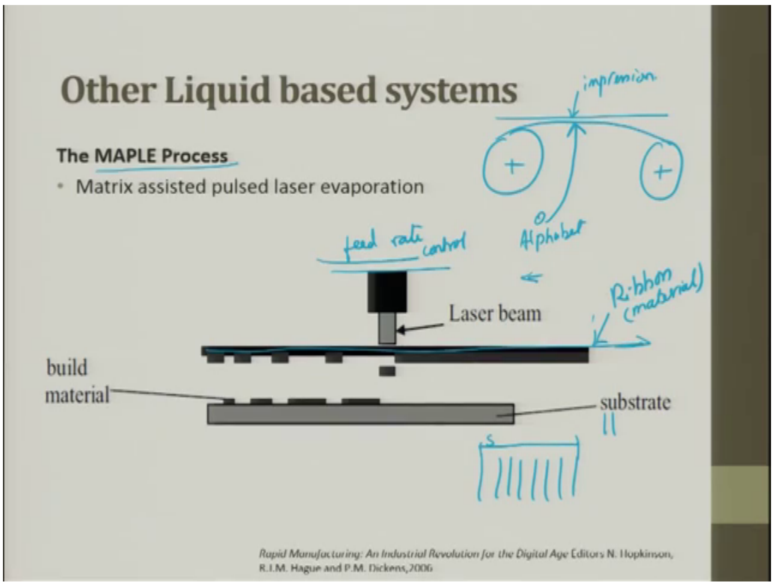

This is the analogy of a typewriter ribbon, look at it here you will have a ribbon which keeps going ok. This ribbon we will have material ribbon you will have the ribbon is the material final material what is to be deposited it is there.

So, now what you do is you use a laser to right and when the laser rights or when it cures this material gets deposited on top of a substrate. So, this is a very very interesting process and people are working on it, but still it has not come to the market in regular use. So, the analogy is like a typewriter in typewriter what we have spool a ribbon is passed through then you have a type or a hammering of a single letter, so this is an alphabet.

So, when you do what you do is you press the alphabet goes and hits at the ribbon, so you have a paper here in this paper the impression is created. So, you can continuously keep doing it you can so what is the limitation the spacing cannot be controlled the spacing is lay fixed the spacing between letters. For example, the spacing between these two letters are fixed same way in typewriter if you want to go lesser than that it is not possible.

So, here also it is the in typewriter that is the limitation, but however in laser what happens you can reduce or increase the distance the pitch between the two letters by increasing and decreasing the feed control feed rate control.

When you start doing a feed rate control over this you can start controlling the spool and then you get this process. So, this is a maple process maple process is also used to for bio printing today to recapitulate whatever we have seen in this lecture.

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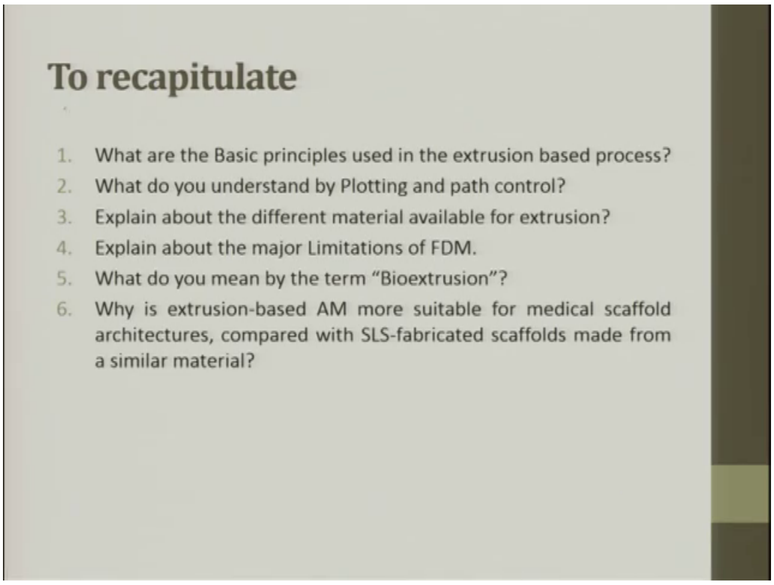


So, we have seen what are the basic principles used in extrusion based processors? What do you understand by plotting and path control? Explain about the different materials available for extrusions? Explain about the major limitations of FDM. What do we mean by the term bio extrusion and why is extrusion based additive manufacturing process more suitable for medical scaffold architecture compare with SLS scaffold made for made from a similar material. So, these are the series which we saw today.

And I thank you for being with me in this lecture.