Rapid Manufacturing
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Lecture – 23
Extrusion and Liquid based processes (Part 1 of 2)

Extrusion and the Liquid based processes. So, in Rapid prototyping we had solid processes in then we have liquid based processes, where in which you can use a liquid and then converted into a solid or you take a solid converted into a viscoelastic state and then make a solid to get the required prototype output.

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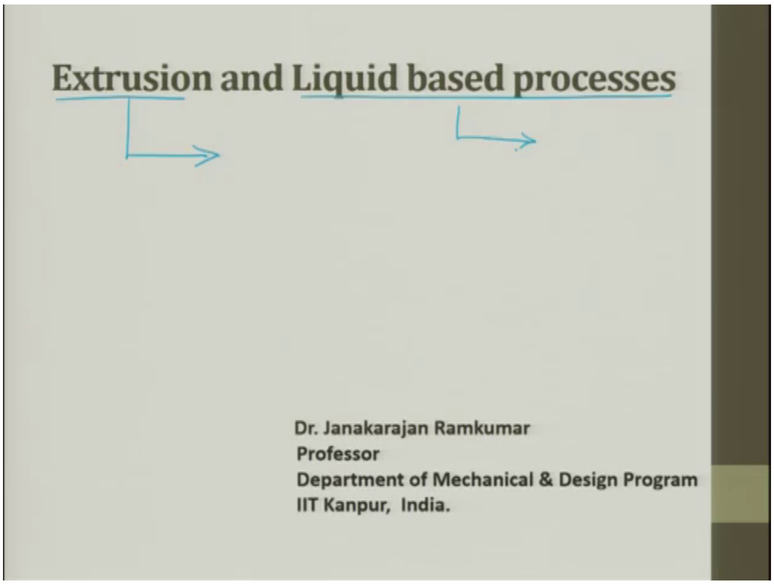

So, this topic we will see extrusion and liquid based processes extrusion process means you are trying to take a wire which will be extruded through a nozzle, where in which the wire from a solid state we will get converted to viscoelastic state.

And then it will be laid on top of a table and then you keep on be repeating it and then decreasing the z. So, you will try to get a full complete solid. So, extrusion is one process and stereolithography we saw some basics that will be un liquid based processes.

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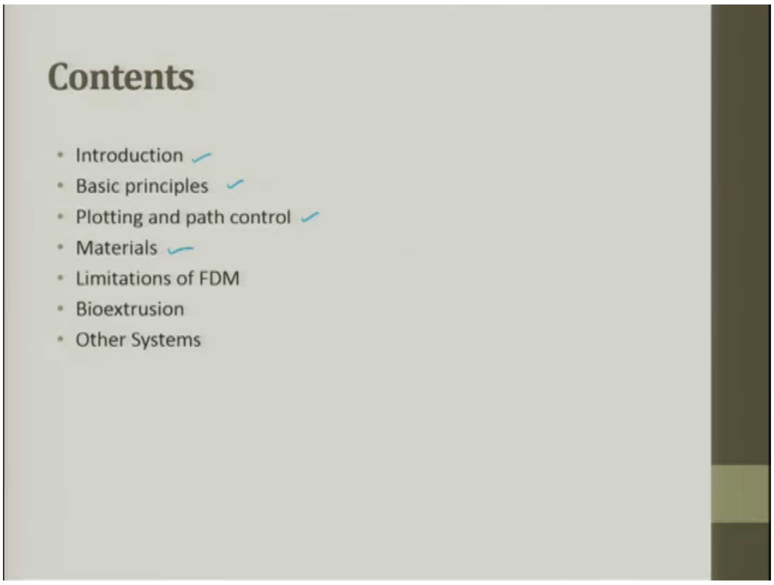

In this chapter we will see introduction, basic principles, plotting and path control, different types of materials which is very important because the entire rapid prototyping process depends upon the basic starting material and today when we talk about rapid manufacturing, we are talking about directly producing the prototype and using it in the real time applications.

For example tissue; tissue printing is something which is more talked about today now it is a polymer starting metal is a polymer and then you make the composition of the polymer to such an extent that, you can try to print tissues and these tissues can be interfaced into the body and it becomes a original part over a period of time. Then limitations of FDM process bio extrusion and the other systems we will try to see in this lecture.

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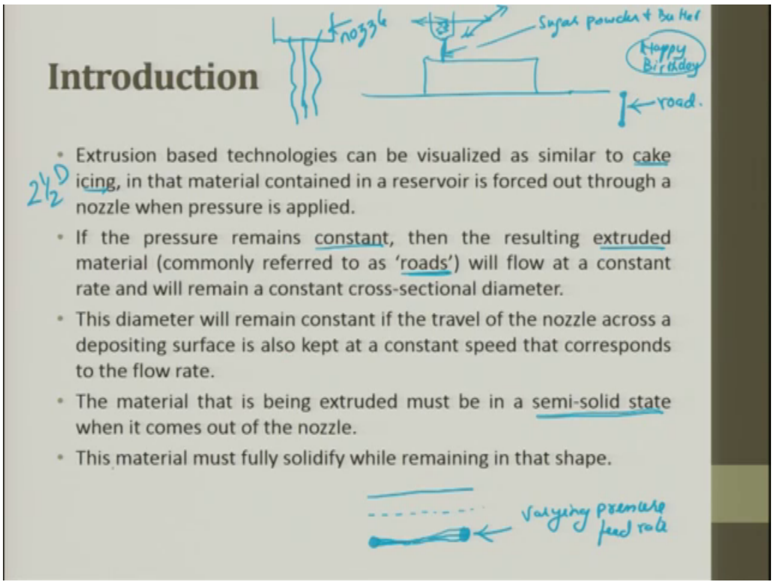

Extrusion based technologies can be visualized as similar to cake icing, in cake icing what we do is we try to have a cake and then in this case top we always give a toping where in which we write suppose it is happy birthday right. So, when we wanted to write this what we do is we use a cone this cone is filled with icing whatever it is and then this is allowed to fall by. And here this hopper whatever we had this is allowed to move in xy direction and when we generally what we do is we use our hand and inside the hopper what we have is all icing.

Icing material that is sugar; sugar powder which is mixed with some butter or something which is in a very viscoelastic state, it is not a solid state it is a visco elastic state such that you apply a very small pressure move your hand in left and right direction, whatever it is and start writing your name. So, if you look at it is lot of flexibility is there in your hand.

So, you can even tilted to whatever you require and at some places you want to stop, some places you want give second line coating it is possible, but; however, please understand when you try to compare it with this cake icing it is more dominator towards 2 and a half D structure; that means, to say the D height will be few millimeter, you cannot go few inches in that ok. So, generally what we do is for easy understanding we try to give an analogy took of cake icing.

So, in the material contained in the reservoir is forced out through a nozzle when the pressure is applied. If the pleasure remains constant, then the resulting extrusion material commonly reefed as road because when you start pushing it and draw a line this h, this is called the road we will follow at a constant rate. Suppose you run very fast when you try to put the road, when you try to run very fast there can be discontinuity in the line or there can be a lump mass at the start at the end and in between you will have a thin line coming up.

So, if they are extruded at a constant pressure then you will get a road widths, and height uniform will flow at a constant rate and we will remain a constant cross section diameter. This diameter will remain constant if the travel of the nozzle across the depositing service is also kept at a constant speed., If we try to draw a line and if we try to do it very fast maybe then you will have this type of when there is a difference in the flow or in the pressure you might get discrete lines or you might get a lump mass then small and then you will have.

So, this slump mass will form a we will get thin down over a period of time and then this will try to thicken and then you will try to get something like this. So, this is also because of varying pressure and varying feed rates, that is a speed with which it moves right. The material that is being extruded must be in a semi solid state, go back to this icing example and please remember this icing cake icing which is very very good analogy.

So, if it is become solid then you cannot push through the nozzle or if it become solid you have to apply lot of pressure to push through the nozzle when it becomes a solid and when you try to apply a lot of pressure there can be at this continuity in the flow even.

Say for example, when the flow happens like this you can have discontinuity in the flow which comes out of the nozzle, this is the nozzle when it becomes a solid. So, it is always a basic understanding to keep in mind that you should use a semi solid state and then push it through the nozzle try to maintain a constant speed and try to maintain a constant pressure ok. The material must full y solidify when remained in that shape.

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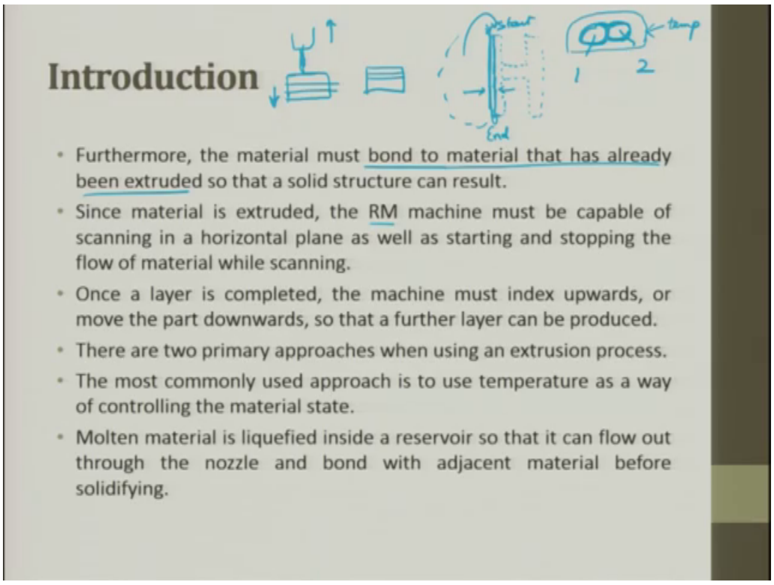

Further the material must born to the material that has already been extruded so that a solid structure can result. For example, you have made a H if the width; the width of the H whatever you have made suppose let us assume you wanted to make a line like this and when you make one pass through the nozzle you get only one line. Now what you have suppose to do is you will go back and you will start putting the next line. So, what I am trying to say is, if there is a discontinuity or if these two lines do not join, if these two roads do not join, then you will not be able to get a proper adhesion between these two roads.

This will try to bring in discontinuity it might give you a very poor look. So, this also should be should be kept in mind that there should be an overlapping or when the overlap happens where his should be a speaking between the two roads, if I try to draw the cross section, it will be like this there has to be something like this. So, this will only make sure that there is a proper bond of material that is already extruded. So, this is first and this is second, if this fellow dries it off then sticking will be a problem.

So, you should make sure that this fellow does not dry and this fellow when it joints it should have a phenomena of sticking. This is only in one layer I am talking, but if you want to construct a 3D object then it should be between layers also there has to be a sticking happening.

So, what has been extruded and what is getting extruded should join and form a solid keep that in mind, this is very important if this does not happened there is phenomenon called as delamination. This delamination will make the of the prototype look very poor and this cannot be used further. Since material is extruded the rapid manufacturing machine must be capable of scanning in a horizontal plane as well as starting and stopping the flow of the material while scanning. So, for example, you started from here the H beginning this is the start point and this is the end point.

And you finished here if you wanted to reuse from here you can start from this side itself and go otherwise you go all the way on the top and start from there. So, that is what they say must be capable of scanning in the horizontal plane as well as start and stopping of the flow of the material while scanning. Ones a layer is completed the machine must index upward or move the part downward, so that the further layer can be produced. So, if this is what is the H we are going in one plane, happy birthday what you write is H is just a single layer.

Suppose let us assume that you wanted to make a three dimensional H. So, if I wanted to draw be plan view of it. Suppose let us assume it is going to take this is first layer, second layer, third layer ok. So, these are the two legs of the h. So, these are the three layers. So, then what we are trying to say is either this fellow should sink the table should sink or the nozzle whatever is there that fellow should go up.

So, that it tries to create the layer there are two primary approaches when using an extrusion process the most commonly used approach is to use temperature as a way of controlling the material state. So, what I am trying to say is, you have already extruded one layer and this layer when it is expose to the atmosphere at certain temperature it will try to solidify.

So, if I have to slow down the solidification process then, what I do is, I use an ambience around it and try to maintain a temperature in the ambience, when I start maintaining the temperature in the ambience then the extruded layer and the and the just extruded layer we will try to join with each other and form a layer or should be a or a road completely in a plane molten material is liquefied inside a reservoir so, that it can flow out through the nozzle and born with the adjacent material before solidifying.

So, now I think you should be able to appreciate when you look into the analogy of icing and when you look at rapid manufacturing extrusion process it is almost the same.

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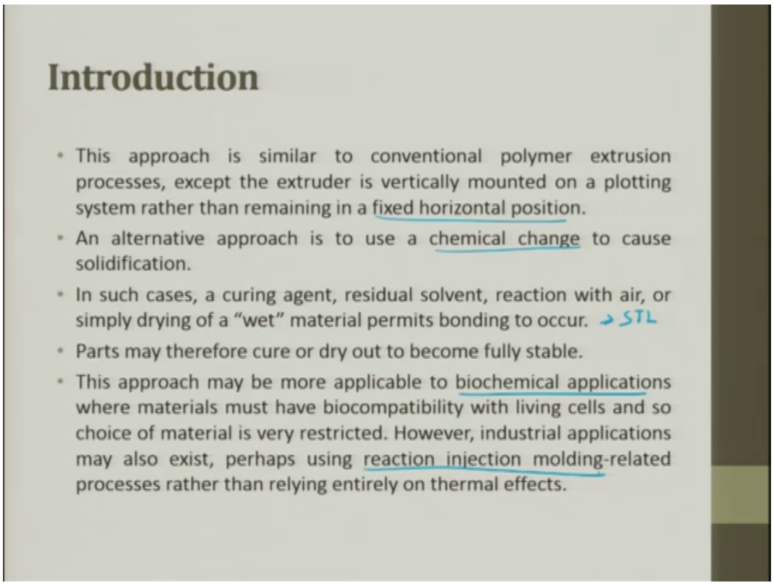

This approach is similar to conventional powder extrusion process, except the extruder is vertically mounted on a plotting system rather than remaining in a fixed horizontal position. An alternative approach is to use a chemical change to cause the solidification, chemical change is what already you have a liquid you apply either a chemical you add in it or you apply a initiating agent for example, you can apply a light which goes hits at a polymer and the polymer has a curing cycle catalyst inside it cures, so that is what is a chemical approach?

In such a case the curing agent residual solvent reaction with air or simply drying of a wet material permits bonding to occur. This process is stereo lithography stereo lithography parts may therefore, cure or dry out to become a fully stable. This approach may be more applicable to biochemical applications where material must have a biocompatibility with living cell and so, choice of material is very restricted this is more bio applications.

However, industrial applications may also exist, perhaps using a reaction injection molding related process rather than relying entirely on a thermal effect is also possible reaction injection we will see that in due course of time.

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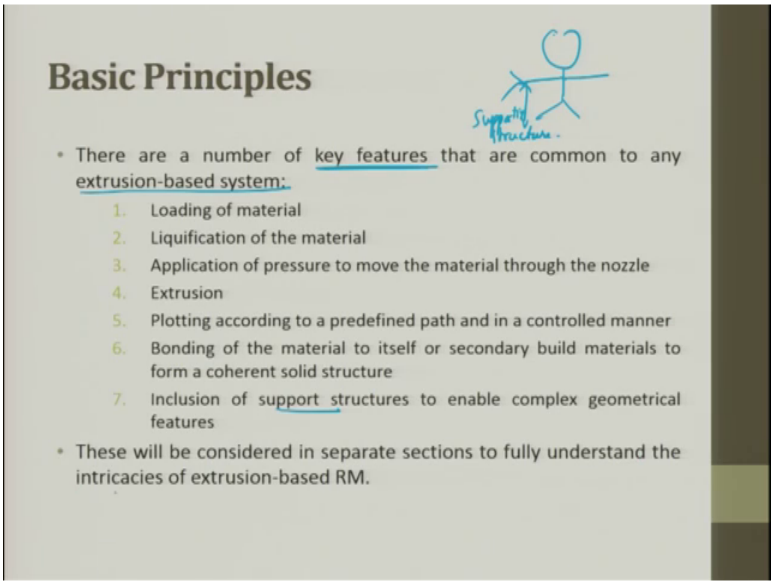

So, there are number of key features that are common to any extrusion based process loading of material, liquefaction of material, application of pressure, extrusion plotting according to the predefined path in a controlled manner, bonding of material to itself or a secondary build material to form a coherent solid structure, inclusion of supporting structure to enable complex geometry features.

Supporting structure suppose I told you last class itself if you have a free hanging body. So, this free hanging body will be done by a supporting structure ok. So, these are all the common key features, which are to be thought of when we talk about extrusion process.

There these will be considered in separate sections to fully understand the intricacies of extrusion based rapid manufacturing process.

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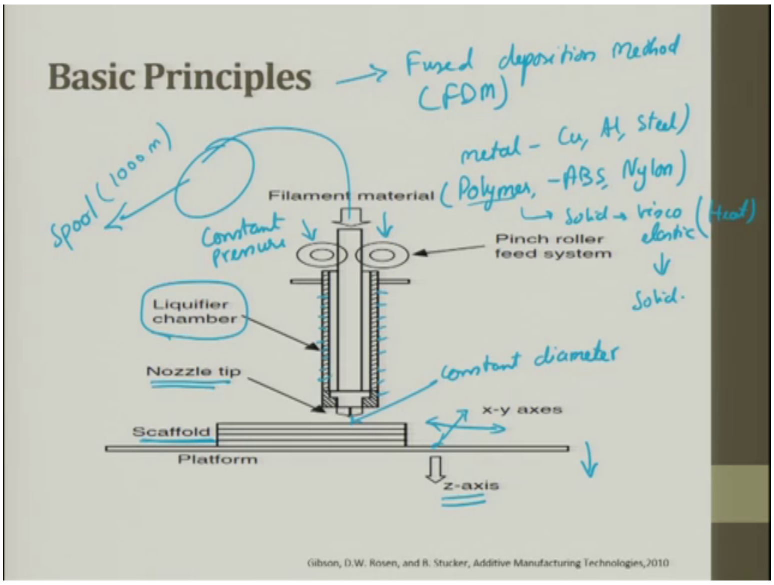

So, this is a basic principle for FDM process Fused Deposition Method FDM process. So, here we try to take a filament wire which is polymer generally, what we uses is ABS; ABS nylon can be used. So, people are now working on various systems you can also have biocompatible material ABS is also biocompatible ABS is there industrial abs is there you can choose any of them choose a polymer.

Why polymer? Polymer sold it goes into visco elastic and then it becomes a solid once again. So, it do not go to a liquid state. So, here you apply heat ok. So, visoelastic; viscoelastic means you take it to a shape such that you can try to give a shape to the solid; it's in a semi keyword form so that is what it is.

So, filament is there polymer is you can also use metals today we are talking about metals where people are trying to use copper, aluminum, steel ok, steel rods are used they are passed though a nozzle ok. So, in order to have a proper tension constant pressure of feeding we use this pinch roller this is for constant pressure you remember in the ice icing cake icing example we talked about constant pressure.

So, this these two pins tallest tried to give a proper tension to the wire, such that the wire moves inside the nozzle and when we are talking about polymer what we do is when the wire is passed through the nozzle it is heated. So, when it is heated it goes to a viscoelastic state.

So, this is done in the liquefied chamber. So, this is a heating completely heating will happen here ok, heating also you do not take a liquid temperature you increase it to some 50, 60 or 100 degree Celsius by 100, 120 degrees Celsius you just heat and then the polymer is passed through and now what is happening through the nozzle tip.

So, here it can get bulged right this can get bulged or this can get deformed whatever it is, but when it is pushed through a constant orifice that is the nozzle tip. So, what you get out is a constant diameter and now what you do is, you try to move the table in x direction and y direction. So, you get a single layer and once the platform is pulled down by one layer thickness, then in the easer direction you try to construct an object. So, the object is called as scaffold.

So, please keep the analogy of icing and then start doing it, so here the feed rates the constant link feed rates are a dictated by the table movement. So, there has to be a synchronization between the pressure with which it exits out or the way it exits out and the speed in order to get a uniform road thickness.

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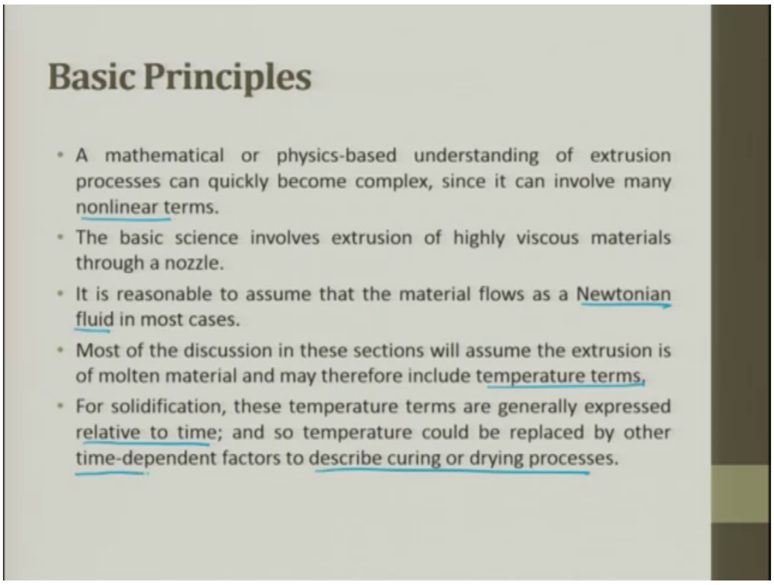

A mathematical understanding of extrusion process can quickly become complex, since it can involve many non-linear terms, extrusion process and second thing it is a polymer the starting metal is a polymer. So, you have lot of non-linear terms.

The basic science involves extrusion of highly viscous material through a nozzle. It is reasonable to assume that the material flows as a Newtonian fluid which is not correct. Ot is a non Newtonian polymer always is a non Newtonian, but we assume that the shear stress versus shear strain follows a linear term Newtonian fluid in most cases most of the discussion in these section we will assume that the extrusion of a molten material and may therefore, include temperature terms for solidification these terms are generally expressed relative to time and so, temperature could replace by another time dependent factor to describe curing all drying process.

So, you see here we are trying to take time. So, temperature would be replaced by time dependent factor.

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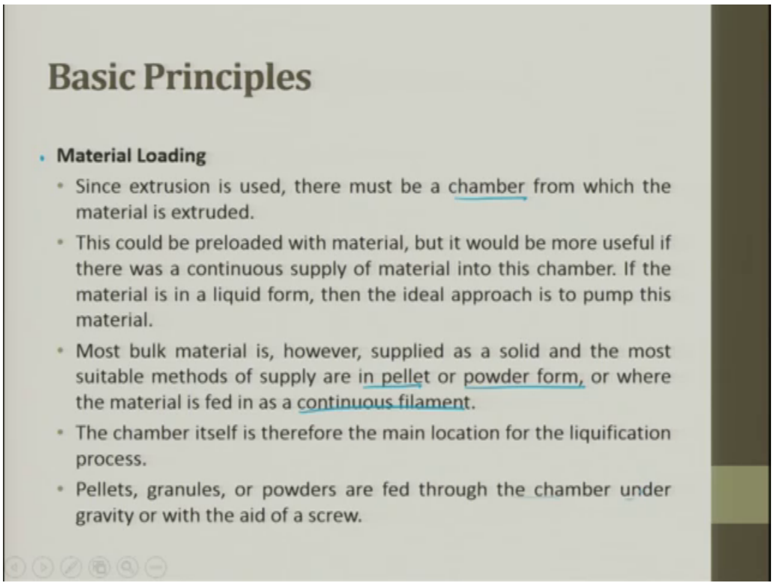

So, we have laid down all the common feature so, material loading is one since extrusion is used there must be a chamber from which the material is to be extruded. So, generally what happens? If you look the nozzle, we will try to have this nozzle will be attached to a spool, this spool will be continuously and in the spool we will have something like 1000 meters long wires which is pass through it ok. So, it is pass through it we will pass and get it.

Since extrusion is used there must be a chamber from which the material is extruded here it is a wire so, you put it in a spool if you do not have a spool if you go back to your icing example it is a huge above the nozzle you should have a hoper so, that is what is a chamber. This would be preloaded with material, but it will be more useful if there was a continuous supply of material into the chamber.

If the material is in the liquid form then the ideal approach is to pump the material. Most bulk material is; however, supplied as a solid and the most suitable method of supplying are in pellet or powder form or where the material is fed in as a continuous filament.

So, this you can have it in pellet, you can have it in powder, you can have it in continuous if you take injection molding it is pellet if you try to take pellet or otherwise called as powder form. So, in injection molding where extrusion is done we use this the chamber itself is therefore, the main location for the liquefaction process which I said there is a heater applied pellets granules or powders are fed through the chamber under the gravity or with the aid of a screw.

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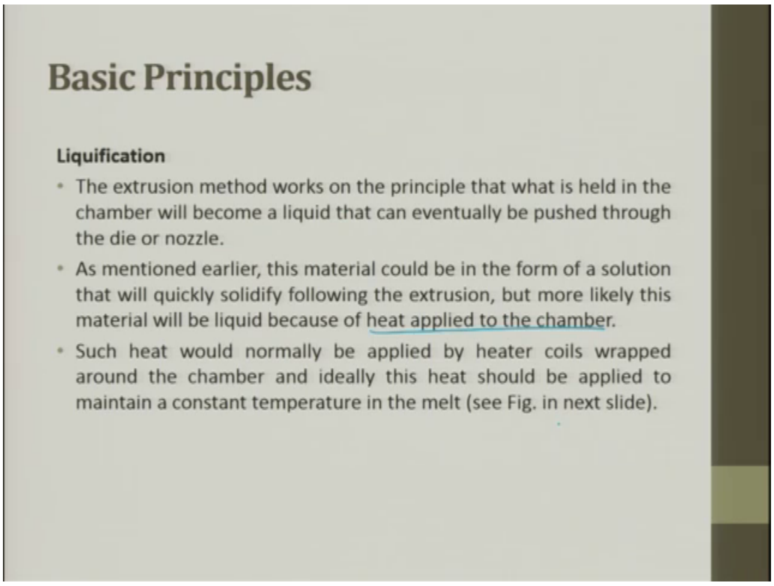

Liquefaction, the extrusion method works on the principle that what is held in the chamber will become a liquid that can eventually be pushed throw a die or a nozzle. As mentioned earlier this material could be in the form of a solution that will quickly solidify following the extrusion, but more likely this material will be a liquid because of heat applied to the chamber.

Such heat would normally be applied by heater coil wrapped around the chamber and ideally this heating should be applied to maintain a constant temperature in the melt.

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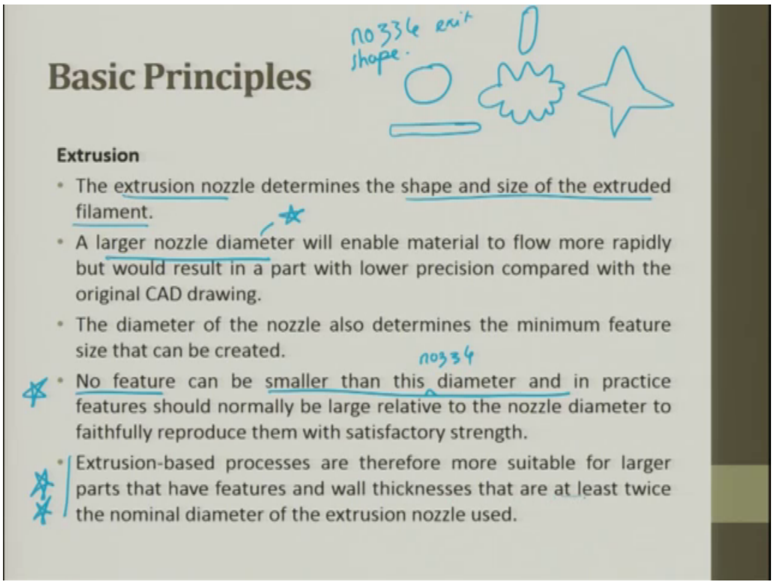

The extrusion finally, first is loading then heating, then extrusion nozzle determines the shape and the size of the extruded filament because what comes out will be a liquid liquid in terms of we call it as a continuous one. So, that is a filament the shape and size is decided by the nozzle orifice you can have a nozzle orifice like this. For example, when you talk about birthday, we have orifices of the nozzle coming like star you can also have oblong, you can also have slits the shape and the size or this is all nozzle exit shape.

The shape on the size of the extruded filament depends on the nozzle exit diameter. The large nozzle diameter will enable material to flow more rapidly, but would result in a part with low precision compared with the original cad drawing. So, the diameter of the nozzle, nozzle dia is a important for deciding the accuracy of the part. The diameter of the nozzle also determine the minimum feature size that can be created.

No feature can be smaller than the diameter and in practical in practice feature should normally be larger should be large related to the nozzle diameter to faithfully reproduced them with satisfactory strength.

So, no feature can be smaller than the diameter can be diameter of the nozzle diameter this is also important point. Extrusion pressure processes are therefore, more suitable for larger parts that have features and wall thickness that are at least twice the nominal diameter of the extrusion nozzle, this is a thumb rule which you should understand.

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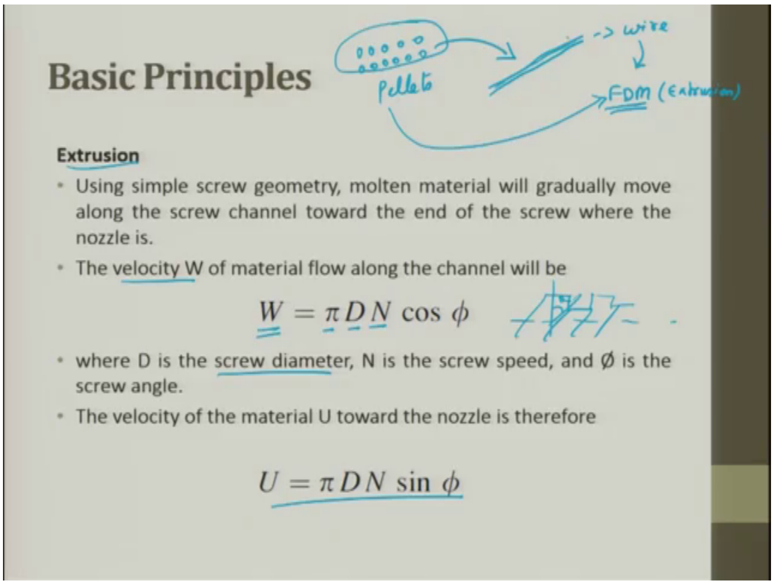

So, the wall thickness that are at least twice the nominal diameter of the extruded nozzle used. So, when we talk about extrusion using a simple screw geometry, molten material will gradually move along the screw this is for injection molding channel towards the end of the screw where the nozzle is velocity W of the material flow along the channel is given as W is nothing, but pi into D into N.

D is the screw diameter, N is the rpm with which it does and the screw angle, say for example, you have a screw, this screw will be this screw angle we are talking about ok. The velocity of the material U towards the nozzle is therefore, given by this and this is the velocity W of the material flow along the channel it is this way. So, these two velocities are different, W is a material flow along the channel this is velocity of the material us towards and nozzle ok. So, here now comes and interesting thought process.

See from the pellets, these are pellets; pellets or powders whatever polymer powders from the pellets you get converted into a wire, this is a wire. This wire is used in FDM process by the process called extrusion we try to make a output. Now people have started thinking why should I use pellets to convert wire and then wire extrude them.

And use it in FDM rather than that why do not I bypass this step and directly go from here to here. So, the starting material for FDM today, people are thinking why do not we use pellets itself. So, this will reduce one process and here when we start reducing pellets, pellets and good directly to FDM, the resolution of the objects can be improved.

So, people have started directly using this pellets instead of the spool feeding nozzle and other things you will have a hopper which is used which is used in injection molding machine hopper then a screw it the pellets will be asked to pass through the screw and it will be exit out through the nozzle and then it will lay on the table. So, this is another process here people have started working why because to improve the resolution of the FDM because if we use a wire there is always a restriction in the feature resolution.

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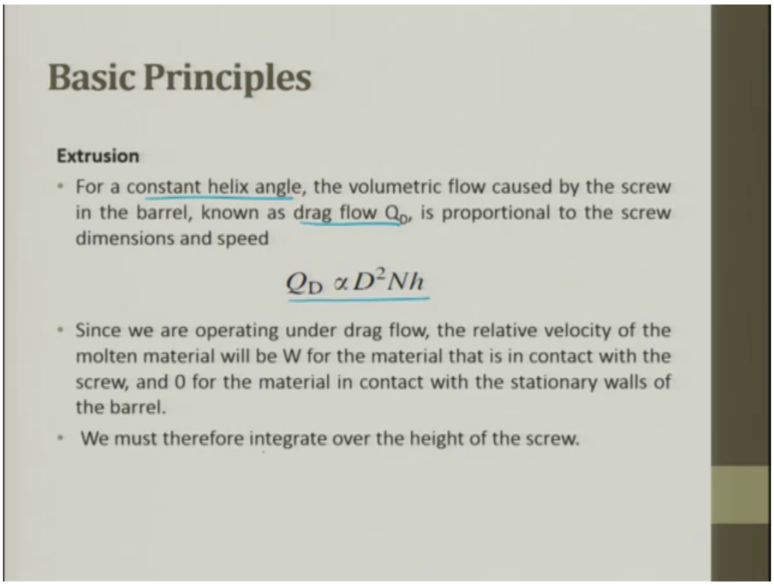

So, the extrusion for a constant helical angle, the volumetric flow causes caused by the screw in the barrel known as a drug flow Q D is proportional to the screw dimension and this speed.

So, constant helix drag force so, drag force is with which it resists to flow. Since we are operating under drag flow the relative velocity of the molten material will be W for the material that is in contact with the screw and 0 for the material in contact with the stationary wall of the barrel. So, we must therefore, integrate over the height of the screw and try to get the Q D.

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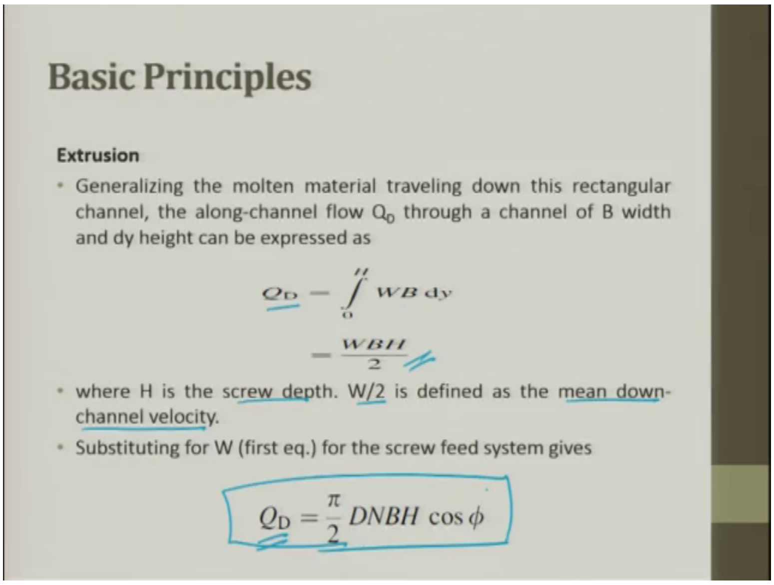

So, Q D the generalized molten material traveling down this rectangular channel the along channel flow Q D through the channel of B with and dy is the height can be expressed in integrating from 0 to H WB dy. So, which is nothing, but W into B into H by 2, where H is the screw depth. W by 2 is defined as the mean down channel velocity, substituting back in the Q D you get this equation.

So, here we assume there is no friction, it's first principle generalized one we get it.

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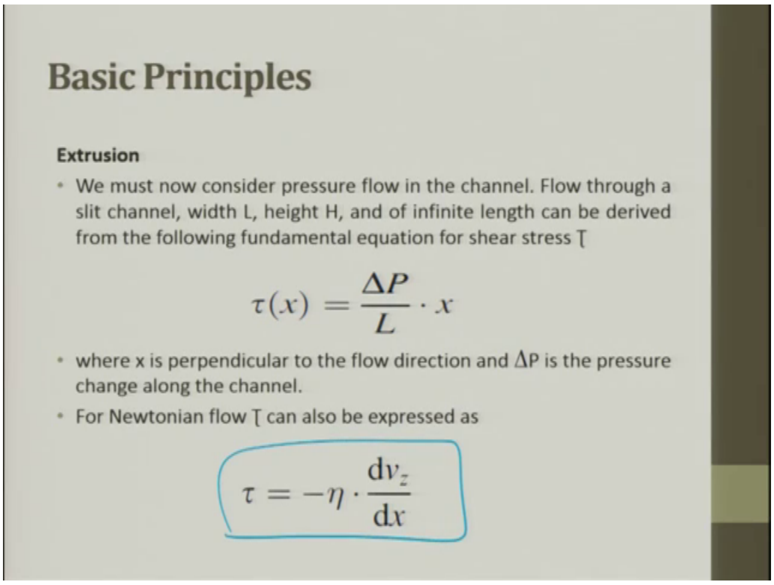

We must now consider pressure flow in the channel. Flow through a slit channel width of L, height is H and the in and infinite length can be derived from the following fundamental equation of shear stress tau; tau is nothing, but d P by L ok. Where x is the perpendicular to the flow direction and d P is the pressure change pressure drop along the along the diameter and L is the length. So, for a Newtonian fluid it is defined like this. So, it is minus viscosity eta into dv z by dx.

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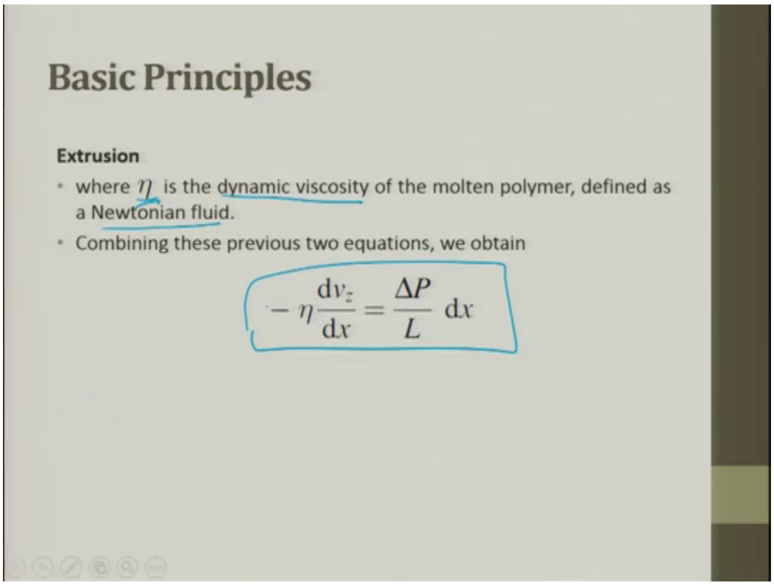

So, where d where eta is nothing, but the dynamic viscosity of the molten flow defined by the Newtonian fluid. Combining these previous two equations we have this is the final equation from here you can try to find out the eta value and try to substituted in the equation.

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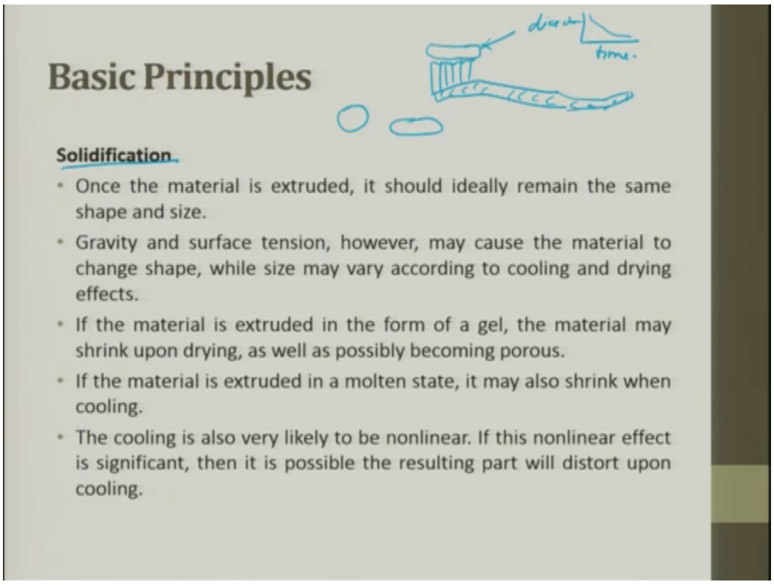

The next one is going to be till now hopper flowing we saw, next one is solidification why solidification? It will lead to delamination you want to avoid delamination, so we have to focus on solidification. Once the material is excluded, it should ideally remind the same shape and size.

The gravity and surface tension polymer material gravity surface tension, however, may cause the material to change shape, while size may vary according to cooling and drying effect. If the material is excluded in the form of a gel, the material may shrink upon drying as well as possible becoming porous. So, far this what I would suggest is, you do and exercise using your toothpaste you have bristles, you have your brush ok.

So, on top of it you try to place the paste and note down the diameter plot the diameter change with respect to time. You see that the diameter will keep reducing with respect to time; this is because of the visco elastic behavior. So, that is what the gravity surface tension; however, may cause the material to change shape, while size may vary according to cooling and drying. If the material is extruded in the form of gel, it can shrink the what happens a diameter will reduce, but it is a constant volume process. So, this diameter will become this diameter.

The height will reduce because it's a constant volume; if the height will reduce the diameter will increase that is all. If the material is extruded in the molten state, it may also shrink when cooling. On top of it shrinkage is cooling is also there, the cooling is also very likely to be nonlinear. If the nonlinear effect is significant, then it is possible that resulting part will distorted upon cooling.

So, you should keep the science in mind when we do the process.

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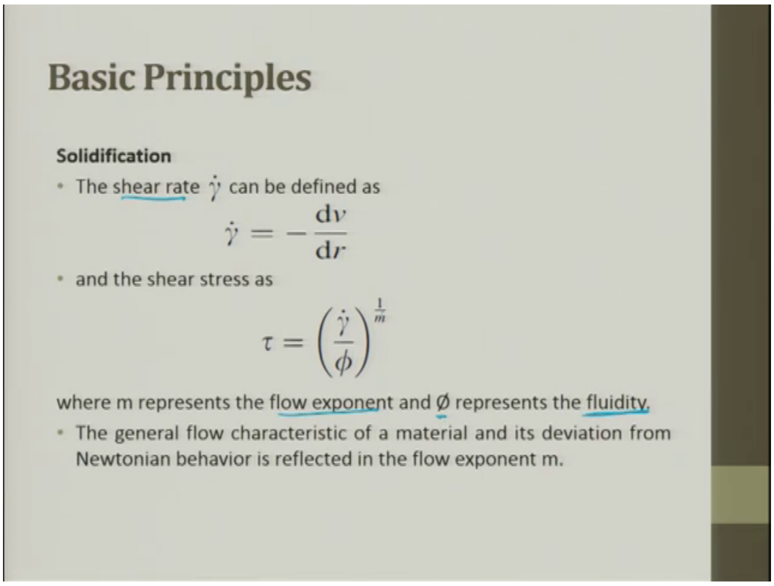

The solicitation rate the shear rate can be the gamma dot can be expressed as dv by dr and the shear stress can be expressed in tau, where m represents the flow exponent and phi represents the fluidity.

The general flow characteristics of the material and its deviation from the Newtonian behavior is reflected in the flow exponent m. So, this takes care.

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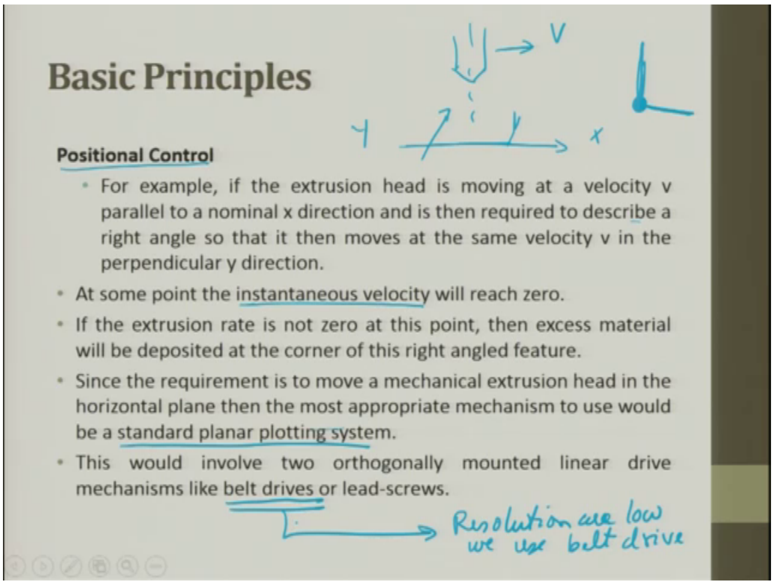

Then the next one is the position control; position control is either you move the nozzle in xy plane or you move the table in xy plane right. For example, if the extrusion head is moving at a velocity v parallel to the nominal x this direction and is then required to describe a right angle so, that it moves at a same velocity v in the perpendicular y direction. So, I am just saying if the extrusion head is moving with a velocity v; is moving with a velocity v parallel to the nominal axis x. So, this is your x plane and is then required to describe a right angle.

So, that it can move at the same velocity v in the perpendicular direction as y direction ok. At some point the instant velocity will reach zero because you have drawn a line completely and then you stop then you take a divergent. So, that is what they say at some at some point the instantaneous velocity will reach zero. If the extrusion rate is not zero at that point, then excess material will be deposited at the corner of this right angled feature.

So, what they are trying to say is if you are a; if you are trying to make some feature like this at this point, you will have a large deposit of material. Since the requirement to move a mechanical extrusion head in the horizontal plane, then the most appropriate mechanism to use would be standard planar plotting system so, standard planner plotting system.

This would involve two orthogonal mounted linear drive mechanism like belt driven or lead screw. Normally in all the FDM process, where the resolutions are not high, resolutions are low we use, we use belt drive. When the resolutions are very high then we use lead screw, but keep in mind it is also depending on the nozzle diameter. See if the nozzle diameter is large you put a lead screw of a very high precision, what you get out will be a low feature. So, there has to be a tradeoff between these two.

Since the requirement is move a mechanical extrusion held in the horizontal plane, then the most appropriate mechanism to be used would be the standard planar plotting system. Plotting system uses a belt drive you have a timer pulley and a belt drive.

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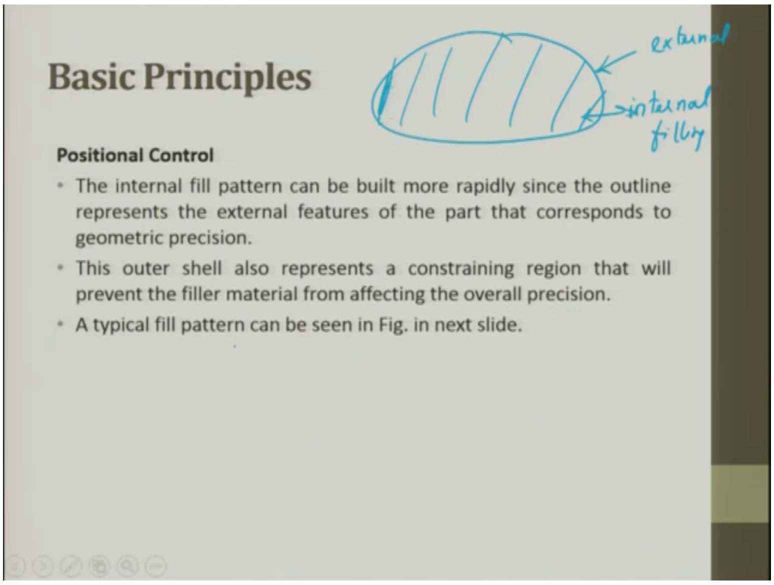

Position control, now we are moved the next thing is position control. The internal filling pattern can be built more rapidly since the outline represents the external feature of the part that corresponds to the geometric precision. So, what we are trying to say you had a layer this is a layer and this is the internal filling, this is the external and this is internal filling ok.

The internal filling pattern so these are the roads what we talked about these are the roads can be built more rapidly since the outline represents correctness of this is what is the who precise controlled required, internal if you can it just to fill material. So, the internal fill pattern can be built more rapidly no control, since the outline represents the external feature of the part that corresponds to the geometric precision. This outer shell also represents a constraining region that will prevent the filler material from affecting the overall precision.

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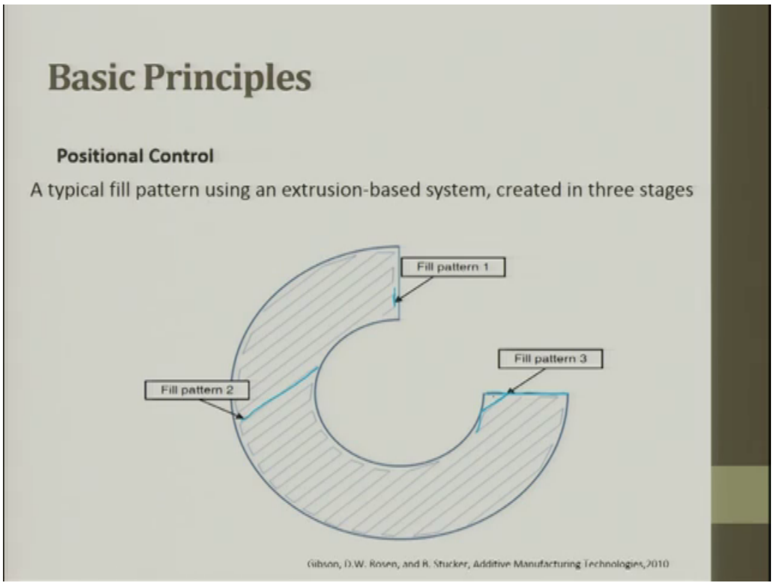

A typical fill pattern can be seen so, this is the; this is the external feature and this is the fill internal fill. So, we can see here this is a pattern; this is a pattern and this is a pattern this top one is a pattern. A position control a typical fill pattern using and extrusion based system created in three stages; one is filling vertical ok, the other one fill pattern is at an angle and the third one is along the a different angle. So, this is the along a straight line.

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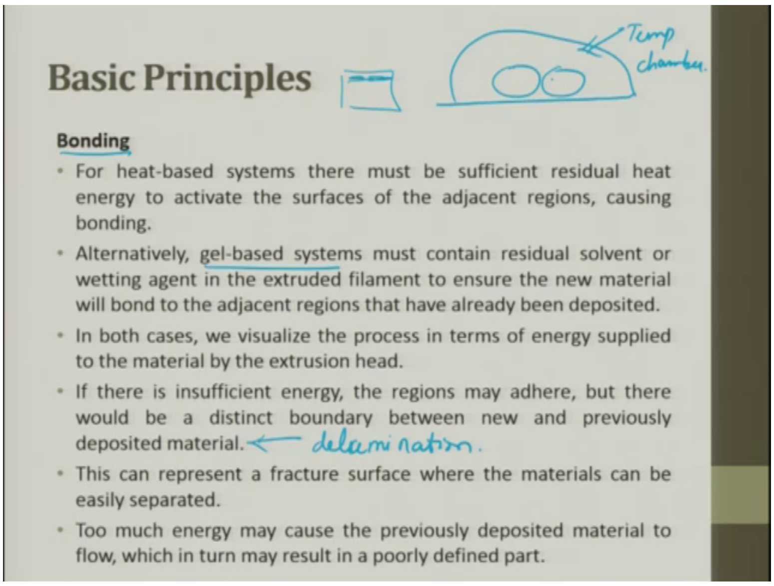

The next key feature is the bonding, as I told you delamination will come. For heat based system there must be sufficient residual heat energy to activate the surface of the adjacent region causing bonding. So, you have one, you have two, so you maintain it under a temperature. This is a chamber temperature chamber so, there sufficient enough to activate and bond.

Alternatively gelled based system must contain residual solvent or wetting agent in the extruded filament to ensure the new material will bond, it is just like a glue stick paper you have glue put on the top and then you have a paper so that something like that. Wetting agent in the extruded filament to ensure the new material will bond to the adjacent region that will that have already been deposited.

In both cases we visualize the process in terms of energy is supplied to the material by extrusion head. If there is insufficient energy the region may adhere, but there would be a distinct boundary between new and previously deposited material this defect is called as delamination. This this can represent a fracture surface where the material can be easily separated.

Too much energy may cause the previous deposited material to flow, which intern may result in poorly defined material. So, if you make the temperature very high then this fellow will be in also visco lastic, this fellow will be also viscoelastic so, it will be very poor surface will be there.

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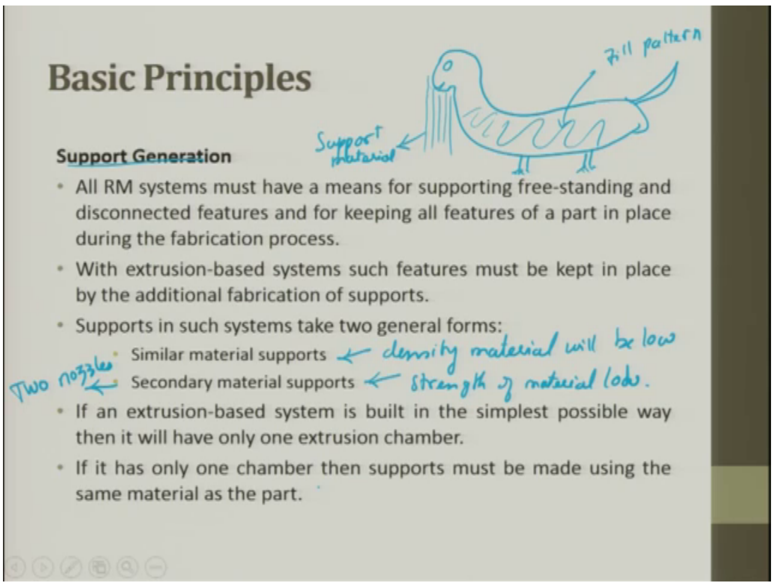

Support generation this I was trying to tell you; you have a free hanging surface, this free hanging surface has to be supported. For example, if you want to make, an object like this so this fellow has to be supported from here, this is called as supporting material which will not be the same as you original material.

So, inside this you will have roads and lay whatever it is pattern this is a fill pattern. The supporting material or the structure whatever it is does not play a role in the final product. All RM systems must have a means of supporting freestanding and discontent disconnected features and for keeping all features of the part in place during the fabrication process.

With extrusion based system such features must be kept in place by the additional fabrication of supports; support in such system take two general forms similar material support or secondary material support. Similar material what will happen is the density of the material fill will be low so that it can be easily broken off. Secondary is that the strength of the material itself, the strength of material is low.

So, here you will have two nozzles two nozzles to feed. If an explosion based system is built in the simplest possible way, then it will have only one extrusion chamber. If it has only one chamber then support must be made using the same material as the part.

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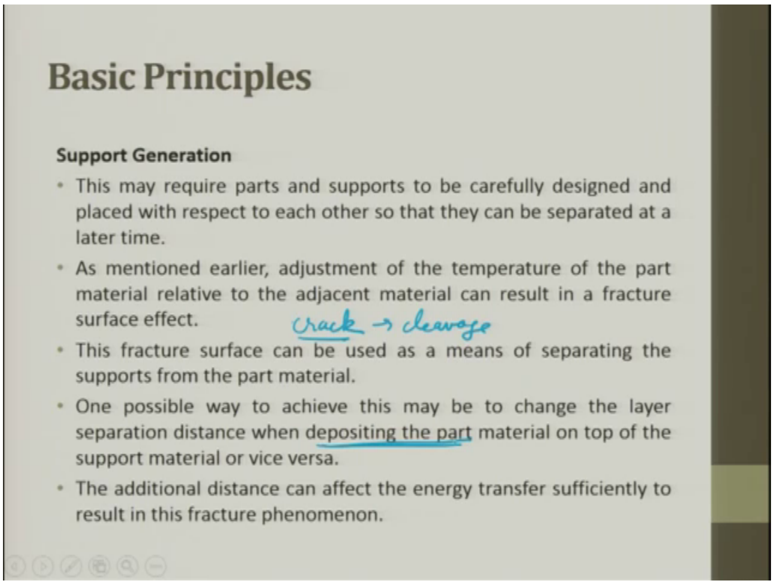

The support generation, this may require parts and support to be carefully designed and placed with respect to each other so that they can be separated at later time. If it is continuous of the supporting material and the original material, then it is going to be very difficult. As mentioned earlier, adjustment of the temperature of the part material relative to the adjacent material can result in a fracture surface effect. This fracture surface can be can be used as a means of separating the support from the part material.

So, what are we trying to do? We are trying to make a crack or a cleavage so, that the cleavage can be is that initiating crack this will easily you propagate further it will break down and it will fall down. This fracture surface may be used as a means of separating support from the part. One possible way to achieve this may be to change the layer separation distance when depositing the material on top and supporting material vice versa.

For example, and that is what I said the density you can change. Additional distance can affect the energy transfer sufficiently to result in the fracture phenomena.

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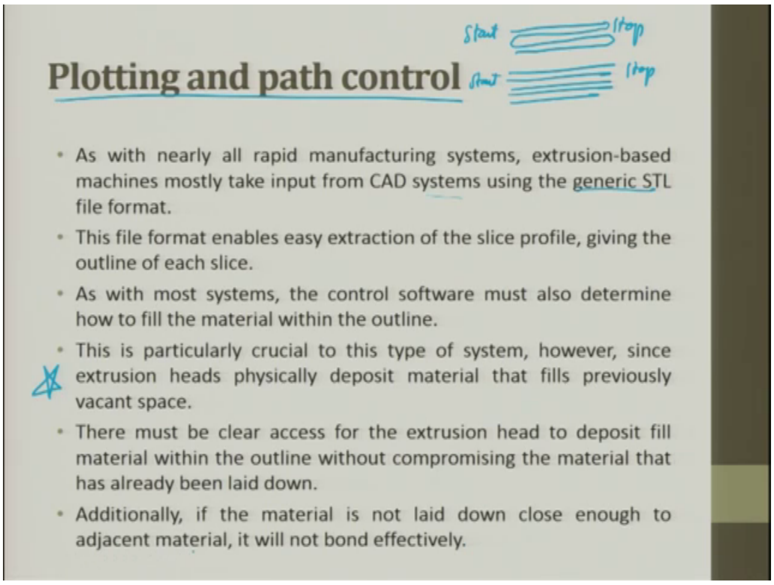

So, plotting and the path control so a path control is start stop this is start stop. So, how do we do it and then how do we come back? Serpentine pattern or we just go like this, this is start this is stop, so these are some of the patterns plotting and path control. As with lean as with nearly all rapid manufacturing system, extrusion based machines mostly take input from the cad system using generic STL file format.

The file format enables easy extraction of the slice profile giving the outline of each slice layer by layer slice. As with most system the control software must also determine how to fill the material with the outline? This is particularly crucial to this type of system; however, since extrusion head physically deposit material, that fill previously vacant space.

This is particularly crucial to this type of system; however, since extrusion heads physically deposit material that fills previously vacant space. There must be a clear asses for the extrusion head to deposit fill material within the outline without compromising the material that has already been laid down. Additionally if the material is not laid down close enough to the adjacent material, it will not bond effectively.

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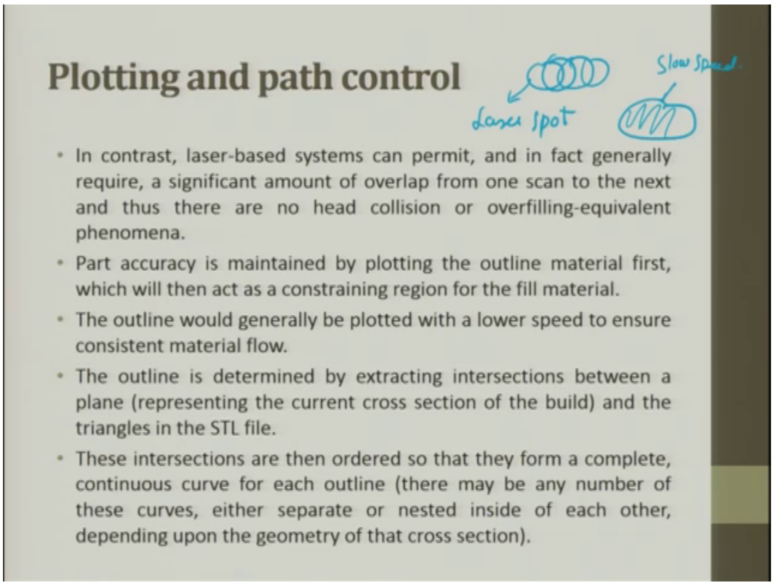

In contrast, laser base system can permit and in fact generally require a significant amount of overlap from one scan to the next and thus there are no head collusion or overfilling equivalent phenomena. One spot the other spot this is a laser spot.

Part accuracy is maintained by plotting the outline material first, which will then act as a constrained region for the filling material. So, external will be filled and then you go for internal. The outline would generally be plotted with a lower speed to ensure inconsistency material flow so this will be slow speed.

The outline is determined by extracting intersections between the plane and the triangles in the STL file. These intersections are then ordered so, that they can form a complete continuous curve for each outline, there may be any number of these curves, either separate or nested inside of each other, depending upon the geometry of that cross section. So, filling we are talking more about this filling which is happening inside.

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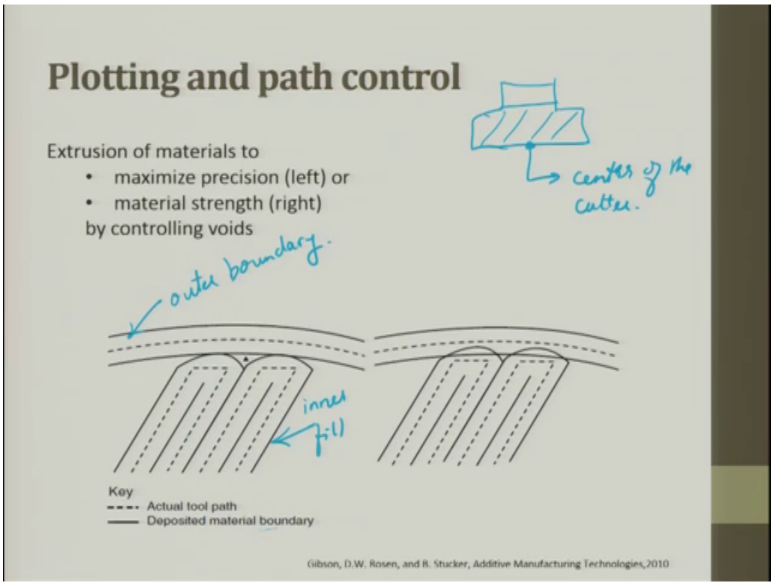

So, the extrusion of material to maximize precision left and maximize strength in the right so, this is the outer boundary, this is the inner fill. So, you can see here maximum precision so you can see it this on the left hand side and this is stitching. So, the you can see the outer and then this is done. So, we can see actual tool path will be this deposited material boundary will be this.

So, it is just like your cutter in your milling cutter what we do? We; what to do? We write the entire program to the centre of the centre of the cutter ok. And this is the diameter off set which is on same way here you write the program to this dotted lines and what gets generated will be the solid lines.

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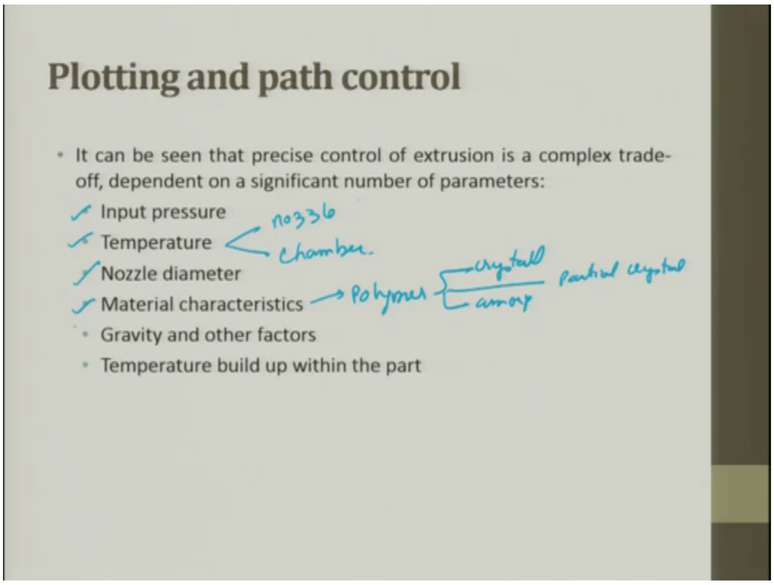

So, plotting and path control it can be seen that precision control of the extrusion is a complex trade off, dependent on your significant number of parameters, input pressure, temperature, nozzle diameter so temperature again nozzle temperature and the chamber temperature nozzle and chamber. Material characteristics, polymer, crystalline amorphous and you have partial crystalline. All this fellows have a direct influence on the mechanical property on the physical property gravity and other factors temperature built in within the part; these are some of the key features which depend on plotting and the path control.

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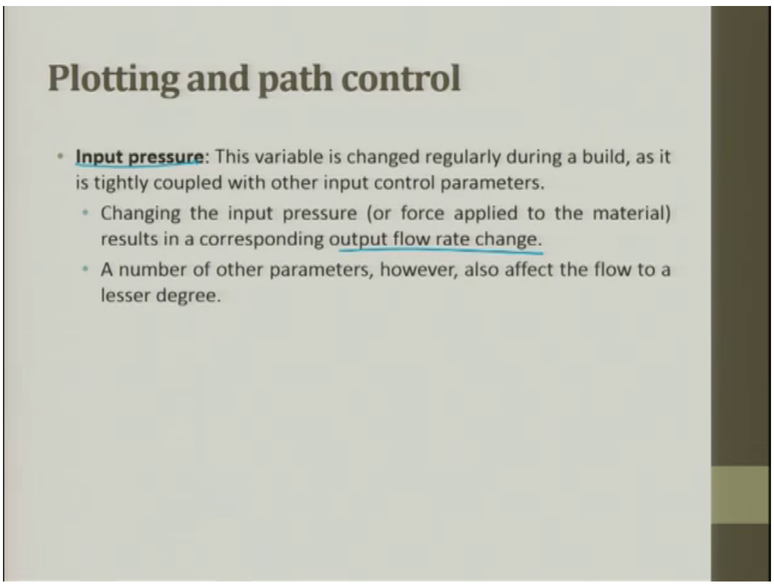

Input pressure, this variable is changed regularly during a built, as it is tightly coupled with the other input control parameters.

Changing the input pressure applied to the material results in a corresponding output flow rate change. A number of other parameters; however, also affects the flow of the to a lesser degree, but pressure is very very important this is what here do go back to your cake icing.

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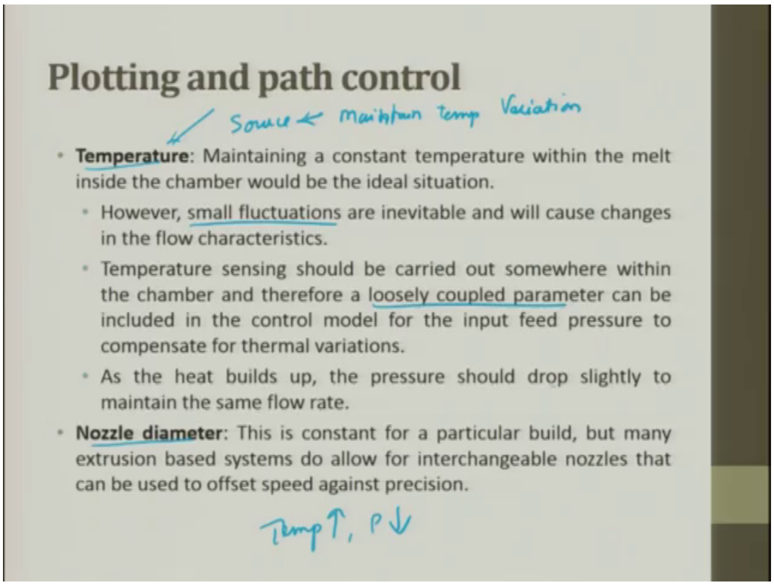

Temperature maintaining a constant temperature within the melt inside the chamber would be the ideal situation. However, small fluctuations are inevitable and we will cause change in the flow characteristics, this can be because of clogging this, can be because of the material property there can be a small fluctuations or the supply. Temperature sensing should be carried out somewhere within the chamber and therefore, a loosely coupled parameter can be included in the control model for the input feed pressure to compensate the temperature variation.

So, basically what are you trying to do is, we are trying to add one more source which tries to maintain temperature; maintain temperature variation ok. So, we had a coupled or we add one more sink whatever it is or we add one more source to make sure. As the heat built up, the pressure should drop slightly as the heat is built up, the pressure should drop so, p should drop slightly to maintain the constant flow because if you give more pressure more flow rate will be there. So, you have to have a trade off.

Nozzle diameter we have already seen is a constant for a particular built, but many extruder based systems do not allow interchangeable nozzles what you buy in the market today which is available, you always get with a constant nozzle diameter. Very rarely they give because when we try to change the diameter what happens is if you do not properly fit in the nozzle. So, you will not get the part whatever you require and this needs little bit of expertise. So, it is all custom made you get only one diameter nozzle.

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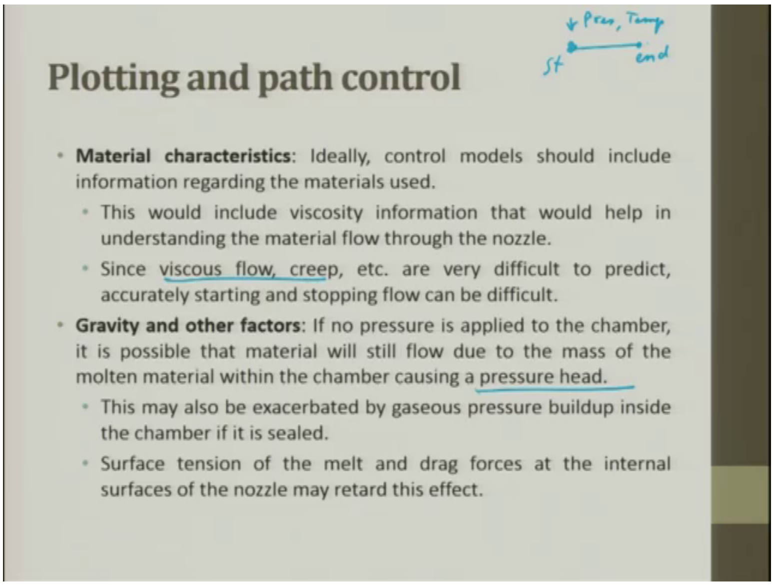

The material characteristics I have told you in the plenty, this would include viscosity information that would help in understanding the material flow through the nozzle. Since viscous flow, creep etcetera are very difficult to predict accurate starting and stopping flow can be very difficult.

So, you start here when you start here it will be pressure temperature, you have to monitor and then it drops down along the line again you have to withdraw back right this is start, this is end with drawback. So, this is very very difficult starting and stopping of the flow is difficult.

Gravity and other factor if no pressure is applied to the chamber, it is possible that the material will still flow due to the mass of the molten material within the chamber causing a pressure head. So, by gravity itself it droops down like for example, when you try to close the top, if sometimes you see after you close also there will be one or two drops coming out, that is basically because of the gravity.

So, if no pressure is applied to the chamber, if it is possible that the material will still flow due to the mass of the molten material within the chamber. This may also be exacerbated by gaseous pressure build up inside the chamber if it is sealed. The surface tension of the melt and the drag force of the internal surface of the nozzle may retard this effect, so we use these things as an advantage for stopping the gravity flow.

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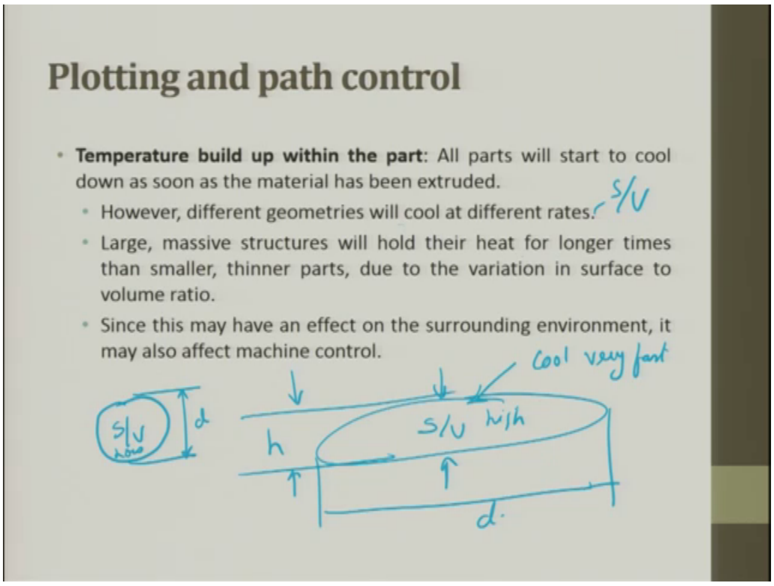

The temperature built in within the part, all parts will start to cool down as soon as the material comes out of the extrusion. However, different geometries we will cool at different rates because it depends on surface to volume ratio. If there is a large surface and the height is this is height and this is height and this is dia fine. So, the same thing I can draw it like this same material. So, the surface to volume ratio is high here, surface to volume ratio is low here. So, that is what we are trying to say. However, different geometries we will cool at different rates.

Large, massive structure will hold their heat for longer time right surface volume ratio low, than smaller thin parts due to variation in surface to volume ratio. Since this may have an effect on the surrounding environment, it may also effect the machine control. So, this fellow might cool very fast, when it cools very fast it also distorts very fast. So, that is what we are trying to tell here.

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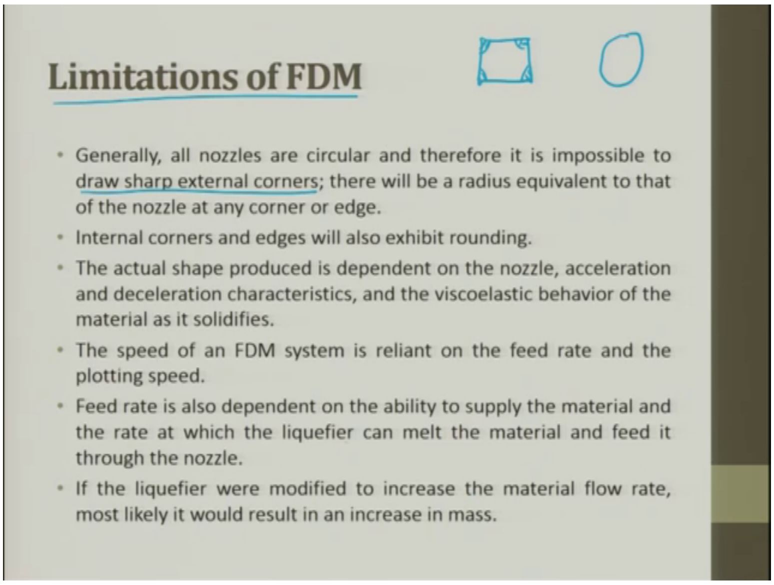

So, the limitation of FDSM generally, all nozzles are circular and therefore, it is impossible to draw sharp external corners, so, we cannot get a nozzle orifice like this, we always get orifice like this. So, these are dead centers where in which the flow will not happened, so we do not go for square nozzles

Internal corners and edges will also exhibit rounding because of dead centre. The actual shape produced is dependent on the nozzle, acceleration and deceleration characteristics and the viscoelastic behaviour of the material as it solidifies. The speed of an FDM system is reliant on the feed rate and the plotting speed.

Feed rate is also dependent on the ability of supply of material and the rate at which the liquefier can melt the material and feed through the nozzle. These are all the limitations if the liquefier, where modified to increase the material flow rate most likely it would result in a increase in the mass flow. So, please make a note of all these things these are the limitations.

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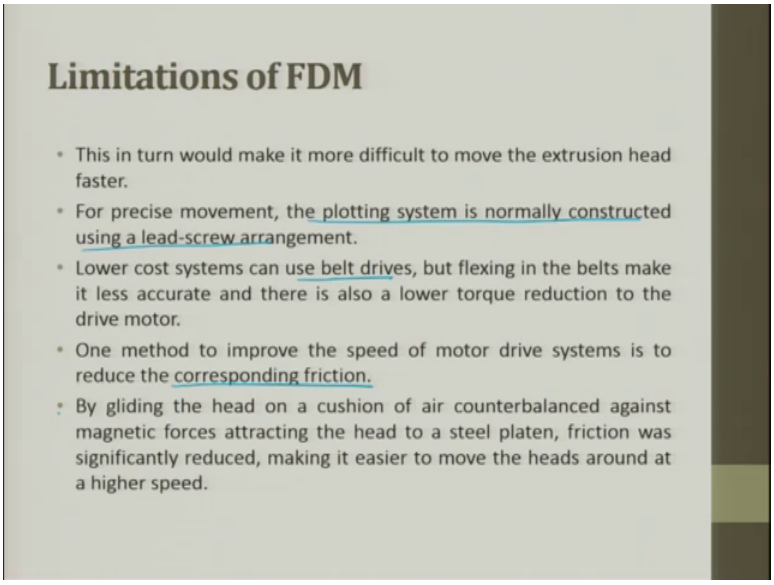

This in turn would make it more difficult to move the extrusion head faster. For precious movement, the plotting system is normally constructed using lead screw this is what I told you. The low cost system will always have built because here the accuracy is are not there.

But flexing in the belt make it less accurate and this is also a lawyer torque reduction to the drive motor. One method to improve the speed of the motor drive system is to reduce the corresponding friction so we go for polymer timer belts. By gliding the head of the of a question of air counterbalanced against the magnetic force attracting the head to a steel platen, friction was significantly reduced making it easier to move the head around at a higher speed. So, this is to reduce the friction.

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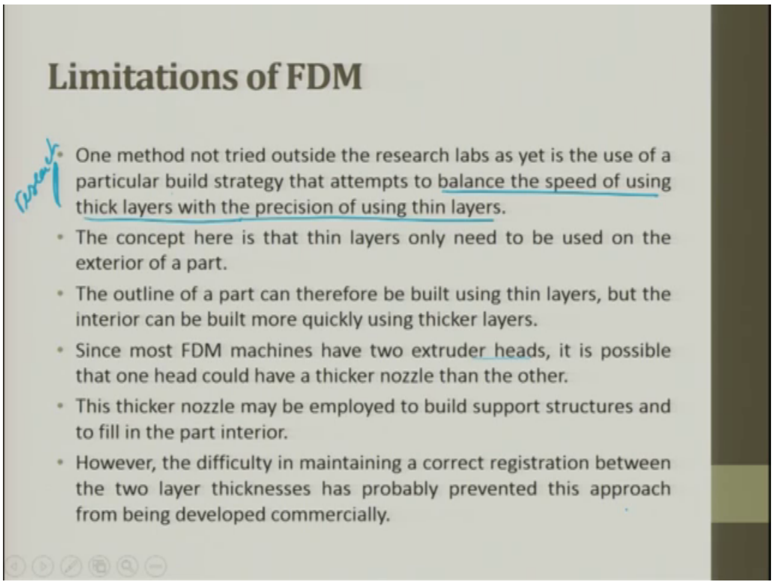

So, one method not tried out the research labs as yet is the use of a particular built strategy that attempts to balance the speed by using a thicker layers with the precision of using thinner layers so this, it is still in research lab ok. The concept here is that the thin layer only needs to be used on the exterior of the part thin layer on the exterior of. The part the outline of the part can therefore, be built in with thin layers, but the interior can be built more quickly with thick layers ok.

So, now current the state of the artists they use same road diameter road width. Since most FDM machines have to extrusion heads, it is possible that one head could be of a thicker nozzle the other one thinner so varying diameter nozzle. This thicker nozzle may be employed to build support and thinner for the external support. However, the difficulty in maintaining a correct registration between the two layer thickness has probably prevented this approach for being developed commercially.