Design Practice - 2
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Lecture - 32
LAB demonstration of Fused Deposition Modelling Techniques

Hello and welcome to this design practice to module 32 we were talking about different rapid prototyping strategies. The first classification was based on what material you were starting with.
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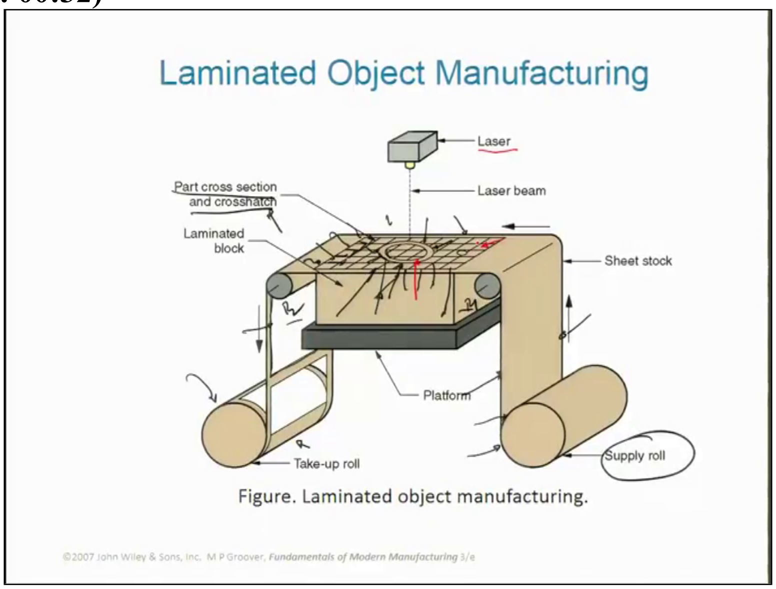

So, in context of the solid based materials we were talking further about the laminated object manufacturing most popularly known as loam where I described our laser actually cuts the sheet of plastic or paper whatever is used as a segment okay and a segment by segment basis in in two different zones. One zone where the actual part segment remains in the other zone is where the crosshatch remains portion remains which can be later on removed as a partner should be released okay.
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Some example problems are some examples are from these two companies the the LOM companies which actually manufacture parts using the laminated techniques the Original technology was developed by the Helisys incorporated which was again acquired by Corum. There are two now two major companies which do this technology or use this technology one is the Cubic Technologies Incorporated and another is the KIRA Corporation Japan.

And these are some parts which have been developed by these two different sources. This right here is a valving module for an automotive structure and this is more like a carry carry bottle which has been developed using laminated object manufacturing or LOM techniques.

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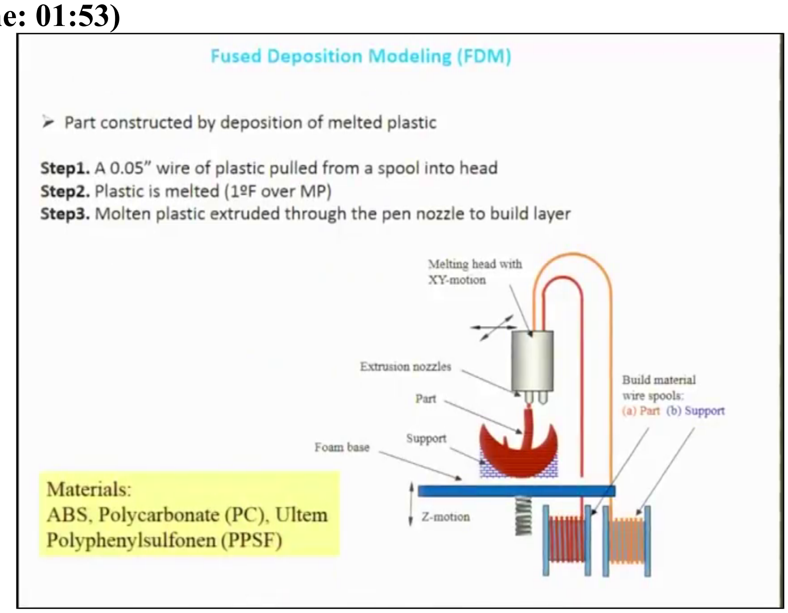

The next very important process which is very widely used across the globe as one of the you know solid based manufacturing processes is a FDM or Fusion Deposition Modeling process.

So, here the part is constructed by deposition of melted plastics the step one of the process involves a wire of a plastic which is fed into the system. It is about .05 inches in diameter and it is pulled from the spool into a head okay.

These are different wire spools there are two different wire you know pulls spools from which wires being fed one which actually corresponds to the whole part material the other which is for the support material they may be same or different polymers okay. And the program is such that the the support material would always be printed in a less dense manner in comparison to the part material.

So, that the separation becomes easier and also there is an optimization take a package which can be worked out in CAD so that the exact supporting systems which would be needed or supporting legs which would be needed to create or construct this part in free space okay can be minimum to the minimum possible extent. So, that the part when it is recovered the legs can be taken off okay and this way you can have a solid part being pulled off.

So, in step two the plastic is melted, melted through an extruder it you know the temperature is taken over the melting point and then the molding plastic is extruded from an extruder through a pen nozzle okay and it is dispensed wherever the nozzle moves and the nozzle would move in a manner so that you have both the nozzles that is the support as well as the part nozzle moving through one head okay in various parts of the geometry.

Some of this geometry you have already programmed and you exactly have filled the volume in space in a CAD package into the portions which are depositing the material and the portions which are depositing the support material. In fact it would be a very wise idea for you guys to see this process and if time permits towards the end of these lectures I would also give you or make open a video which is how you can do FDM process to build a small millimeter grade part okay.

Using various strategies of supports etc which will latter de-couple from the different aspects of the part. So, there are different materials which are used for FDM processes for example a kylo butadiene styrene, polycarbonate, atom is basically an aerospace grade polymer otherwise chemically known as poly ethyl ether amides. Then there is this poly phenyl sulfur nan PPS F. So, these are some of the materials which can be printed through this fusion deposition modeling process.

If I looked at very closely how this part is being shaped you can see the support material right here in blue and the base material for the part you know which otherwise could not have been created in 3D space had this support not existed okay. So, the support is something that is a very less intensity in printing density it is just like legs for a structure so that it can stabilize while the build-up is happening.

So, this is all a part of the package which comes with the FDM tool through which you can actually design supports in an optimized manner losing as less parts as possible.

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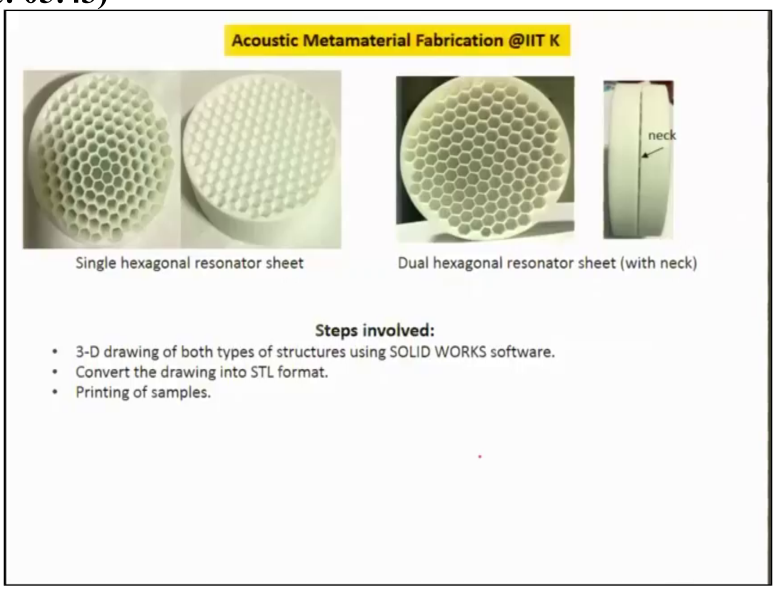

So, generally the MDM process is quite instrumental in printing these days many complex structures and geometries these are a set of single X and L resonator sheets we here by means of the research being carried out in the area of FDM and it is applications of develops of materials which can perform you know can do acoustic damping of aquatic emissions acoustic energies to a very high extent.

And for that a complex geometry is needed where you have these exact neural channels as well as small pores and necks interconnecting several such layers of channels. And otherwise if you were to print or manufacture it using some other method it would have been really a complex way of manufacturing but the idea here with the CAD to reality concept as is being promoted by this FDM process this future deposition partial process makes it very simple to manufactures at geometries.

You can see here small channels interconnecting two different layers you know layer 1 L1 and L2 each of which has these honeycomb-like structures. So, such a kind of a 3-dimensional complex shape getting printed through normal process or normal machining is next to impossible and it can happen only while you are building things additively. So, basically the 3 steps are 3D drawing of both types of structures using SolidWorks software.

Converting the drawing files into STL formats and printing all the samples using the technique that I have Illustrated before.

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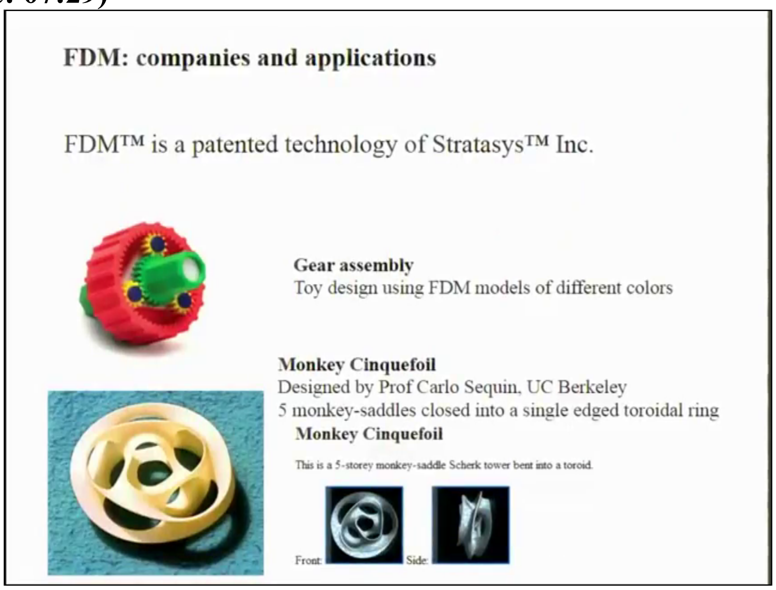

There are many FDM companies one of the major companies across the world is Stratasys which has a patented technology for this FDM okay. You know these are some examples there is a gear assembly being printed using the polymers ok used in toy design using different colors. Then there is this monkey seen cinquefoil designed by Pro Carlos Sequin and UC Berkeley. These are like five monkey saddles closed into a single-edged toroidal ring.

Extremely complex geometry which if not realized may not be so easily able to get visualized you know mentally and so therefore in such kind of structures just before building the structure out it is probably a wise idea to have some kind of a smaller scale prototype in place for which 3D printing is you know 3D printing or rapid prototyping is the way to go.

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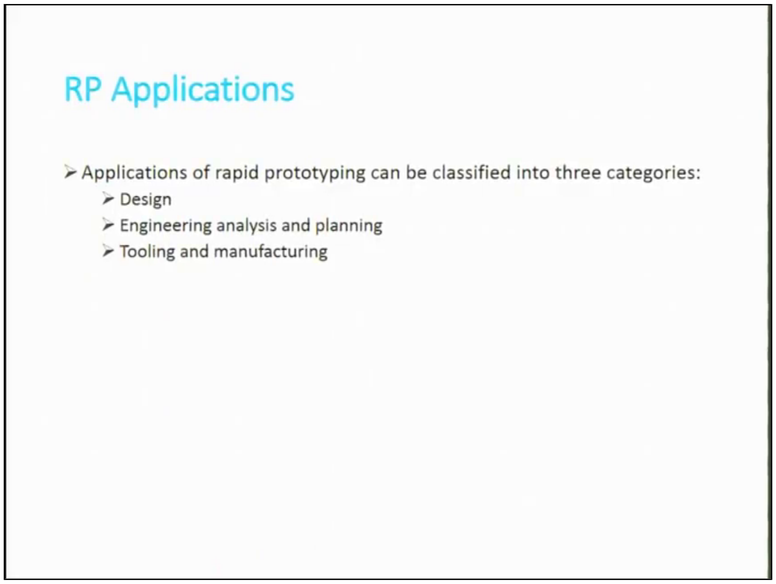

So, there are various applications of rapid prototyping their applications in design particularly part design. It can also be applied to engineering analysis and planning sometimes and then you know it can do a substantial design intervention in design and defining or designing or manufacturing tooling as well as other manufacturing other manufactured components. So, in investment casting for example before you pull out the final dye shape.

It is always sometimes good to find out what is the negative of the dye and whether the part that comes out of the dye is actually going to be accurate. Half of the times and prosthetics when you are building up an artificial leg using a polymer using injection molding techniques it is probably a wise idea to do this iteration iteratively to see from a dye shape if we can pull out the negative of the cap geometry. Is it really going to be the part which is being intended to get manufactured okay.

So, before putting it in place before realizing the dye you could actually build up this geometry and see if it is working out before going ahead and CNC machining the dye so that it can be put into injection mold. So, such are the interventions that RP has particularly solid photography has in development of manufacturing processes.

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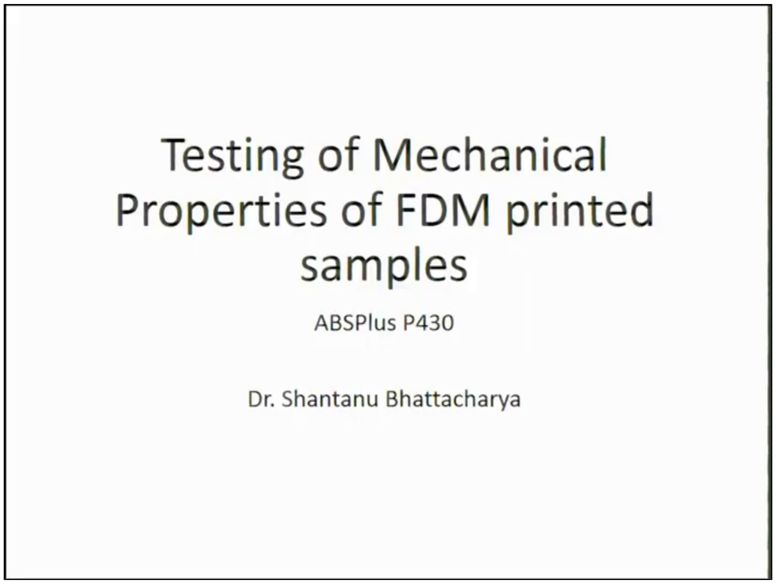

So, I would like to just go take you through some of the aspects of you know FD imprinted samples and some properties these are just some reference slides just from an aspect of giving an idea of how we can mechanically test some of these samples for ultimate yield strength on these samples were printed using variety of polymers one of them was of course ABS plus P 430 grade.

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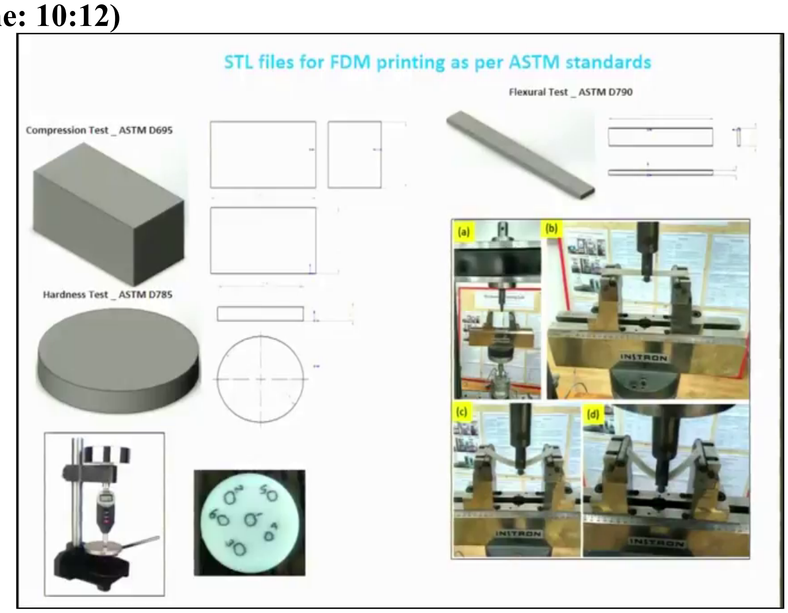

So, generally parts which are printed on IBM machine can be taken through different tests like compression tests as per the ASTM D 695 standard the flexural test where the geometries are being readily available or the hardness test this disk here shows the hardness test. The variety of you know flexural as well as ultimate legal strength testing and hardness testing being carried out through some of these machines here you can see. These are for example 4 photographs which shows the flexural test happening till the part breaks down.

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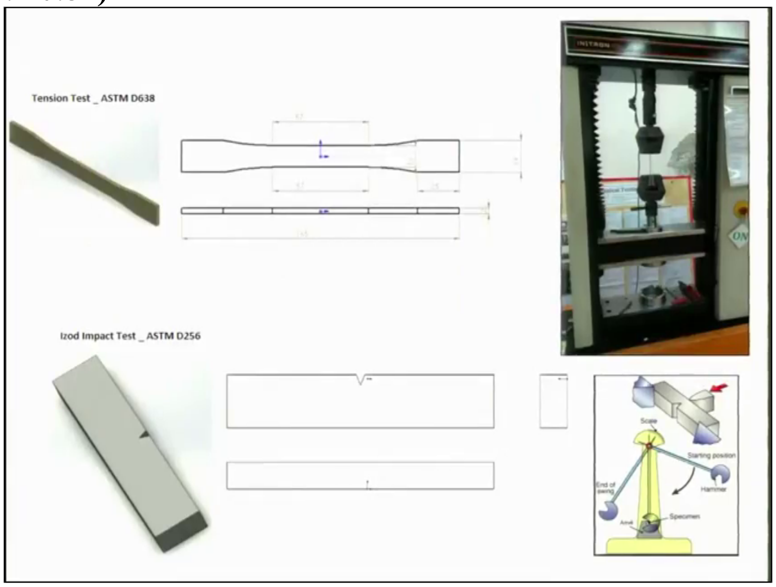

And if we look at the ultimate yield strength you could do this on a tensioner you know using this ASTM D 638 standard there are certain standard dimensions for this part machine which does you know which pulls the component and see steel point or the fracture point okay where failure happens. You could also do the Izod Impact Test you know which would give you an idea which would give you an idea of the impact resistance of the material being printed.

So, in several of these tests we are trying to take through our samples which are 3D printed in two different aspects of mechanical characterization.

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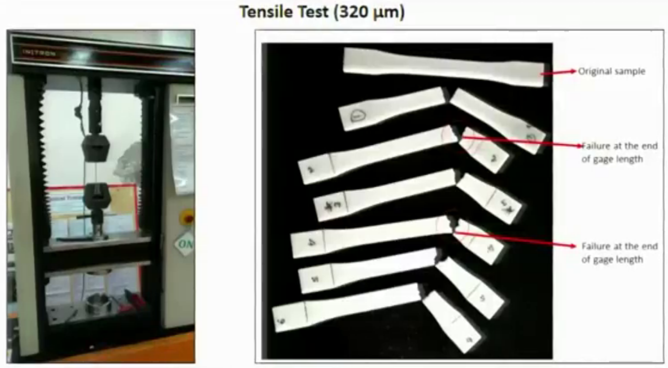
Tensile Test (320 μm)



	Sample 1	Sample 3	Sample 6
Rate (mm/min)	1	3	5
Gage Length (mm)		57	
Peak Stress (MPa)	25.45	26.832	26.508
Peak Load (kN)	1.059	1.116	1.103
Yield Load (kN)	0.69	0.747	0.555
Upper Yield Point (MPa)	16.577	17.957	13.333

And with the ABS plastic that I said these are some results that I can share you know depending on how they are printed at different rates of put push forces that the samples are excised with. This is the original sample this is the failure at the end of the gauge length of different samples okay which are in place. And then we can see the peak stress, the peak load, the yield load, upper yield point of some of these printed in a certain direction okay.

And as the direction of printing may change it may result in the material properties also vary quite a bit based on what is the direction of printing. So, in a way ah what can be found out through all these studies and all these tests is that the mechanical strength mechanical stability of some of the 3-dimensional parts are really highly anisotropic in nature and depends on how these samples are being realized through what direction of printing.

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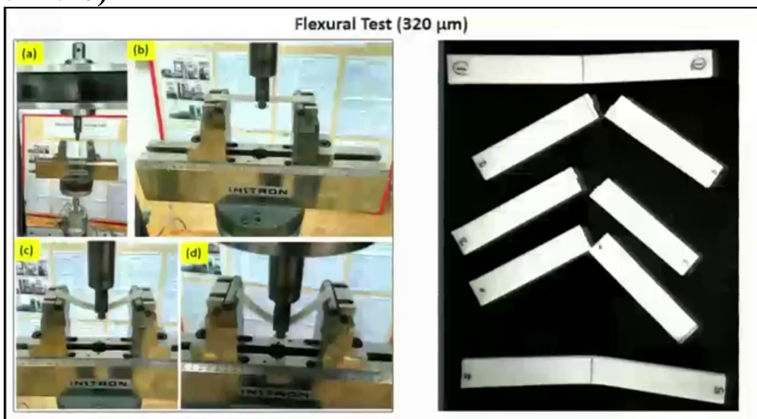

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Rate (mm/min)	1				
Gage Length (mm)	102				
Flexural Peak Stress (MPa)	11.426	11.772	11.017	9.639	9.727
Peak Load (N)	38	40	37.167	32.519	32.813

You know similarly we have values for flexural test here just to give you an idea of how we test some of these samples for mechanical properties or hardness here.

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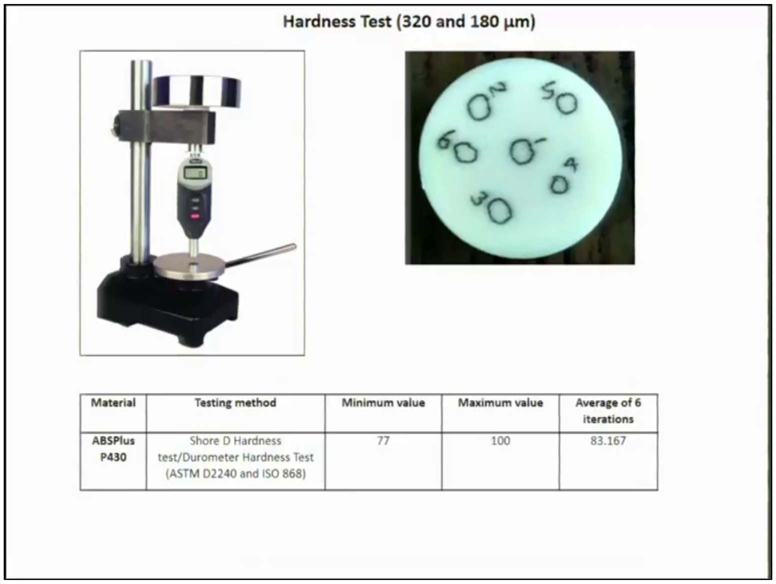

Material	Testing method	Minimum value	Maximum value	Average of 6 iterations
ABSPlus P430	Shore D Hardness test/Durometer Hardness Test (ASTM D2240 and ISO 868)	77	100	83.167

You can see about the hardness value to be about 83.167 okay as per the Shore D Hardness test based on ASTM d2240 standard.

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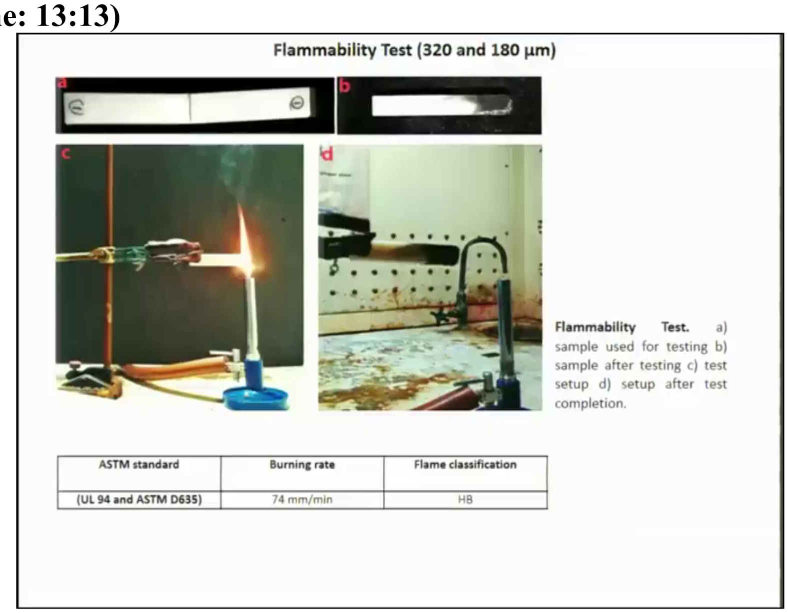

ASTM standard	Burning rate	Flame classification
(UL 94 and ASTM D635)	74 mm/min	HB

Again you know for the particular polymers there are questions related to their burnability house you know how they can be how could they can they can yield to high temperature of flames. So, there are typically flammability tests which are being carried out to address those issues as per the ASTM D 635 system where we can have burning rates of one of the polymers ABS for example is 74 millimeter per minute.

So, these are some baseline values of what would be the mechanical properties or incredibility properties of some of these printed parts 3D printed parts. So, if we compare them with the solid plastic or the solid you know Comp polymer that is being fed into an FDM system as a as a wire they are substantially different okay when they go into printed stage. And one of the reasons why that is so is that the printed architecture gives you in a sense of strength in a particular direction.

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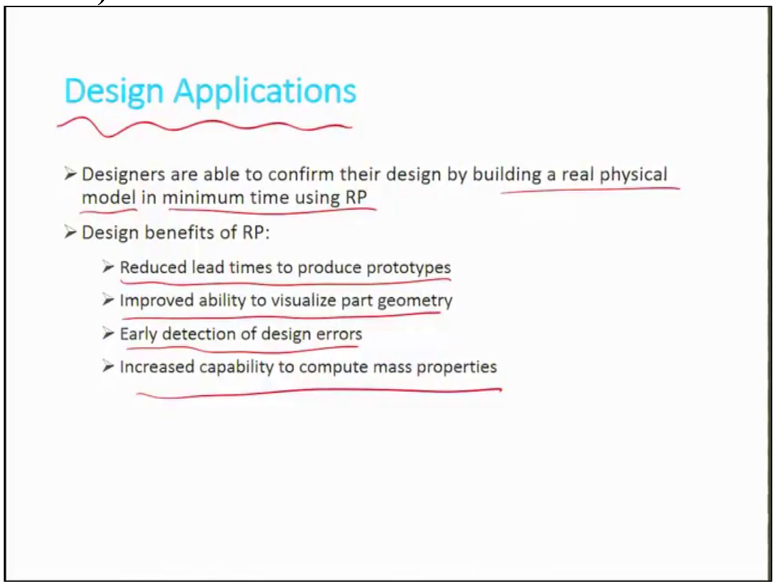

So, what can designers do with such kind of systems designers are able to confirm their design by building a real physical prototype in minimum possible time from cap to reality. The benefits to improvising the design converging the design so there are reduced lead times to produce prototypes improved abilities to visualize path geometry early detection of the design errors, increased capability to compute mass properties okay.

I think I showed you some illustration of how mechanical properties are being gauged in comparison to such parts.

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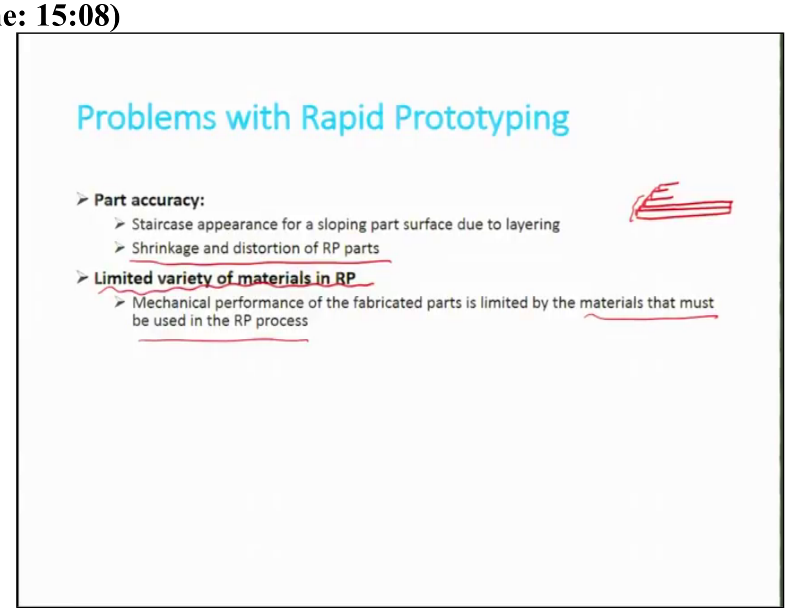

There are certain problems as well with such rapid prototyping techniques particularly the FDM process techniques. So, one of them is part accuracy obviously when we talk about zooming close to a party we will always find a staircase type orientation. And you can see differences between the layers there is no reflow mechanism between layer 1 and layer 2. For example if you have printed something in layer 1 and then you know another in L2 these are like pyramidal in nature okay.

So, this staircase orientation actually comes up you know as the FDM process goes up had there been a reflow option where you know they would have slightly labeled of it would really have changed quite a bit of surface properties. Also associated with rapid prototyping also there are certain shrinkage and distortions of rapid prototype parts obviously there is a very limited variety of the input material and mechanical performance of the parts are limited by the materials themselves.

You saw some of the materials and if we compare that with for example metal there is no comparison and in engineering parts where we need more of mechanical endurance sometimes rapid prototyping or MDM processes particularly may not be a very good option. So, load-bearing parts are typically it is preferred that you make it out of metal and not polymer.

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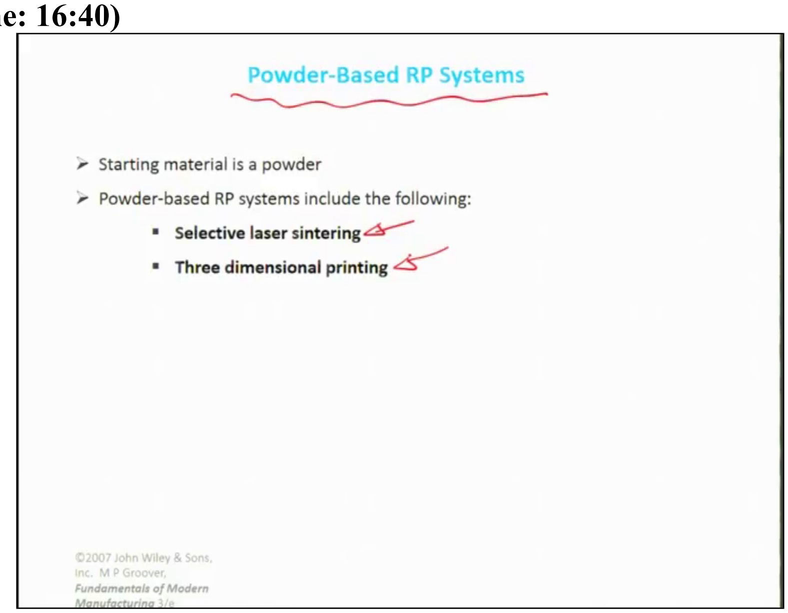

In most of these systems so let us now get into the third variety of the RP systems which are based on powder based or powder beds and this process is very well known as SLS or selected laser sintering where there is granular material present in the bed and you basically heat reading the material in a manner so that the granules combined to each other through a melting binding kind of a process.

And this way your building layer by layer architecture for an overall 3-dimensional geometry. So, one of these are selective laser sintering then there is another very important process which is also known as 3-dimensional printing both of them are powder based processes and a lot of industry is actually increasingly looking into metal 3D printing where they take both the SLS and the 3-dimensional printing processes through metallic granules.

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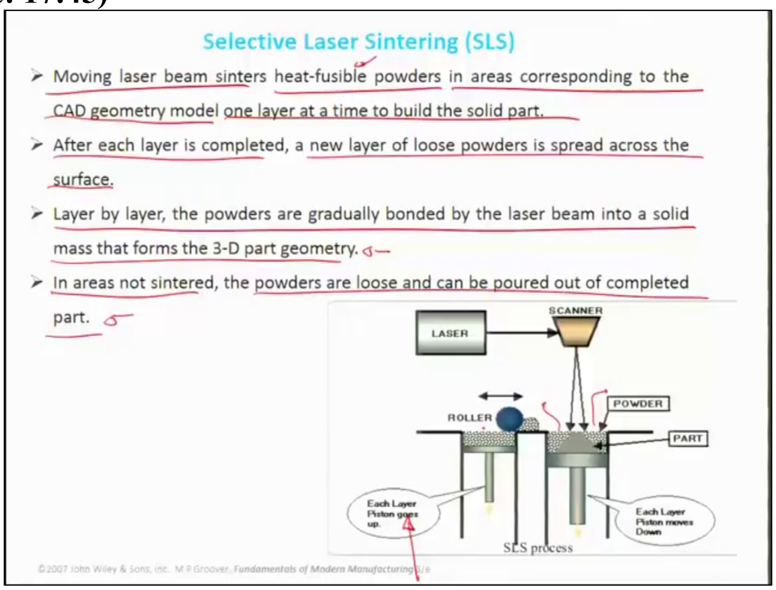

How; What is the basic nature of the process you have a moving laser beam with centers heat fusible powders could be metal powders or powders even could be polymer powders okay. So, but they have to be heat fusible and so you are trying to fuse them in areas which are corresponding to the CAD geometry splice model and building one layer at a time to build the solid part in a powder bed.

So, every time there is a part being constructed you can think of that the remaining powder which is left over is removed and a new layer of powder being sprayed so that that powder can now get freezed so that the next layer can come up okay. So, after each layer is completed a new layer of loose powder is spread across the surface which is again laser treated or heat fused so that it becomes a part you know one additional layer to the lathe that was ending the part below.

And this way layer by layer the powders are gradually bonded by laser beam and they formulated into a solid mass that form a 3D part geometry the areas in areas not sintered the powders are loose they can be poured completely because the laser did not focus on them. And so you can reuse some of this powders for the spreading classes okay in some of the later runs. Each layer piston you know each layer the piston goes up by a certain amount okay.

And in in the in the powder feeding piston and the second piston which is the part building piston the powder which comes out of the part of feeding piston is rolled over the part feeding piston and this comes down okay so as of the whole part is being built in this manner.

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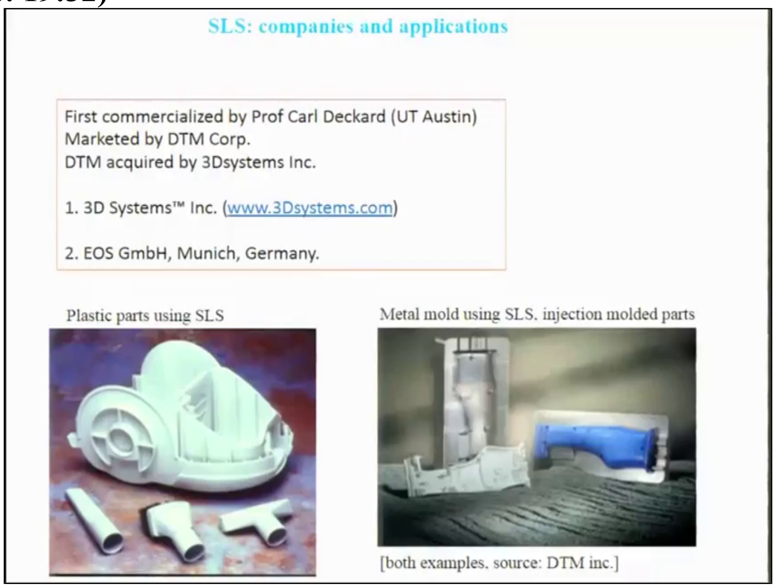

So, there are some examples of SLS processes initially it was commercialized by protocol decade of UT-AUSTIN marketed by DTM Corporation acquired by 3d systems again. And these are some plastic parts printed using SLS processors or even metal molds for injection molded parts both are examples from the source DTM Incorporated. They have been currently acquired by 3D systems and US, Munich and they form one of the frontline technologies in terms of manufacturing.

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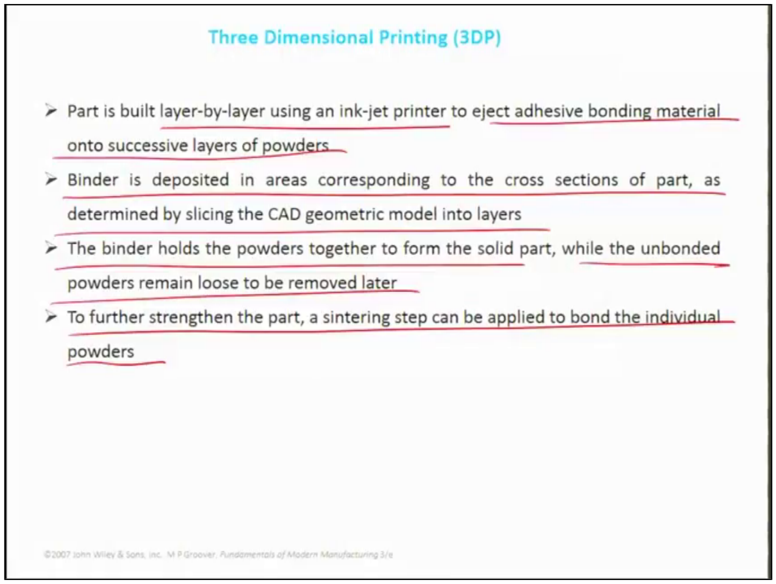

Let us look at the second aspect of Prada based printing which is also known as the 3D three-dimensional printing. Here the part is bit layer by layer using an inject printer to eject an SF bonding material on to successful layer of powders. So, here you are not heat curing but here you applying some kind of virus F with joins the powder together okay. So, the only difference between SLS and this process is that although both of them have input material as powders.

In one case they are heat cured or heat treated in another case they are bonded together through adhesives so or binder. So, the binder is deposited in areas which are corresponding to the cross section of parts as determined by slicing the CAD geometric model into layers. And the binder holds the powder together to form the solid part while the unbonded powder remains loose to be removed later.

So, wherever there is a binder which comes in place the powders would the powder would or the granules or the powders would part of would get bonded to each other firmly and further strengthen the part as a sintering step can be applied to bond the individual powders in place.

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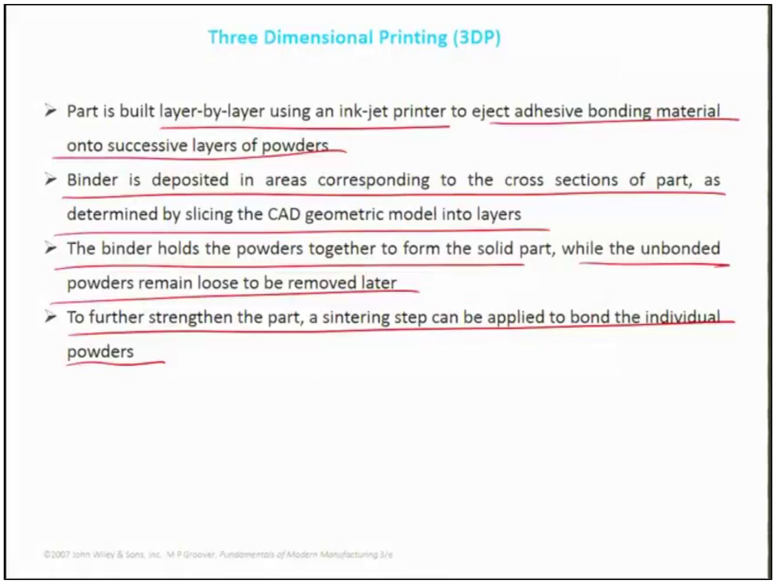

So, this is how it would look like you have a powder layer deposited okay and then there is an inkjet printing head which dispenses the binder material in certain zones and wherever the binding material is being displaced they are solidified. So, this part for example has been solid defied this is in the process of getting solidified. Here again the binder would be disposed of this part gets solid defied.

The remaining is again powder form can be brushed off or brushed aside and you can generate this whole bound the powder you know form of part okay in place. So, one is further layer deposited to inkjet printing of areas that will become parts 3 pistons is lowered for the next layer and in this process enforce layer the powder is taken off and the part is treat okay. So, that is how 3-dimensional printing is carried out.

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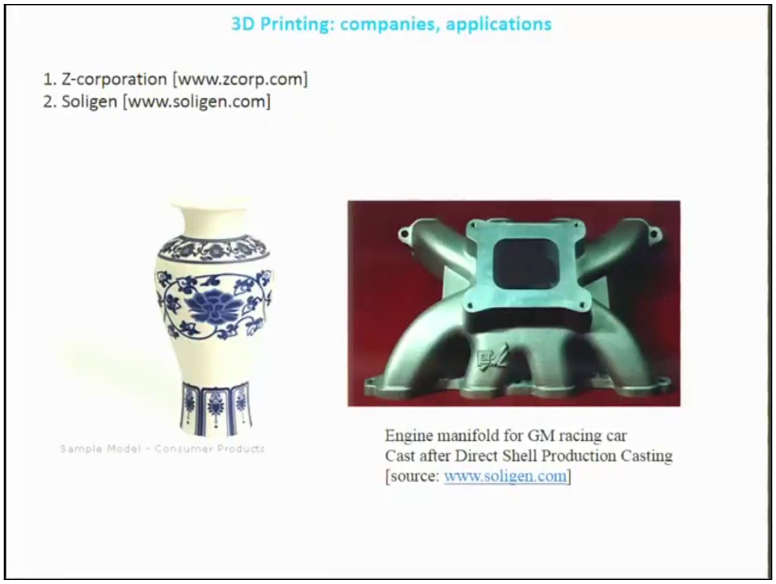

So, these are some companies with 3d printing options you know Z-corporation for example you can see a engine manifold for GM racing car cast after directional production casting or Vase here which has been through the 3D printing process, Soligen for example is another company which works in this area so that is how all this rapid prototyping is across is practiced across the different design and manufacturing industries.

So, I would like to end this particular lecture here in the next module probably we will look up into aspects of rapid tooling and we will also try to quickly get into the next domain which is about some linkages some mechanisms which is again an essential part of this course. And aspects of aspects related to spot strengths or structural stiffness of stability. So, as of now I am closing this module, thank you very much.