Social Innovation in Industry 4.0
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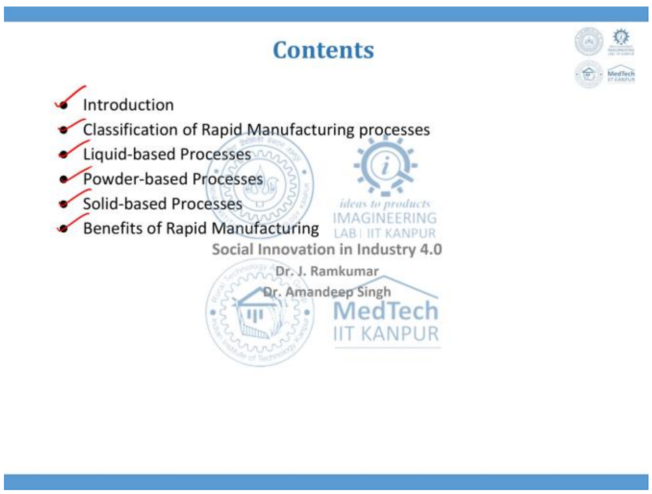
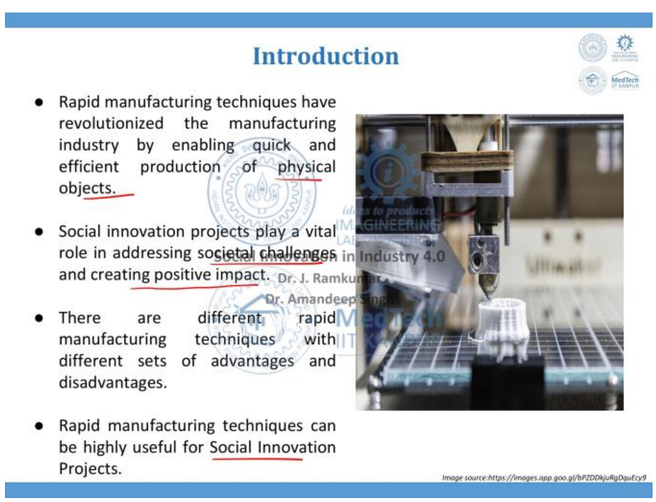
Lecture 39
Rapid Prototyping Techniques

Welcome to the second lecture of this week we are trying to focus on Rapid Prototyping, and I am trying to talk about the Additive part of Rapid Prototyping, which is Rapid Manufacturing only. Rapid Prototyping Techniques we will see in this lecture.

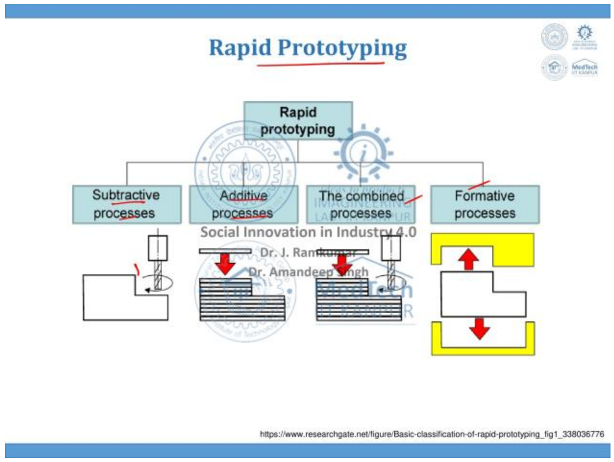


The Contents will cover Introduction to the Techniques, then we will try to see the Classification of Rapid Manufacturing Processes, which are Liquid-based, Powder-based, and Solid-based Processes. Then, we will try to see the Benefits of Rapid Manufacturing in detail, which we have also seen in the previous lecture.



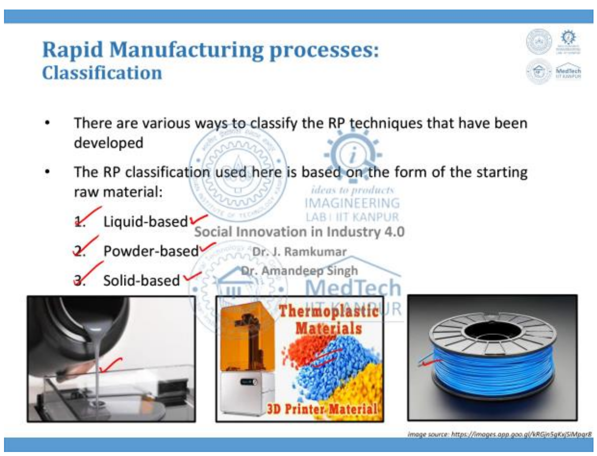
Rapid Manufacturing Techniques have revolutionized the manufacturing industry by enabling quick and efficient production of physical objects. Social Innovation projects play a vital role in addressing societal challenges and creating positive impact.

There are different Rapid Manufacturing Techniques with different sets of advantages and disadvantages. Rapid Manufacturing Techniques can be highly useful for Social Innovation projects.



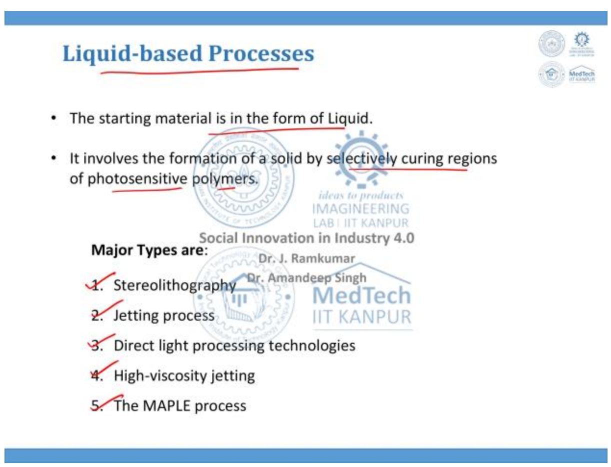
Rapid Prototyping when I say as a general term as I mentioned in the previous lecture has Subtractive Processes and Additive Processes. Subtractive are those where the material is removed, and Additive layer-by-layer material is added.

Therefore, material wastage is minimum. In Additive Processes there could be combined processes when the shape of the component is little complex, it could be Combined Process where Additive as well as Subtractive could go, and Formative Processes just converting the shape into the desired form.

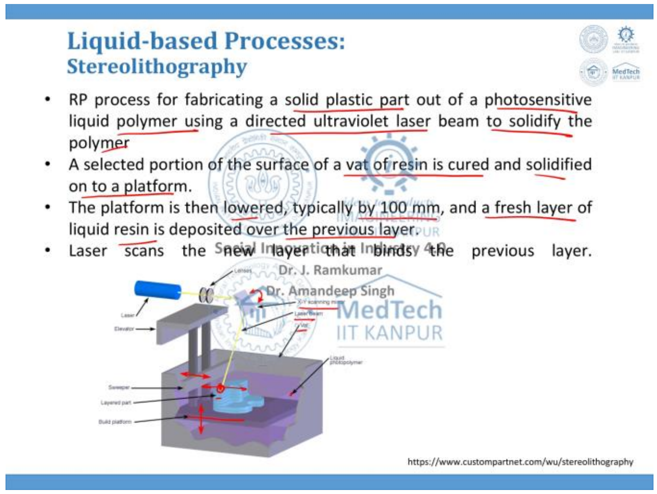


Rapid Manufacturing Processes can be classified into various types which are Liquid-based, Powder-based and Solid-based. There is a liquid, that is helpful to manufacture something as a build or a prototype. Then, we have thermoplastic materials which is in the form of the granules or filaments, that become solid type, and there is also a powder available.

This powder form is one of the another forms, we will try to see how do we try to use. All these kind of the types of the materials and try to classify the Rapid Prototyping processes. So, when I talk about any of these types let me say liquid-based types, it has further of its types, maybe inkjet or photopolymerization types of the Rapid Prototyping technologies. Inkjet includes multi jet modeling, drop on demanding jet, or so, and photopolymerization includes the UV, that is poly jet technologies or stereolithography processes. The powder-based processes also have certain classification within themselves, that is SLS, that is Selective Laser Sintering is part of it, 3 dimensional printing is also part of it.
Then, comes the solid modeling there could be gluing techniques, there could be extrusion techniques. When I talk about gluing techniques, those are the layers are glued together, that laminated object manufacturing is one. That is sheet, metal-based processes. Then, we have extrusion kind of a processes which is Fused Deposition Modeling (FDM) process, what is the highly common process in Additive Manufacturing.



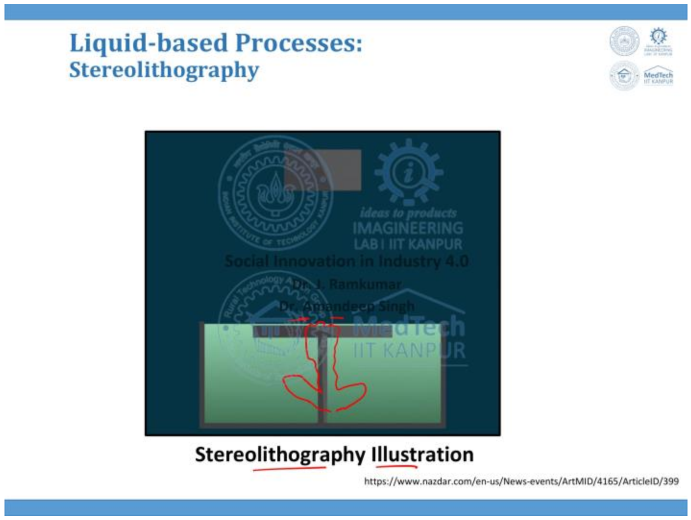
Let us try to talk about the Liquid-based processes first. The starting material is in the form of liquid here, it involves the formation of a solid by selectively curing regions of photosensitive polymers. The major types are stereolithography, jetting processes, direct light processing technologies, high viscosity jetting and the maple process.



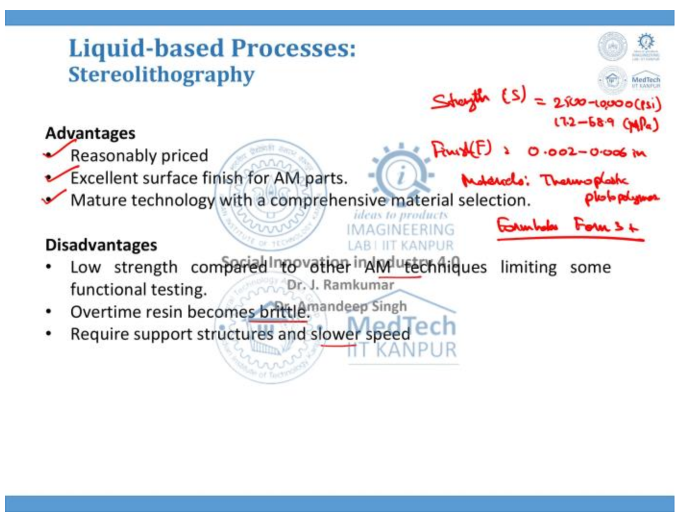
I would not discuss all of them because we have a limited time to cover this lecture within an hour, but major of the processes, such as stereolithography would be taken into account. Rapid Prototyping Process for fabricating a solid plastic part out of photosensitive liquid polymer using direct ultraviolet laser beam to solidify the polymer is known as stereolithography. A selected portion of the surface of vat of resin is cured and solidified onto the platform.

The platform is then lowered, typically by 100 mm in general, and a fresh layer of liquid resin is deposited over the previous layer. The laser scans the new layer that binds the previous layer. So, here are the small components of this we have a build platform. On this build platform, we have the layered part and this is a sweeper, that keeps on sweeping the component and we have liquid photopolymer here which is cured using laser beam. We have XY scanner mirror which helps us to only cure the component area, that is required for the final printing in that layer.

We have elevator for lifting the platform up and we have lenses that helps you to focus the laser on the specific part that is there.

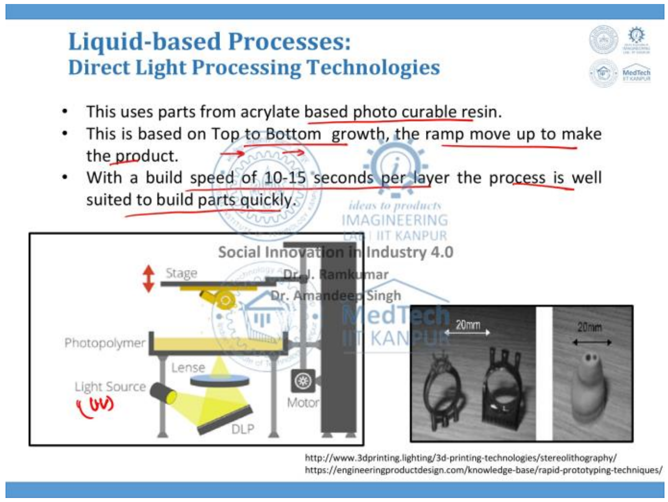


So, you can see a 3D animated system here as well. So, this laser is curing only the part wherever curing is required. So, we are able to develop this component here. So, this is stereolithography process.



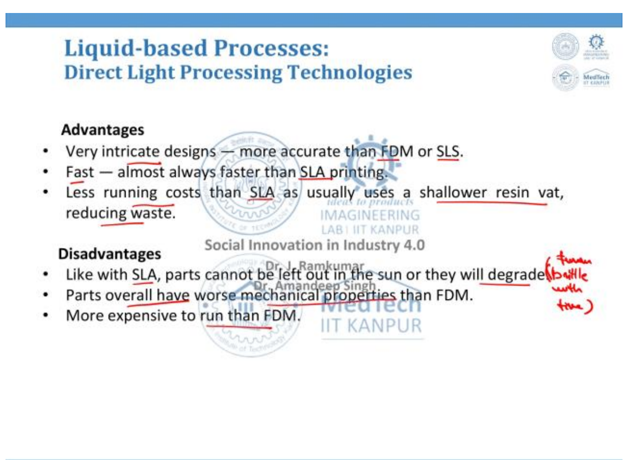
Certain advantages of this are, it is reasonably priced, excellent surface finish is there, for Additive Manufacturing parts, it is a mature technology with a comprehensive material selection. These advantages could be the low strength compared to other Additive Manufacturing techniques and they are limiting to some functional testing only. Then, overtime that is with time resin becomes brittle. So, the life of the components which are manufactured through this stereolithography process is not very long. It requires support structures and it is slower in speed.

The strength typically for the recent components of the machines which are available in 2023 varies from 2500 to 10000 PSI, that is 17.2 to 68.9 mega Pascal. And, the finish which I denote by F here between layers is from 0.002 to 0.006 inches. For example, materials are thermoplastics like photopolymers. And, representative machine for the finish and strength which I have given is Formlabs which is a manufacturing concern Form 3 plus.



Next comes, direct light processing technologies which is also one of the liquid-based processes, in which the parts from acrylate based photo curable resin are taken. This is based on top to bottom growth, the ramp move up to make the product.

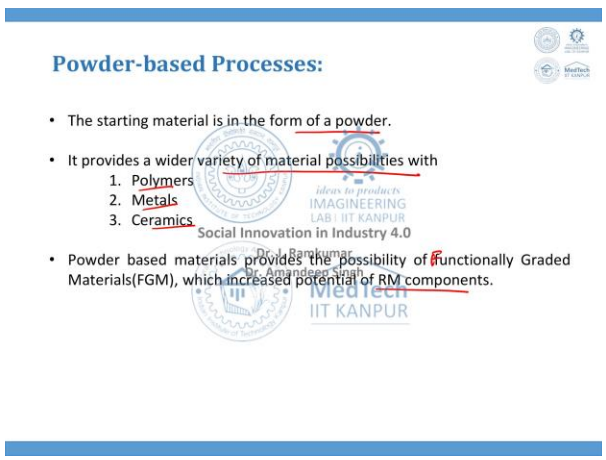
With a build speed of 10 to 15 seconds per layer the process is well suited to build parts quickly. Here, we have a stage, we have a lens and using a light source that is a direct light source. This is generally a UV light that helps to cure the resin and we are able to build the part from the top to bottom. So, this is similar to what we have discussed in stereolithography the source here is UV in general.



So, it is used for very intricate designs that is more accurate than fused deposition modelling or selective laser sintering.

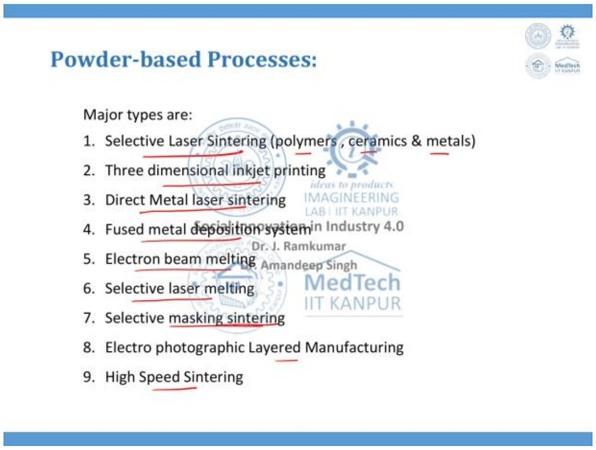
It is faster process that is almost always faster than SLA printing. It has less running cost than stereolithography operators as uses shallower resin weight and it also reduces waste. Like stereolithography operators the parts cannot be left out in the sun, or they will degrade. That parts are brittle or become brittle with time. Brittle with time, I would say here it turn brittle with time.

The parts overall have worse mechanical properties than FDM that is the break or crack more easily and the risk of deteriorating over time is there. More expensive to run than FDM because resins are far more expensive than filaments and regular replacement of resin tanks and occasionally we print platform also adds up to it, because when the resin is spilled over on the print platforms those are also to be replaced frequently.

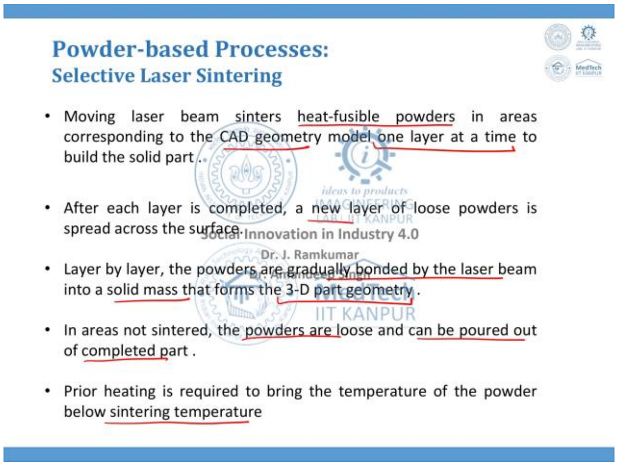


Next come the powder-based processes. The starting material is in the form of a powder. it provides a wide variety of material possibilities for between polymers, metals and ceramics, whatever could be converted into powders, and on heating or curing with laser that could be converted into solid, it could be used as a raw material for the powder-based processes.

Powder-based materials provide possibility for functionally graded materials, that is FGMs which increase the potential of Rapid Manufacturing components.

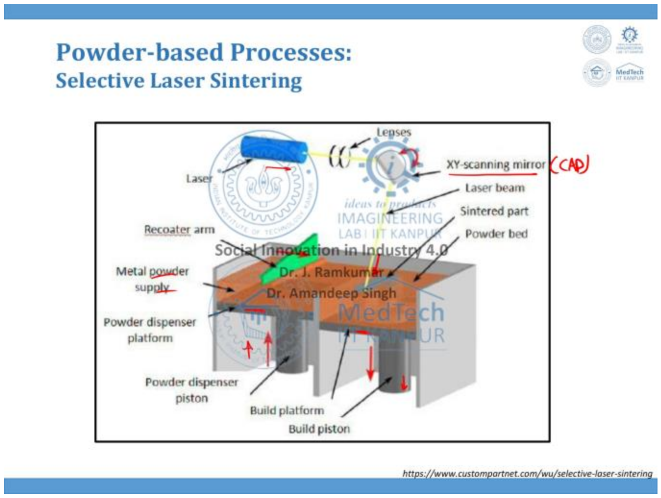


Major types of the powder-based processes are SLS as one of the major kinds, that is polymers, ceramics and metals are all used here. Then, three dimensional inkjet printing, direct metal laser sintering, fused metal deposition system, electron beam melting, selective laser melting, selective masking sintering, electro photographic layered manufacturing and high speed sintering are all types of it. I will try to only discuss about selective laser sintering and three dimensional inkjet printing here.



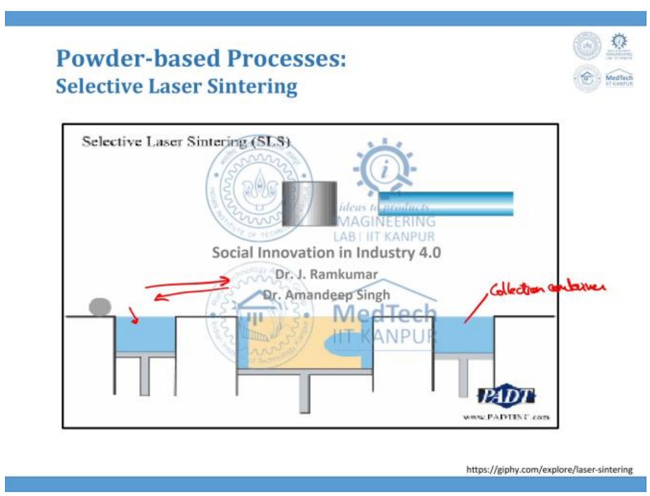
Regarding selective laser sintering here, a moving laser beam sinters huge-fusible powders in areas corresponding to CAD geometry model one layer at a time to build a solid part.

After each layer is completed a new layer of loose powder is spread across the surface. Layer-by-layer, powders are gradually bounded by the laser beam into a solid mask that forms a 3D part geometry. In areas not sintered, the powders are loose and can be poured out of the completed part. Prior heating is required to bring the temperature of the powder below the sintering temperature, that is preheating is also required here.

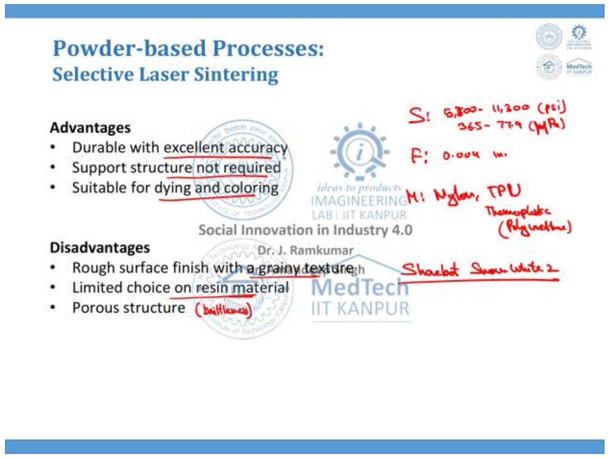


So, this is the typical setup of the SLS process, in which this is a recoater arm, and we have a powder spread here this is metal powder supply.

This powder is spread over the printing area and similar to the previous process, that is SLA process there is a laser and using lenses it is focused on the specific part. Then, we have XY scanning mirror, based upon the CAD modeling that we have received it scans the component, and try to only cure the component that is required. So, this is the powder bed and this we have got the sintered part. Here you can see, the powder sintered dispenser piston is there which is moving in upward direction to provide the powder as and when it is being used and there is a piston that is moving down that component that is being built is coming down only. So, this is a build platform the left side is the powder dispenser platform.



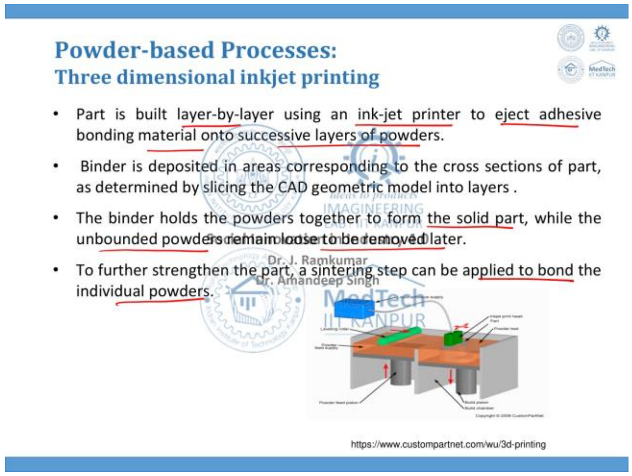
You can see the animated picture over it you can see here. So, all the leftover powder is put into the collection container. This is my collection container and here this becomes my collection container. So, this is a two way roller or recoater that helps you to keep on coating time and again so we do not waste the time of going right, and then coming back. So, each time it is just layering or coating this material over it. This is typical SLS printing process.



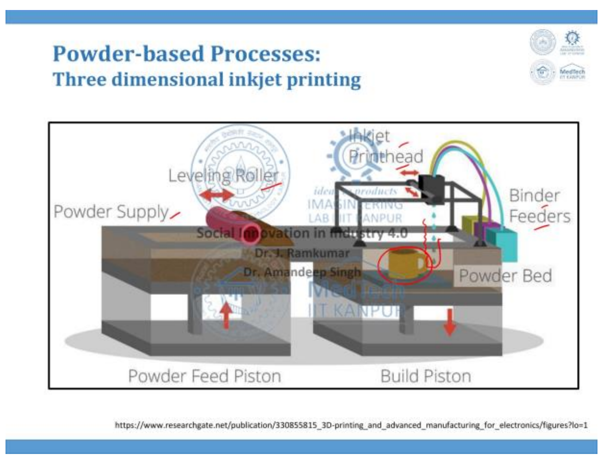
Let us try to see advantages and disadvantages of it. Advantages are, it is durable with excellent accuracy, the support structure is not required at all here and suitable for dying and coloring. The disadvantages could be the surface finish with grainy texture do come, limited choice of resin material is there, and the structure is also porous here that is again brittleness do come. And, if I talk about the strength, finish and example materials here, the strength here is between 5300 to 11300 PSI, that is from 36.5 to 77.9 mili Pascal.

And, the layers that we have gotten here in the finish are of around 0.004 inches. For example, materials could be nylon, that is the flexible material, and TPU can also be one of the materials, TPU also I mentioned in the previous lecture as well. TPU is a flexible material that helps you to get something close to the rubber, where the full form here is thermoplastic polyurethane. Silicone is also one of the materials which is a flexible material and also that curve also be 3D printed here.

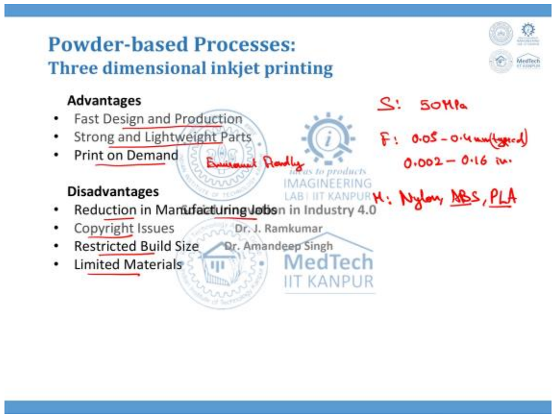
Here, the representative machine, that is there, is shear board snow white 2 for which this surface finish and strength is given.



Next comes, three dimensional inkjet printing. Three dimensional inkjet printing is simple printing process where the part is built layer-by-layer, using an inkjet printer to eject adhesive bonding material onto successive layers of powders. Binder is deposited in areas corresponding to the cross sections of a part, which is determined by slicing the CAD geometric model into layers. The binder holds the powder together to form the solid part, while the unbounded powders remain loose to be removed later. To further strengthen the part, a sintering step can be applied to bond the individual powders. Sintering is heating the powders so that the bond becomes stronger.



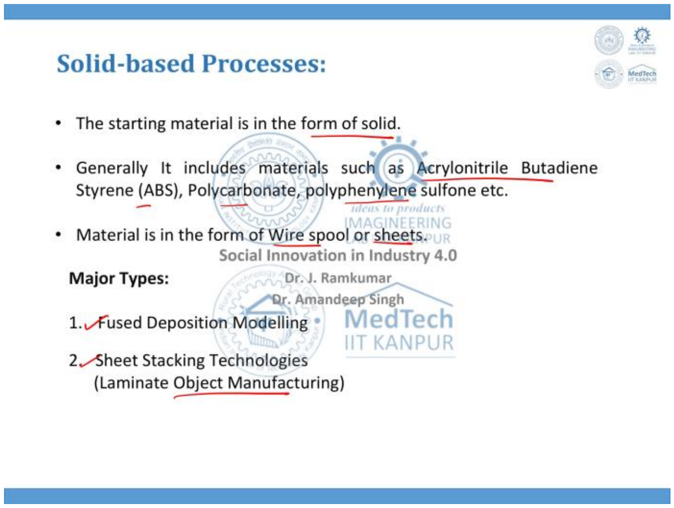
This process also has a construction as we have a leveling roller here, powder supply here, inkjet print head is there, binder feeders are there and binder feeders is only major addition, that is added here in the inkjet printing process over the SLS process. Here, we do not have laser only the binders are there, feeders are there, which are trying to bind the powder to the form that is required. So, we have build piston and powder feed piston, the mechanism is almost similar to the previous processes.



To talk about the pros and cons, fast design and production becomes one of the advantages of three dimensional inkjet printing. It is strong and lightweight parts could also be produced from it, then print on demand that whenever and whatever is required could be printed and also it is environment friendly. The disadvantages which are jotted down here are reduction in manufacturing jobs, copyright issues could be there, restricted build size and limited materials. Though, the strength that I could quote here for the 3D inkjet printing components is as high as 50 mega Pascal. The finish that could be gotten from the three dimensional inkjet printing is between 0.05 to 0.4 millimeter.

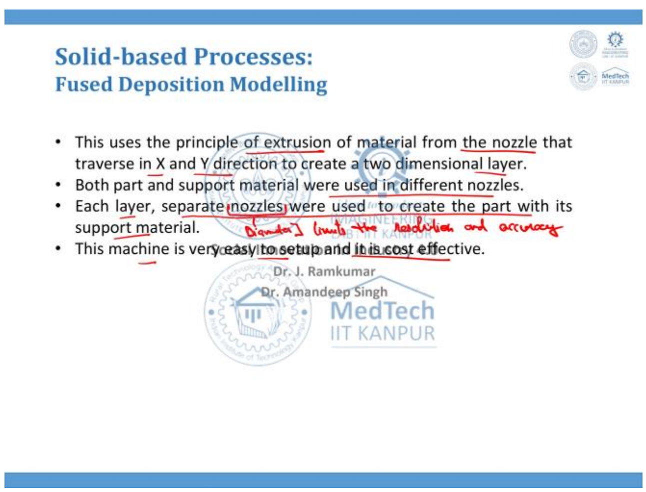
This is, I am putting a typical finish here, which in the inches, if I try to put this becomes 0.002 inches to 0.4 mm that is 0.16 inches. Then, example materials here could be nylon, ABS, then polylactic acid, and so.

ABS is 0.02 is Acrylonitrile Butadiene Styrene PLA is Polylactic Acid. Next comes the Solid-base Processes.



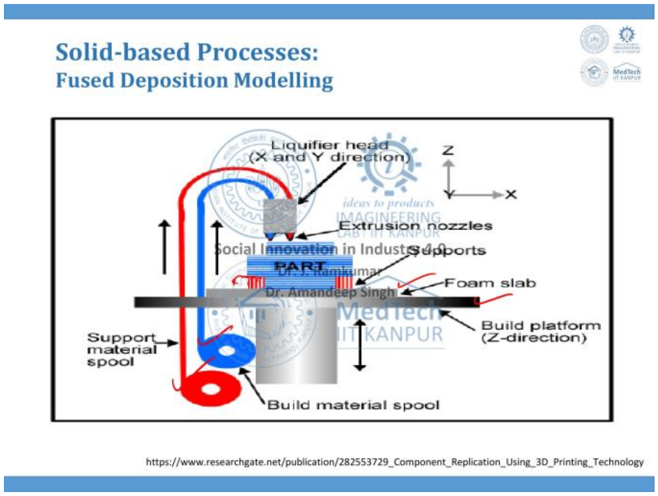
The starting material in the Solid-base Processes is a solid. Generally, it includes material such as ABS, polycarbonate, polyphenylene sulfone, etcetera. Material is in the form of wire spool or sheets.

Major types are fused deposition modelling and sheet stacking technologies, that is laminate object manufacturing. These two processes also I will discuss.



Fused Deposition Modelling uses the principle of extrusion of material from the nozzle that traverse in x and y direction to create a two dimensional layer. Both part and support material were used in different nozzles. Each layer, that is separate nozzles are used to create the part with its support material.

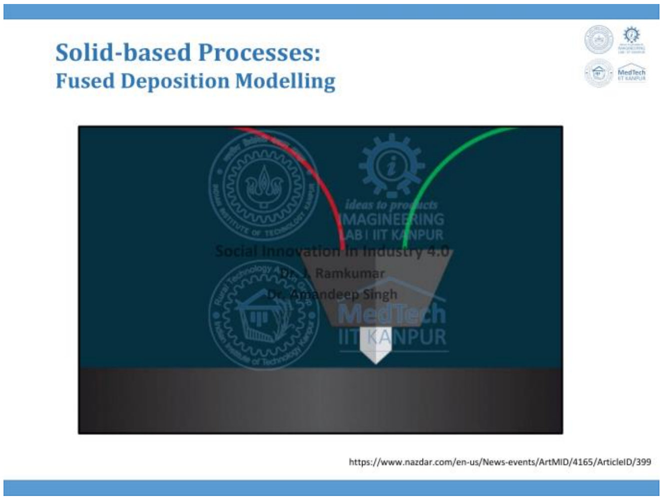
This machine is very easy to set up and is cost effective as I just said, a printer cost could be as those as 6000 rupees or so. The diameter of the nozzle is one, nozzle diameter I will put here, that limits the resolution and accuracy.



A typical setup is something like this. We have liquefied wire head where two nozzles are there. This is build spool the blue color that is shown the final material that is to be as a part or component.

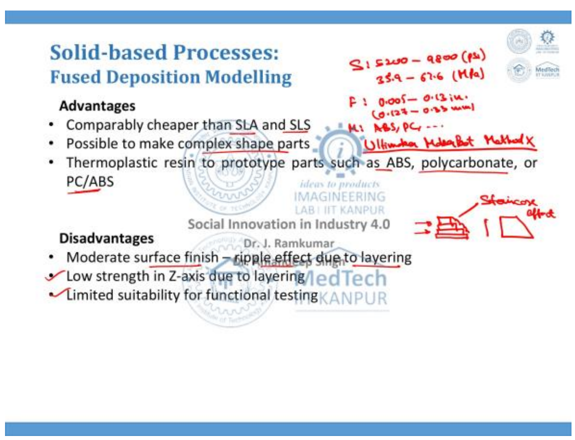
In the red color we have the support material. For example, this component this part is to be built here. So, this could not be built in air. So, a support material is to be provided which is later removed. So, two separate spools are there for the support and for the build material. A single material could also be used for support and for the build material, but there the wastage of material could be there.

So, material that is expensive that is the major part material is blue and support material is a material that could be removed and also is not very expensive. So, we have supports extrusion nozzles here, we have x y direction moving extruder here, build materials spools are here and we have build platform and we have foam slab.



Let us try to see the two filaments are connected and we are trying to complete this here. Here both the filaments could also be form materials only. The form materials, for example, this the lower part is giving one color, the upper part is giving the other color.

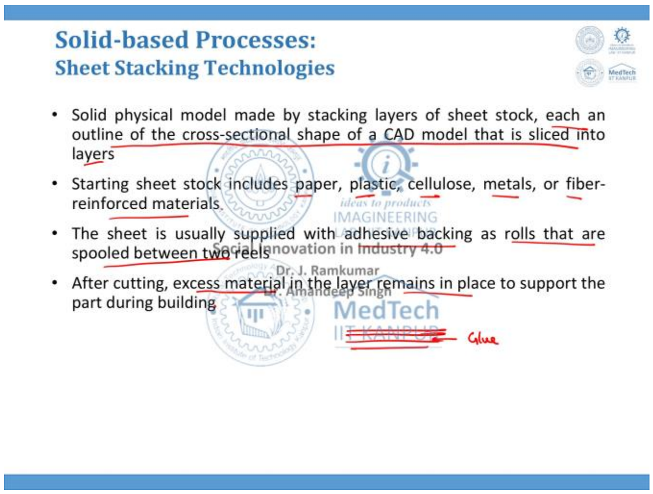
So, the two materials which are using are not support and build material, but both of them are build materials and they are providing the color variation in the final print that we are getting through this process.



The advantages that could be quoted here are comparatively cheaper than SLA and SLS. It is possible to make complex shape parts, thermoplastic resin to prototype parts such as ABS, polycarbonate or a mixture of PC and ABS could be produced. Disadvantages are, it has moderate surface finish that will ripple effect due to layering is there. That is, we have staircase effect here as and when the component is being manufactured.

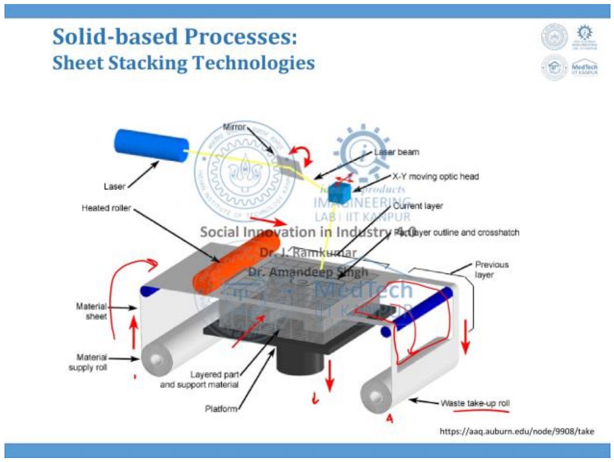
The layers have this kind of a staircase effect. So, that means exactly smooth component is not produced. Something like, this is not produced we have a staircase effect here. Then, it has low strength in z direction due to layering because we have a bond at each layer, so it has strength lower in the z direction, but in the x and y direction strength is okay. Limited suitability for functional testing that is suitability at certain functional testing is very low. If I talk about strength of the components which are produced using this is from 5200 to 9800 PSI, which is 35.9 to 67.6 mega Pascal.

The finish that comes is from 0.005 to 0.13 inches that is 0.127 to 0.33 millimeter and the materials I have already mentioned it could be ABS, polycarbonate and so on. The representative machine that is giving this strength and this finish is Ultimaker MakerBot and the model name is MethodX. Let us now talk about sheet stacking technologies that is laminated object manufacturing.



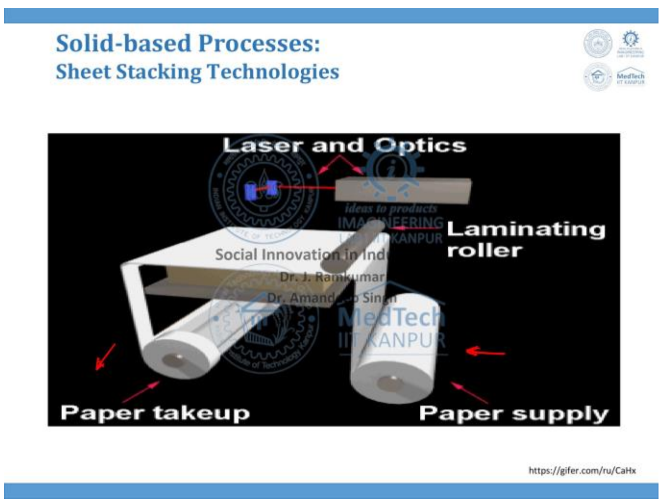
Solid physical model made by stacking layers of sheet stock, each an outline of the cross-sectional shape of CAD model that is sliced into the layers. Starting sheet stock includes paper, plastic, cellulose, metals, fiber-reinforced materials or so. The sheet is usually supplied with adhesive backing as rolls, that is, they are spooled between two reels. After the cutting of the sheets, excess materials in the layer remains in place to support the parts during the building.

That means, different sheets are there. This is sheet 1, sheet 2, sheet 3 in between we have glue. This glue is there which helps us to bond the sheets, which are stacked one over each other.

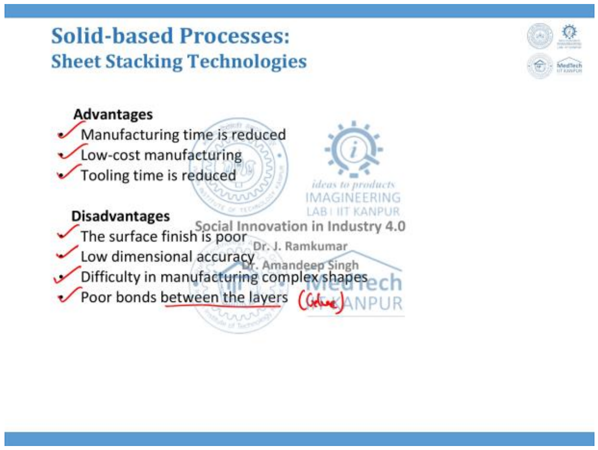


So, here you can see the material supply roll is there. From here the material is going in this direction and here material is being collected back. So, this part is cut out of it, this part is cut here and as per shape XY moving opening head is there, which is cutting the material using laser and heated roller is there, wherever the sheet is required the glue is heated to fix it there.

So, waste take-up roll is here that takes the waste out, and this is a platform that is coming down as and when it is being manufactured and this is the component, you can see inside, that is been manufactured using the sheet stacking technology.

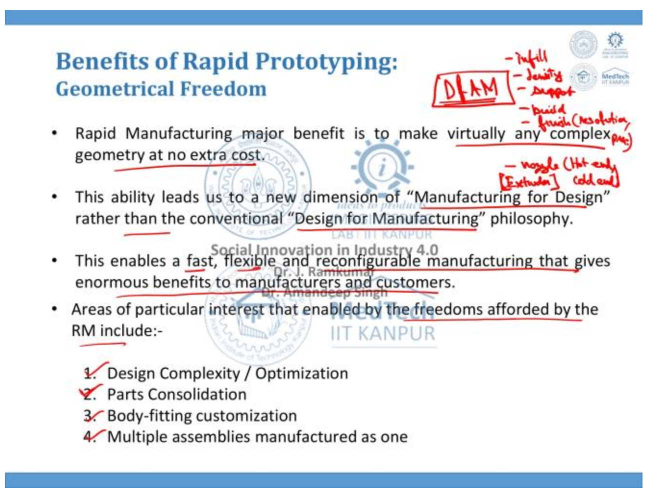


Let us try to see this, as well you can see the paper supplies going from right to left, it is being manufactured in a laminated form. This is also known as laminated object manufacturing. The object that is there, that are the sheets are being laminated over each other.



The advantages of sheet stacking technologies are that manufacturing time is reduced, it is a low-cost manufacturing, and the tooling time is reduced as well.

And, it applies to a vast variety of materials. Disadvantages are only that the surface finish is poor, low dimensional accuracy is there, There is difficulty in manufacturing complex shapes, and poor bond between layers is there because that is just a glue. This is another material itself.



Let us now talk about certain Benefits of Rapid Manufacturing or Rapid Prototyping. Rapid Manufacturing major benefit is to make virtually any complex geometry at no extra cost. This ability leads us to a new dimension of "Manufacturing for Design" rather than conventional "Design for Manufacturing" also, this is something known as DFAM.

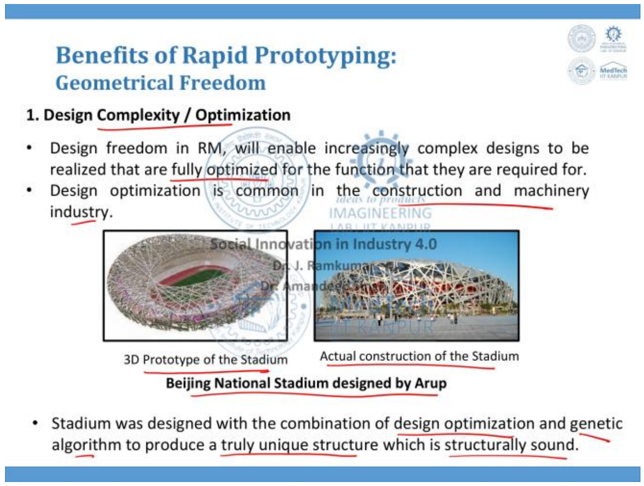
Design for Additive Manufacturing. When we say Design for Additive Manufacturing, whatever the design is made in such a way, that is the support material is minimum, and the material should be able to be manufactured in different modules and could be assembled together, and different modules are each developed using the Additive

Technologies, that is a Rapid Manufacturing Technologies only. So, this is known as DFAM. There are certain terms, when I talk about DFAM, are infill of the material. Infill is, when I am trying to build a material or solid component, it is not 100 percent solid component there are certain voids in it. So, what should be the void density? It could be vary from maybe infill.

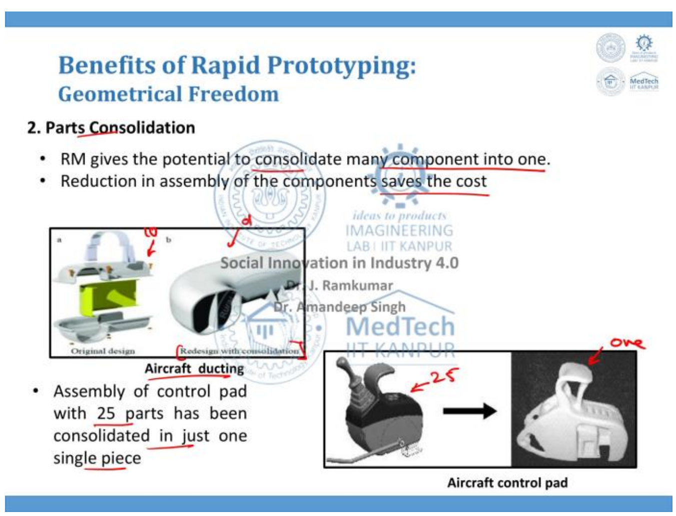
If it is 90 percent of the material is to be filled, 10 percent could be void we say 90 percent infill. If we say 80 percent infill, 20 percent of the voids are there. Similarly, we have density. Density is similar to infill but only it is different than the how infills are being located, so that the material becomes dense or not.

I think support and build material we have already discussed. Support material and build material, these two terms we have already discussed, it is build is the major material support is only the support material. Then, we have resolution or precision or finish that we have mentioned here. I would say finish also I will call it resolution or it is also called as precision. Then, when we talk about the nozzle as well because nozzle only determines the resolution and precision in the case of the FDM process, there is a hot end and there is a cold end. Because we are talking about nozzle if I put it as a broader term, and call it as extruder it only has hot and cold end.

The cold end majorly control the rate, at which the material is to be supplied, that is the flow of the material and hot end is only to adequately heat the material, so that the plastic material that is fused or melted is made to pass through the nozzle. So, these are the few terms when we talk about design for routine manufacturing kept in mind and we try to design the part accordingly. Geometrical Freedom in Rapid Prototyping enables a fast flexible and reconfigurable manufacturing that gives enormous benefits to manufacturers and customers. Areas of particular interest that enabled by the freedoms afforded by the Rapid Manufacturing include design complexity and optimization, parts consolidation, body-fitting customization, multiple assemblies manufactured as one.



Let us see each of these. First is design complexity and optimization. Design freedom in Rapid Manufacturing enable increasingly complex design to be realized that are fully optimized for the function that are required for. Design optimization is common in the construction and machinery industry. You can see this is a stadium, that is a Beijing National Stadium designed by Arup. This is 3D prototype of the stadium and actual construction of stadium also happened based upon this prototype which was developed. Stadium was designed with the combination of design optimization and genetic algorithm to produce a truly unique structure which is structurally sound. Structurally sound and minimum material is also used, it is designed accordingly.

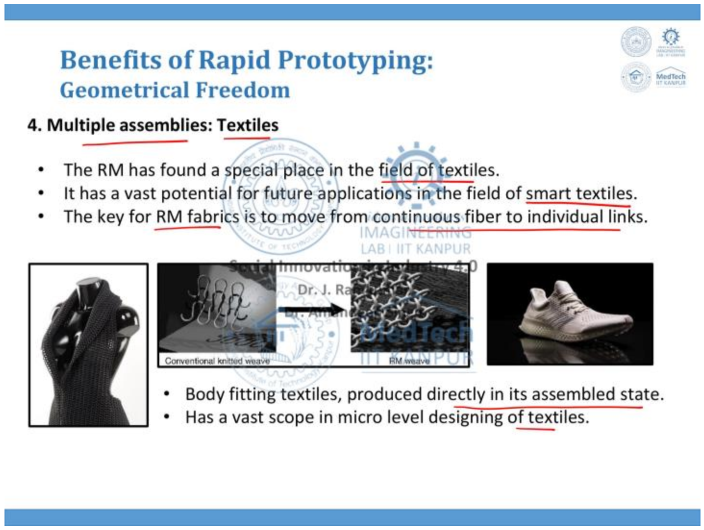


Then, parts consolidation that is Rapid Manufacturing gives the potential to consolidate many components into one. Reduction in assembly of the components save the cost. That is why, I just mentioned previously as well design complexity becomes almost free here. There are different components you can see here, it might be 10 components, this is just a one component, that is being manufactured using parts consolidation in Additive Manufacturing.

This is aircraft ducting. Then, assembly of control pad with 25 parts has been consolidated in just one single piece. You can see this is a control pad, these are 25 components and this is a fun component. This is known as part consolidation.

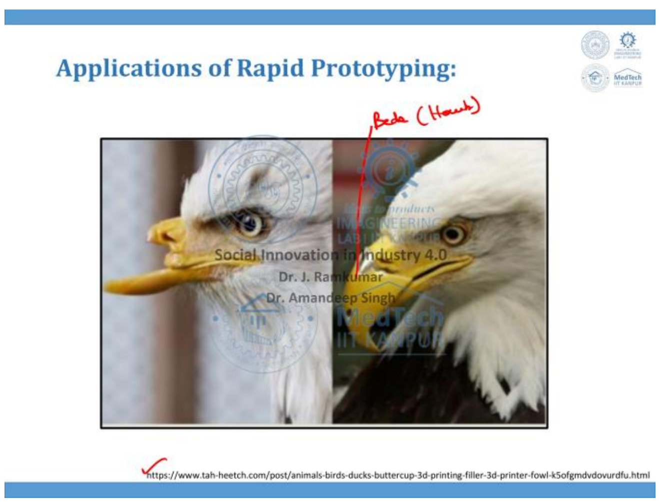
Body-fitting customization, conventional manufacturing, especially body-fitting custom products are out of the reach of general public due to high cost. Customer were forced to buy mass produced goods only which are easy to manufacture by conventional methods only.

So, by Rapid Manufacturing and Reverse Engineering, the products are now available in the customized form and according to the need of the customer, the products now can be manufactured according to the best fit for the customer, that is customized products are also developed.

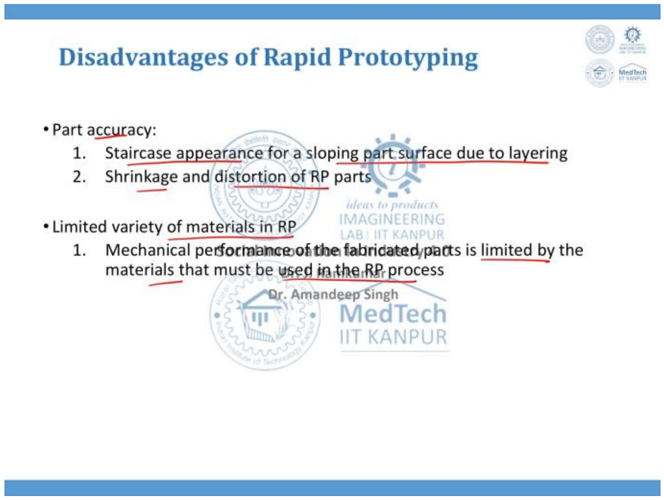


Next is multiple assemblies, that is textiles. Rapid manufacturing has found a special place in the field of textiles. It has a vast potential for future applications in the field of smart textiles.

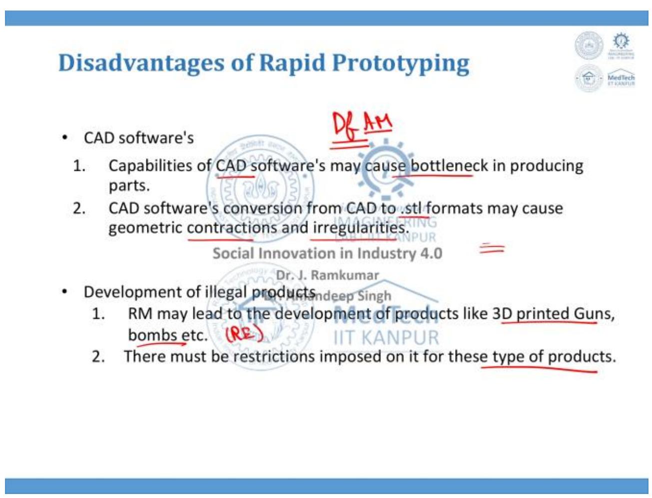
Smart textile that is a textile industry where the textiles change their shape. With the change of the stimulator maybe heat, maybe weather, maybe using by adding some chemical, or so. The key for Rapid Manufacturing fabrics is to move from continuous fiber to individual links. Body-fitting textiles produced directly in its assembled state has a vast scope in micro level design of textiles.



This is certain but this is one of the applications in medical prosthetics where a beak is dwelled for a hawk, this is beak for a hawk that was missing. This is one of the applications I have just taken from this reference.

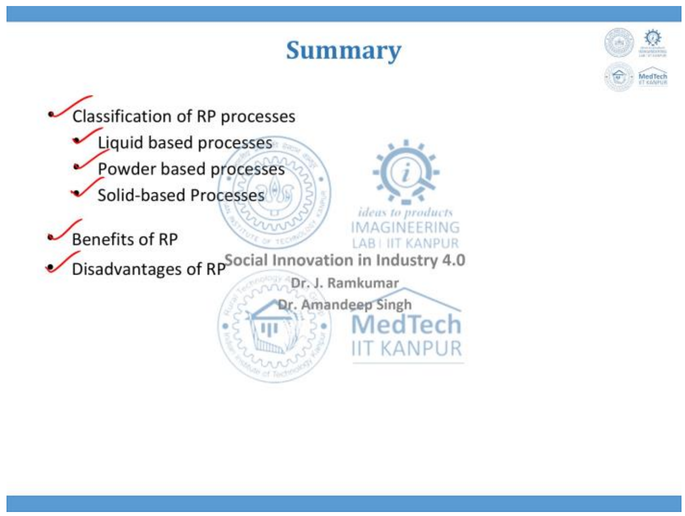


Now, Disadvantages of Rapid Prototyping, though it is mentioned the disadvantages of specific process is there. In general, part accuracy here staircase effect is there that I showed you that sloping part surface due to layering is there. Shrinkage and distortion of Rapid Prototyping part is there. Then, we have limited variety of Rapid Prototyping materials, that in mechanical performance of the fabricated parts is limited by the materials which are available for Rapid Prototyping only. Other material which cannot be rapid prototyped could not be utilized here.



Then, CAD software, the capability of CAD software may cause bottleneck in producing parts. That is, that we are talking about Design for Additive Manufacturing. Though, we are trying to work for Additive Manufacturing certain other tradeoffs might have been compromised here. CAD software's conversion from CAD to STL formats may cause geometric constrictions, that is, irregularities might also come because we all will be trying to focus on the layer-by-layer functions, some intricacies might be lost. Development of illegal products, that is Rapid Prototyping may lead to development of a products, like 3D printed guns or bombs, etcetera, that is what I have mentioned about the Reverse Engineering is not to copy, Reverse Engineering is just for improvement.

But, Rapid Manufacturing just to reverse engineer a gun and to reproduce, it is kind of a disadvantage of it. There must be restrictions imposed on it, and therefore these kinds of products should not be able to be allowed to be re-engineered.



So, to Summarize this Classification of Rapid Prototyping processes as we have seen, in which we try to solve about liquid-based processes, powder-based processes and solid-based processes, and some of the majorly used processes are also discussed in detail, Benefits and Disadvantages of Rapid Prototyping were given in this lecture. We will meet in the next lecture where we will try to see the demonstration on using mark forged metal X 3D printer.

This is a metal 3D printer, though 3D printing could be used with any of the material, that I have mentioned the materials which are majorly available in the market are polymer materials only, which are low-cost and the printer is also not having very high cost, but I would like to talk about the little complex 3D printing, that is the metal X 3D printer, which has 3 components, that is, printer is there, then we have washed system is there with a chemical which is used for printing is washed, and also scintillator is there.

So, metal X 3D printer has 3 major components which is a little advanced method of the 3D printing. We will try to see the 3D printing demonstration in the next lecture. Thank you.