Rapid Manufacturing

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Lecture - 32
Materials in Rapid Manufacturing (Part 2 of 2)

Good morning. ~~welcome~~ Welcome back to the course Rapid Manufacturing., ~~we~~ We have discussed various rapid manufacturing processes in the previous weeks.

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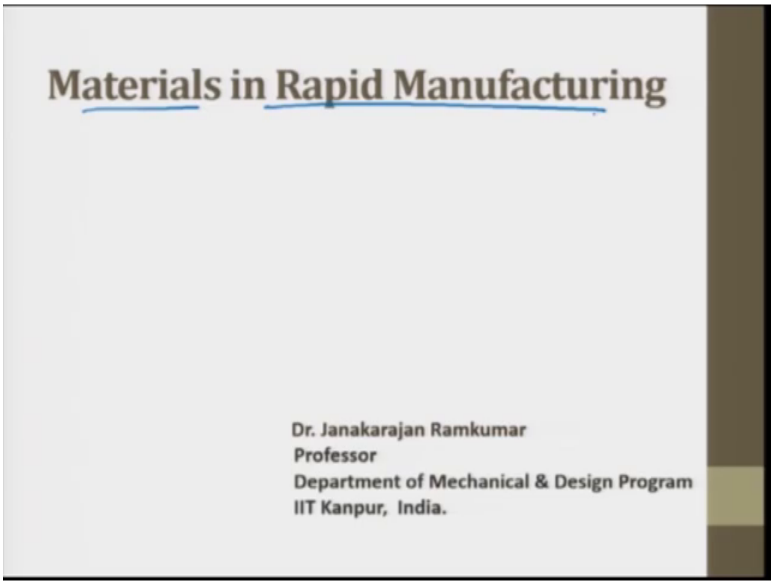

In this lecture, I will discuss rapid manufacturing materials or ~~materials~~ Materials in ~~rapid~~ Rapid ~~manufacturing~~Manufacturing. So, I will like to put some light on these processes and the materials which are being used.

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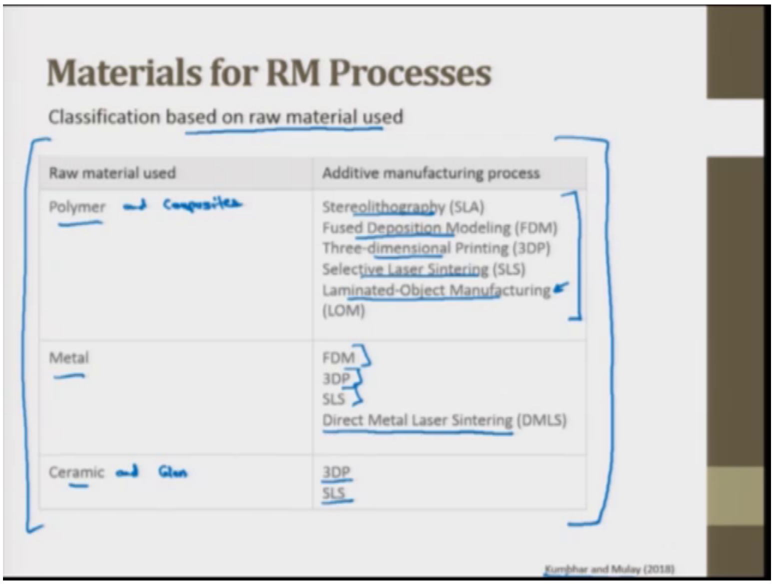

This is put in a chart taken from a study by Kumbhar and Mulay, the classification based on raw material used; polymer, metal and ceramic. Polymers are used in these processes. Stereolithography, Fused Deposition Modelling, Three-dimensional Printing, Selective Laser Sintering and Laminated Object Manufacturing. The paper and the sheets polymer sheets are used in this process. So, different processes used different kinds of polymers in this way.

And metals are used in FDM again Fused Deposition Modelling, 3D printing, Selective Laser Sintering and Direct Metal Laser Sintering process. Ceramics is used in 3D Printing processes and Selective Laser Sintering process. These were being discussed when we have discussed material as well. The glass etcetera is being used here in a SLS. So, glass come in this class only; ceramic and glass I will put, in polymers I can even put and composites.

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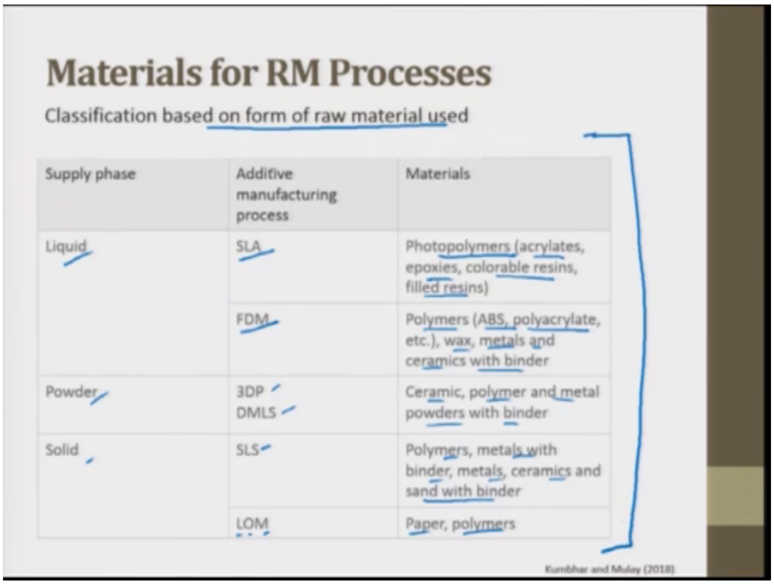

Next is classification based on form of raw material used; form of raw material is liquid, powder and solid. Liquid, powder for liquid base processes the specific processes are Stereolithography apparatus and FDM. Now these use materials like photopolymers, acrylates, epoxies colorable resins, filled resins and FDM uses polymers that is ABS, polyacrylate etcetera, wax metals and other ceramics then PLA all those powder.; ~~powder~~ Powder form as I said ceramics polymers and metal powders with binder are used in this process is 3DP and Direct Metal Laser Sintering. Solids;: solids polymers metals with binder, metal, ceramic and sand with binder are used in Selective Laser Sintering processes and Laminated Object Manufacturing papers and polymer sheets are used here. So, this table actually provides the information in a crispy way, similarly this one. This was study taken by Kumbhar and Mulay in 2018 very recent study.

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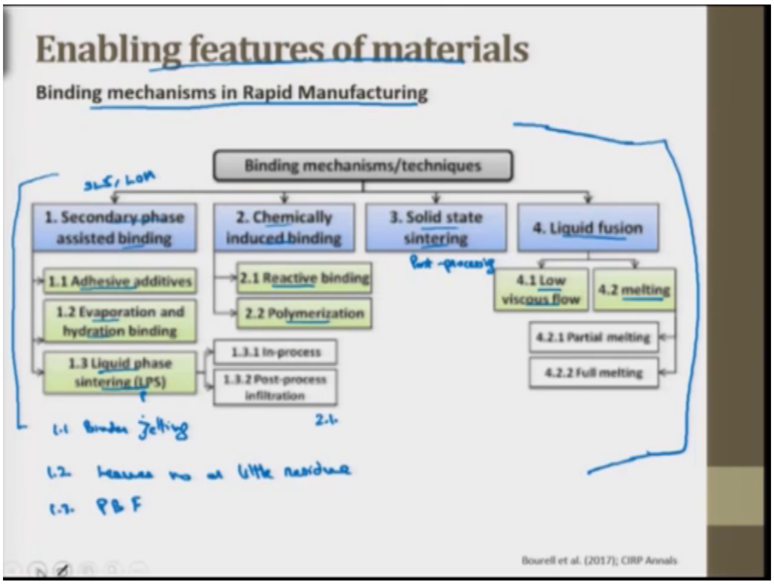

Next after discussing what materials let us come back to the enabling features of materials binding mechanisms in rapid manufacturing. So, binding mechanism techniques in rapid manufacturing are like these secondary phase assisted binding, chemically induced binding, solid state sintering, liquid fusion. We have discussed these when we have discussed the different processes the rapid manufacturing process in the previous lectures.

But to put some light here depending upon the kind of material used.~~;~~ ~~since~~ Since additive manufacturing process the only possible through an efficient binding of the additive layers.~~,~~ ~~the~~ the binding technique is the one that determines the process speed and the path properties. ~~the~~ The binding might be classified into ~~this~~ these four categories as I said. So, very first secondary phase assistant binding; the first in this is adhesive additives.~~;~~ ~~in~~ In secondary phase, assistant binding the processes like binder jetting SLS, sheet lamination I can put here SLS.

Then LOM; this process is used as Secondary phase binding material together. Secondary binding phases that is in the form of liquids or powder coatings can be added using different techniques such as mixing, coating know the injection etcetera, adhesive additives is during binder jetting. Input 1.1 is used in binder jetting. So, adhesive wonder can be a liquid or dry liquid binder such as some polymerizations or inks contain all the binding components in the printed liquid. So, in comparison dried as you can also be added to powder bed which binds a powder may be physically or chemically after interacting with the deposit liquid these are adhesive additives.

Next is evaporation and hydration binding. In evaporation and hydrated binding a common concern with the binder additives is the binder residue that may affect purity and properties of final parts. So, there are volatile binder that can be evaporated offer binding leaving little or no residue. So, 1.2 they leaves no or little residue, example may be chloroform that can bind biodegradable polyesters and then evaporate during the 3D printing process. The main drawback is the need of a post processing treatment to improve the part strength in this case. Next is LPS liquid phase sintering, liquid phase sintering this category applies to the powder bed fusion process. ~~this~~ This is 1.3 is for powder bed fusion process. So, this is the liquid phase sintering.

Next is chemically induced binding this also is discussed in the previous lecture. Chemically induced binding what is this? The polymerization processes and material jetting use chemical reactivity of the material consequents to bind the material and the price can be reactive binding and polymerization. 2.1. Reactive binding this mechanism involve the use of thermally activated chemical reactions between the two types of powders or between powders and atmospheric gases to form a by-product which binds the powders together. So, this is active binding polymerization is discussed already it is cross linking of the photo curable resin which when hardens and then set the material.

So, next is Solid state sintering:~~,~~ solid state sintering this is a solid diffusion binding mechanism. Solid state sintering is mostly applied as a post processing technique; this is post processing generally.~~,~~ ~~for~~ For example it can happen in furnace. It can identify porous ceramics after removing the polymer binder etcetera. So, next is liquid fusion, liquid fusion is one of the processes that is a rapid mass transport mechanism that may include low viscosity flow in polymers and melting in metals. Liquid fusion can happen in low viscous flow and after melting.

Low viscous flow this mechanism is most common in plastics, where a heated plastic is fused to the previous player point deposition. In melting what happens; the complete or full melting happens that is discussed in the base processes before, this mechanism enables a rapid fusion of the metallic materials upon exposure to an intensive heat source to this which heat source can be laser or EBM, so this mechanism can achieve completed dense metals and from a single materials. So, these are certain binding mechanisms you just recall them that determines the strength and the type of material that can be used again.

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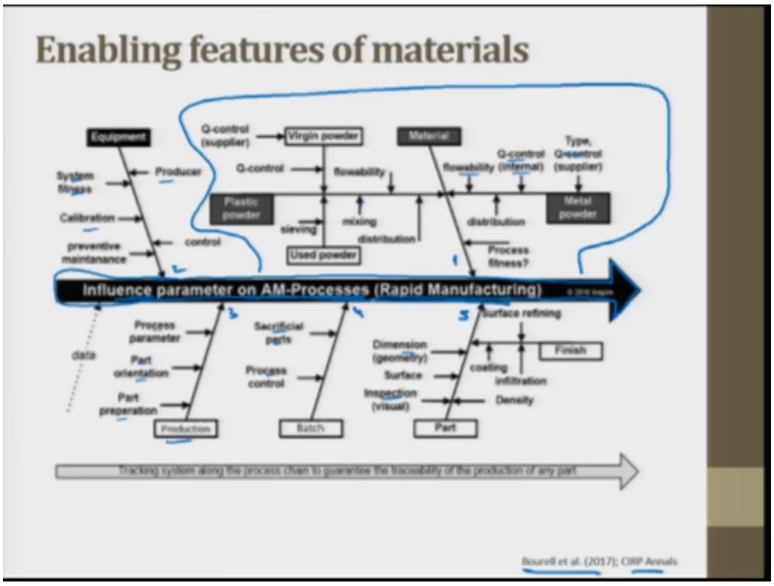

Next this is an Ishikawa or cause and effect diagram that tells us about all the features to obtain a final rapid manufacture part. You can see this is also called as Fishbone diagram. It looks like say fishbone like this is the main bone of the fish and these are all branches, is a major branches 1, 2, 1, 2 actually here 3, 4 and 5. This is 1.1, so 1 is material the kind of materials.

So, I am more concerned about material here; the main branch is actually are the part that is to be produced or surface finish of the part that is required, inspection that is required, then batches; sacrificial parts then the production. In production process parameters part, orientation part preparation. Then in equipment we have system fitness produces calibration of the equipment, then major thing which were concerned here is the material. For material is it virgin powder or used powder or is it a plastic powder or metal powder. We are just talking about the powder materials here; in this study they have taken only powder material here.

So, is it a plastic powder or a metal powder. If plastic powder what is flow ability, what is mixing, what is distribution, what is quality control in case of virgin powder, it can also be a used powder, flow ability, quality control and quality control for supplier, distribution all these are the concerns in case of the metal powder. So, this is Ishikawa diagram that helps us to disseminate the complete process into smaller parts and the parts and the further branches and the sub branches all those are obtained using this diagram and it is one of illustration of the rapid manufacturing process influence parameter on additive manufacturing processes. This is the Ishikawa diagram for that.

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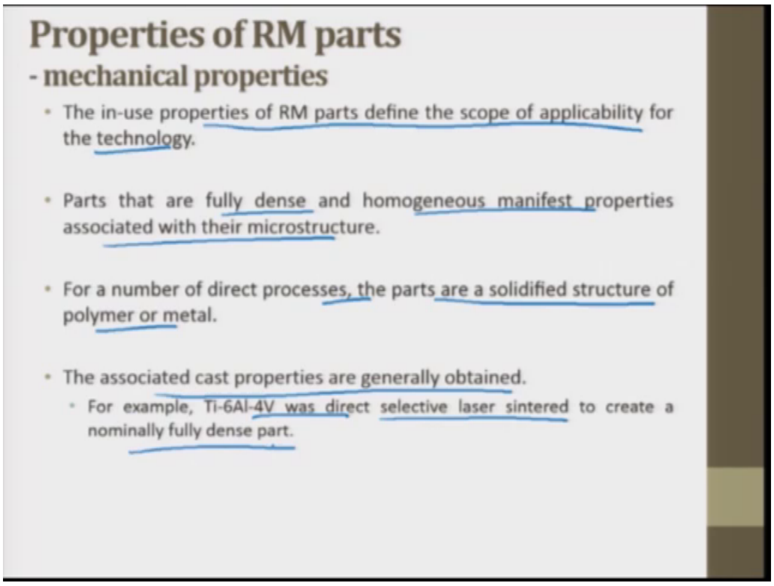

Next is properties of Rapid Manufactured parts; mechanical properties, The in-use properties of rapid manufacturing parts define the scope of applicability of the technology. Parts that are fully dense and homogeneous manifest properties associated with their microstructure. For a number of direct processes, the parts are a solidified structure of polymer or metal. The associated cast properties are generally obtained, for example titanium alloy was direct selective laser sintered to create a nominally full dense part.

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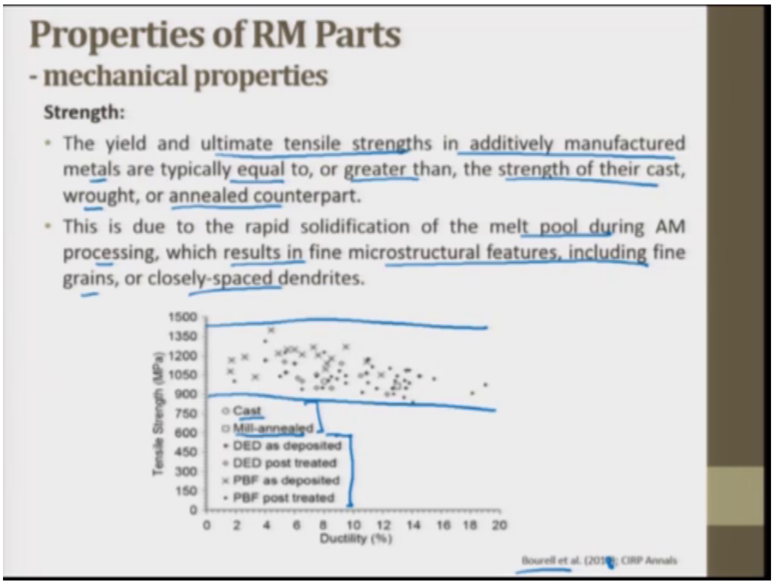

So, mechanical properties can be divided into the categories. First ~~categorie~~ category is strength. The yield and ultimate tensile strength in additively manufactured metals are typically equal ~~to,~~to or greater than, the strength of their cast, wrought or annealed counterparts. You can see these are the cast parts, this circle the square is the milled part and these are all the additive manufacturing processes.

This is due to the rapid solidification of the melt pool during additive manufacturing processes which results in fine micro structural features including fine grains or closely spaced dendrites. So, this is the study that is taken by the same researchers in 2018 and they have seen that the properties of the tensile strength lies in this range only with different parts. So, there is not a significant difference of the strength from the cast and the mill-annealed generally annealed parts, so this is strength of the rapid manufactured parts.

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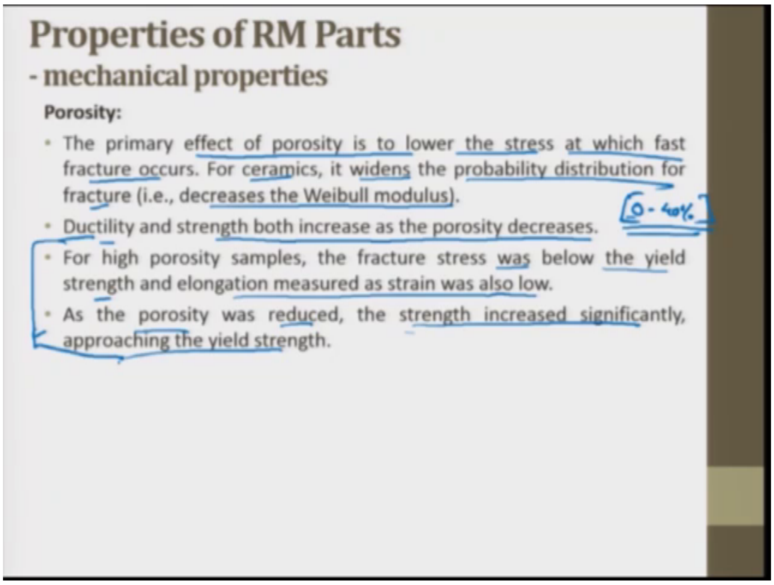

Next is porosity, porosity as we have just discussed something about the porosity, the primary effect of porosity is lower the stress at which fast fracture occurs. For ceramics it widens the probability distribution for fracture it decreases the Weibull modulus. Ductility and strength both increase as the porosity decreases. Overlapping stress strain curves forth certain parts have shown that the amounts of a given porosity range is from 0 to 40 percent in the rapid manufacturing parts.

For high porosity samples the fracture stress was found to be below the yield strength and elongation measured as strain was too low as the porosity was reduced the strength increase significantly approaching the yield strength for this was again in a study that taken by these persons; Bourell et al.. So, they had a study on the laser sintered polyamide samples with varying amount of engineering porosity. This porosity range for 0 to 40 percent. So, this was the inference they came up with.

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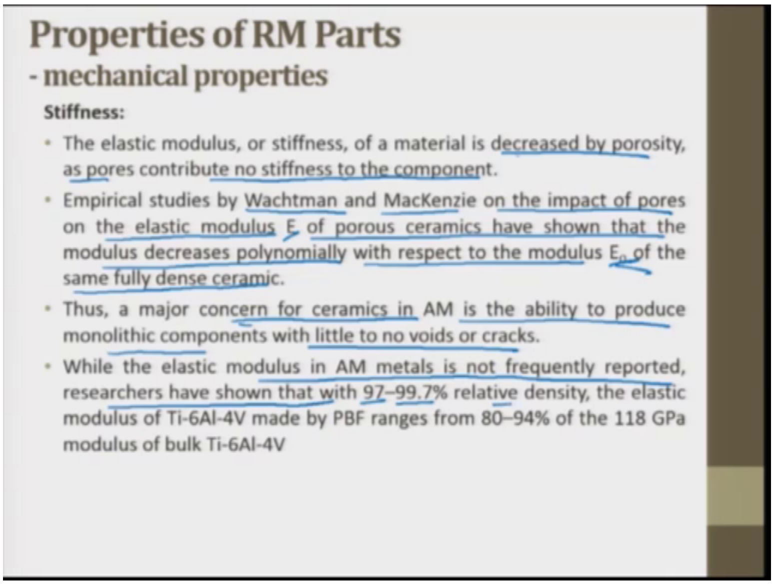

Next is stiffness. The elastic modulus or stiffness of a material is decrease by porosity as pores contribute no stiffness to the component. eEmpirical studies by Wachtman and MacKenzie on impact of pores on the elastic modulus of porous ceramics have shown that the modulus decreases polynomially with respect to the modulus of the same fully dense ceramic.

Thus, a major concerns for ceramics in additive manufacturing is the ability to produce monolithic components with little or no voids or cracks, while elastic modulus in additive manufacturing metals is not frequently reported. Researchers have shown that with 97 to 99.7 relative density the elastic modulus of titanium alloy made by the powder bed fusion process ranges from 80 to 94 percent and 118 Giga Pascal modulus of bulk titanium alloy. So, this is stiffness.

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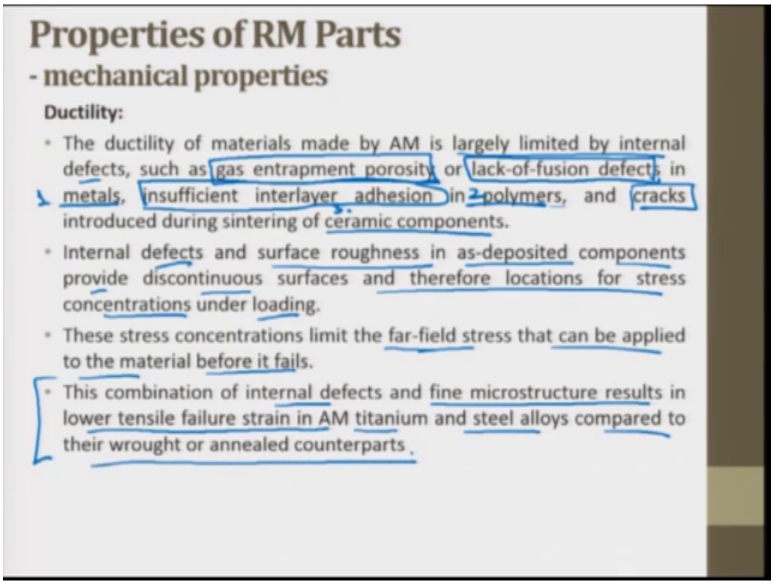

Next is ductility. Ductility of materials made by additive manufacturing with largely limited by internal defects such as gas entrapment porosity or lack-of-fusion defects in metals, insufficient interlayer adhesion in polymers and cracks introduced during sintering of ceramic components. So, first is metals, second is polymers, third is ceramics. In metals, it is gas entrapment porosity or lack of fusion defects. In polymers it is insufficient interlayer adhesion and cracks in ceramic components. This determine the ductility. Internal defects and surface roughness in as-deposited components provide discontinuous surfaces and therefore locations for stress concentration under loading.

These stress concentrations limit the far-field stress that can be applied to the material before it fails. In metallic materials lack of fusion results in long sharp pores which locally amplify the stress in the components, in addition fine microstructure feature due to rapid solidification lead to increased strength, but it reduces ductility. Limited dislocation motion, that might be there. So, this combination of internal defects and fine microstructure results in low tensile failure strain in additive manufacture titanium and steel alloys compared to their wrought or annealed counterparts.

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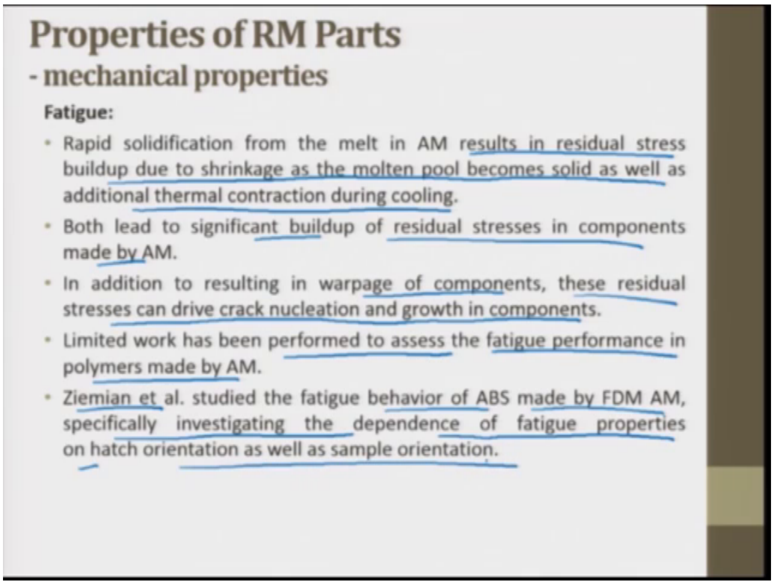

Next is fatigue. Rapid solidification from the melt in additive manufacturing results in residual stress buildup due to shrinkage as the molten pool becomes solid as well as additional thermal contraction during cooling. Both lead to significant buildup of residual stresses in components made by additive manufacturing. In addition to resulting in warpage of components, these residual stresses can drive crack nucleation and growth in components. Limited work has been performed by the researchers to assess the fatigue performance in polymers made by additive manufacturing. So, Ziemian et al. specifically studied the fatigue behaviour of ABS made by FDM additive manufacturing specifically investigating the dependence of the fatigue properties on hatch orientation as well as sample orientation.

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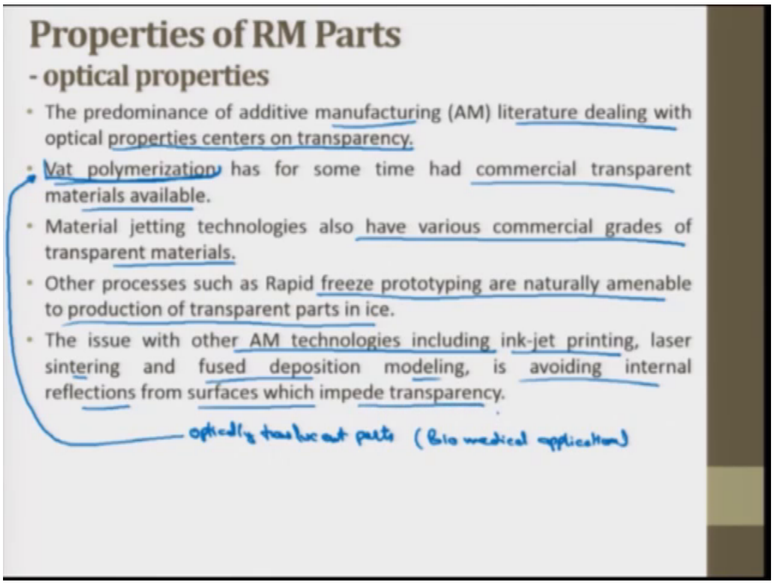

Next are the optical properties. The predominance of additive manufacturing literature dealing with optical properties centers on transparency. Vat polymerization has for some time had commercial transparent materials available. So, material jetting technologies have also various commercial grades of transparent materials. Other processes such as rapid freeze prototyping are naturally amenable to production of transparent parts in ice.

A certain approaches have been dwelled by which that transparent quartz parts were produced using filament side few mechanism into a laser power source. The certain optical properties or optical transmission parts made using vat polymerization optically translucent parts which are made using vat polymerization, so they are being used in biomedical because of their optical features. So, issue with other additive manufacturing technology include ink-jet printing, laser sintering and fused deposition modelling is avoiding internal reflections from surfaces which impede transparency. To the certain issues those are in fall involving material as well like reflectivity, as we discussion in the laboratory demonstration and medium is material that is some a little bit lustre.

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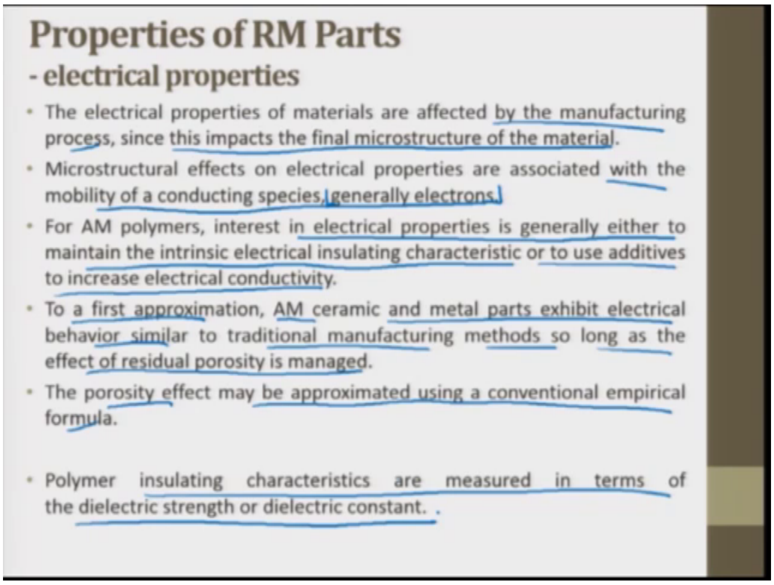

So, the reflectivity that tamper the scanning but in case of optical properties sometimes these are beneficial as well. We will discuss about the issues in materials and the defects in materials in the next lecture.

So, next are electrical properties. The electrical properties of material are affected by the manufacturing process, since this impacts the final microstructure of the material. Microstructural effects on electrical properties are associated with the mobility of a conducting species generally electrons. So, how electricity moves this is the general theory in that. Additive manufacturing polymers, interest in electrical properties is generally either to maintain the intrinsic electrical insulating characteristic or to use additive to increase electrical conductivity. Improvements to a additive manufacture polymer electrical conductivity can be done by additions of conductive media such as carbon. Carbon is a great candidate that can help to improve the electrical conductivity. To a first approximation additive manufactured ceramics and metal parts exhibit electrical behaviour similar to traditional manufacturing methods so long as the effect of residual porosity is managed.

The porosity effect may be approximated using a conventional empirical formula. Polymer insulating characteristics are measured in terms of the dielectric strength or dielectric constant. So, we are not moving into the mathematics or the models to determine the electrical properties and porosity, but yes porosity is the one that determines the electric property because of flow electrons has to happen. So generally electrons have to flow. So, carbon or other constituent material that can added it to improve the electrical properties. We can get a composite material and functionally graded material can also be obtained to have the better electrical properties in rapid manufactured parts.

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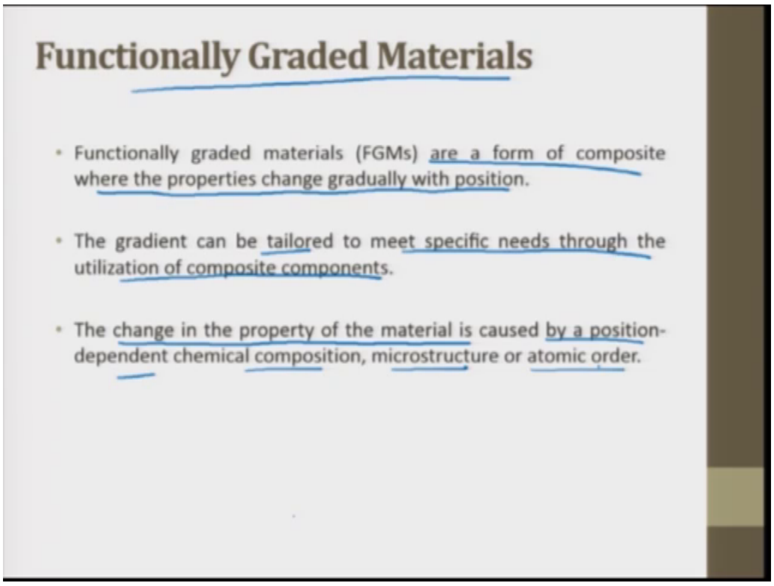

So, next is functionally graded material. As I said functionally graded materials a form of composite where the properties change gradually with position. The gradient can be tailored to meet specific needs through the utilization of composite components. The change in the property of the material is caused by a position-dependent chemical composition microstructure or atomic order. These functionally graded materials can be obtained from conventional processes, but nowadays rapid manufacturing process is also used to get this material; what are FGM?

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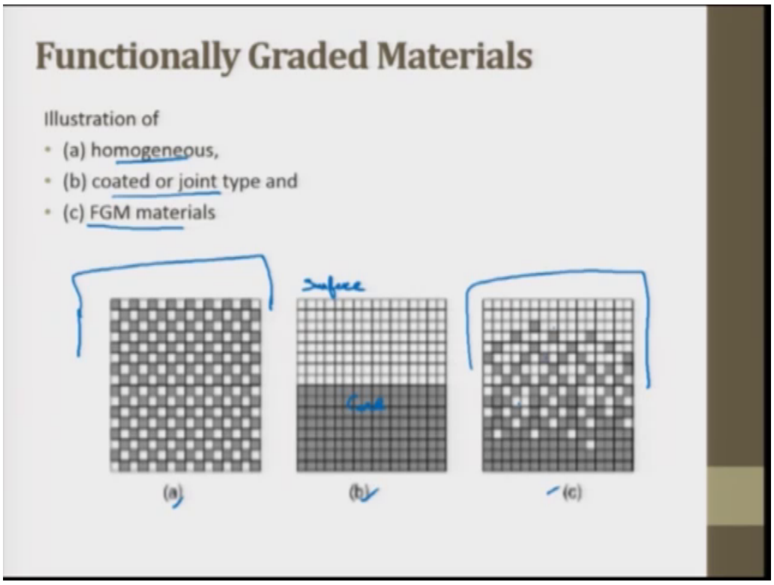

This represent the graded composition. This is homogeneous composition; a is homogeneous, b is coated and c is the functionally graded materials. So, homogeneous material is complete homogeneous mixture, so this type of composite aims to reinforce material properties by mixing a dispersed phase homogeneously within the matrix. So, the second type which is coated or joint type; it is characterized by having different material characteristics of separate surfaces in or in separate parts.

So, this can be a surface, this can be core. Typical examples for this are the coatings that enhances of the surface properties, however the sharp boundary existing within the structure of often exhibits various adverse effects in material properties. So, these functionally graded materials are the third option. They have gradually varied composition between different constitutes. You can see the composition between the white and the black boxes which are different materials is varied gradually.

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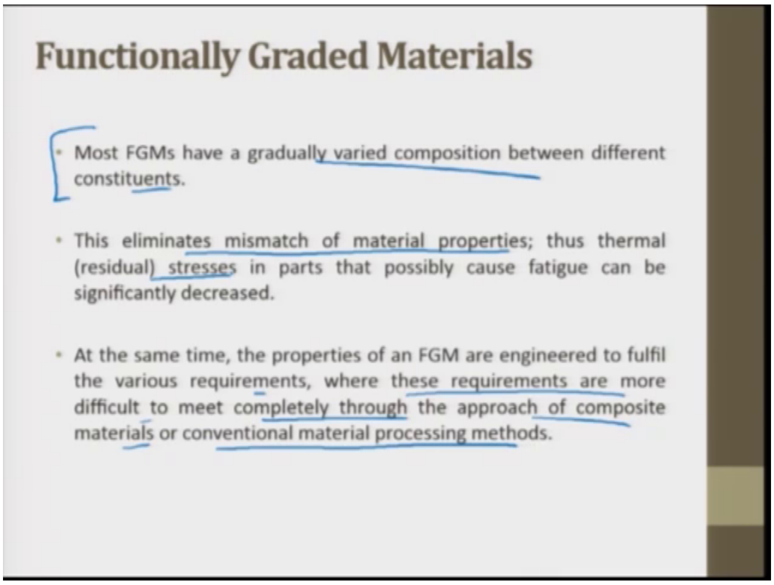

This eliminates the mismatch of the material properties. Thus thermal or residual stresses in the parts that possibly may cause fatigue can be significantly decreased and at the same time the properties of a function graded materials are engineered to fulfil the various requirements, where these requirements are more difficult to meet completed through the approach of composite materials or conventional material processing methods. So, FGM or Functionally Graded Materials have varied composition between different constituents as I said this eliminates the mismatch of material properties to thermal stresses are then reduced, so fatigue is lesser.

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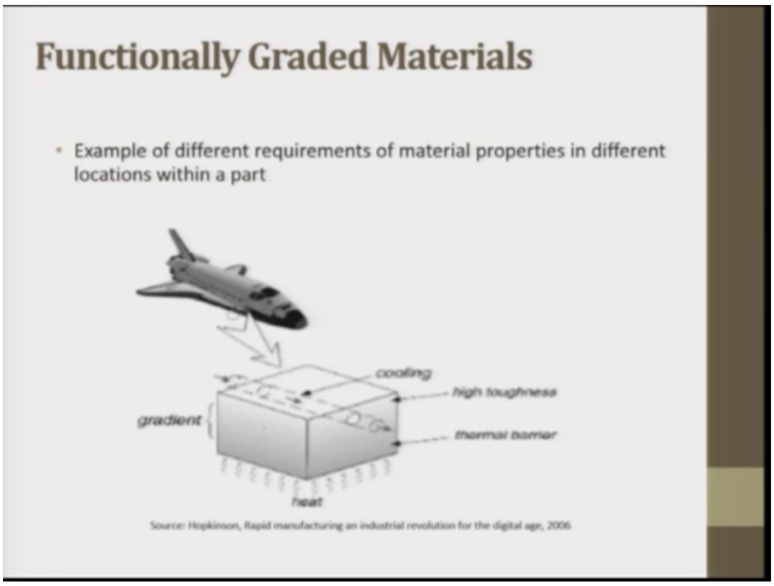

Example of different requirements of material properties in different location; for instance at gradient material that is used here in the fin of a air jet it has different properties, you know this is a gradient and this is thermal barrier, this is high toughness and this cooling; because of this the cooling is happening.

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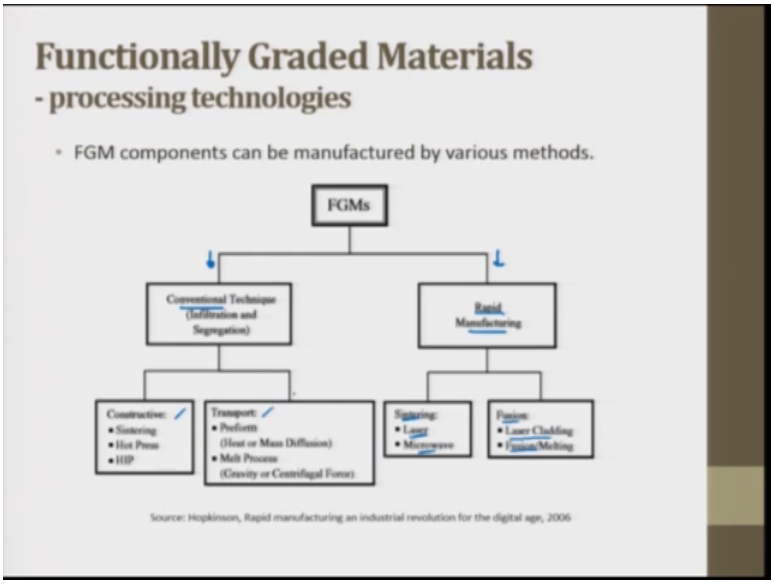

So, these kinds of applications are there where FGM can be used. Now FGMs can be obtained using the conventional techniques and rapid manufacturing techniques these techniques we have discussed in the course fusion laser sintering then microwave sintering laser cladding the LPS liquid phase sintering all those processes.

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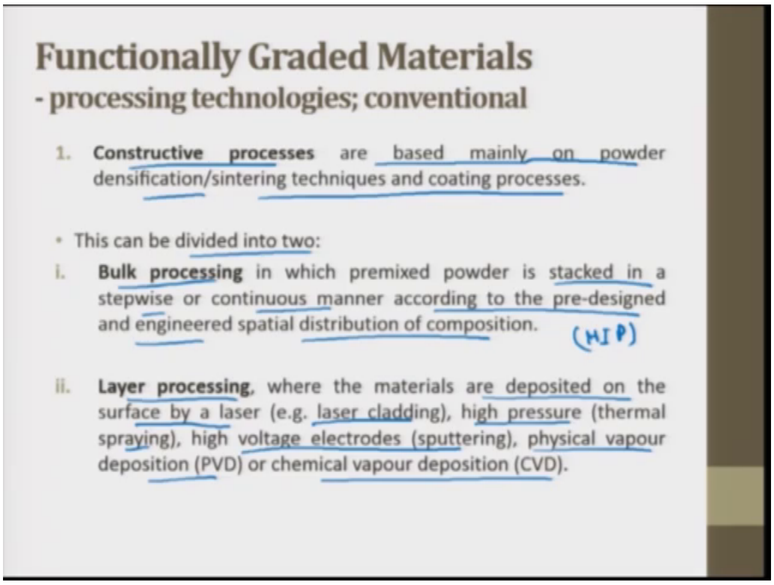

So, conventional techniques are generally constructive and transport just to have a quick glance on these; the conventional techniques are constructive process are based upon mainly on the powder densification or sintering techniques and coating processes. This can be divided into two parts; bulk processing and layer processing, Bulk processing is one in which premixed powder is stacked in a stepwise or continuous manner according to the predesigned and engineered spatial distribution of competition and in layer processing what happens; the materials are deposited on the surface by a laser that is laser cladding, high pressure thermal spraying, high voltage electrodes sputtering, physical vapour deposition or chemical vapour deposition.

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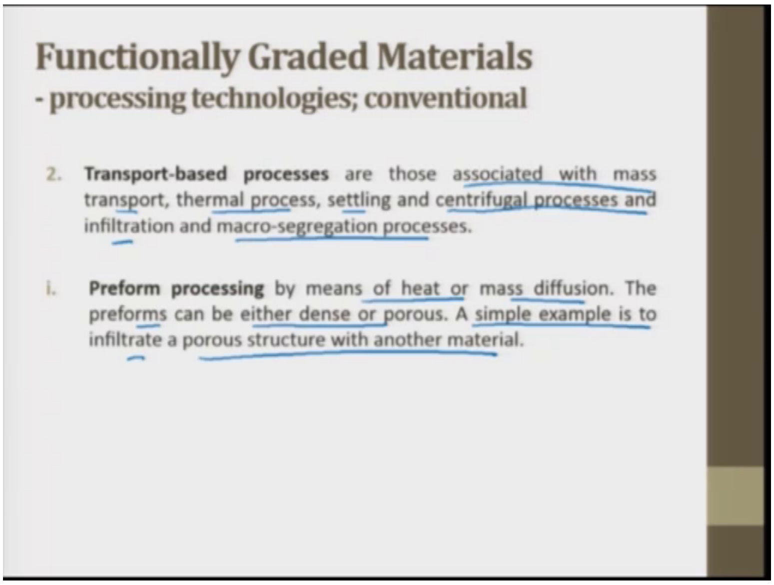

For this is a constructive processes; then transport based processes are those associated with mass transport thermal processes, settling centrifugal processes and infiltration and macro-segregation processes. In bulk processing, HIP can also be one of the process; Hot Isostatic Processing HIP. In transport-based processes one of the process it is preform process. Preform processing by means of heat or mass diffusion; the performs can be either dense or porous a simple example is to infiltrate a porous structure with another material, so this is one of the FGM processes.

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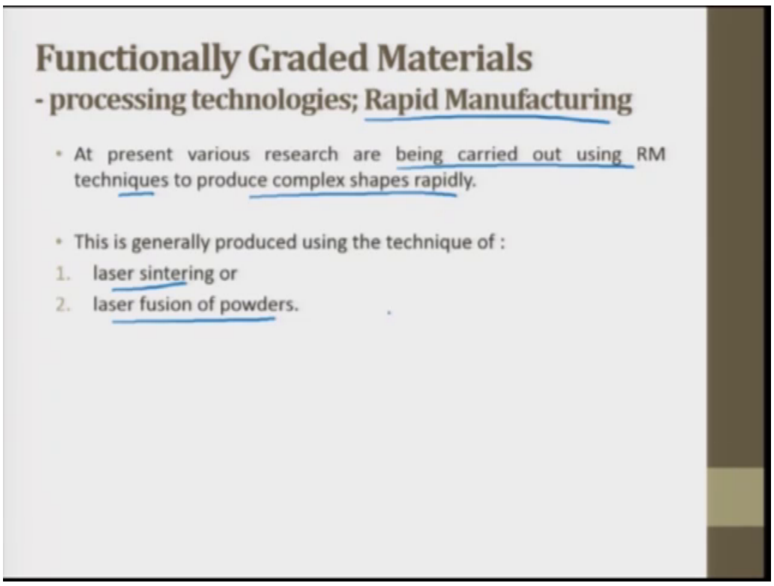

Now, rapid manufacturing processes are laser sintering or laser fusion of powders, at present various research is being carried out using rapid manufacturing techniques to produce complex shapes repeatedly.

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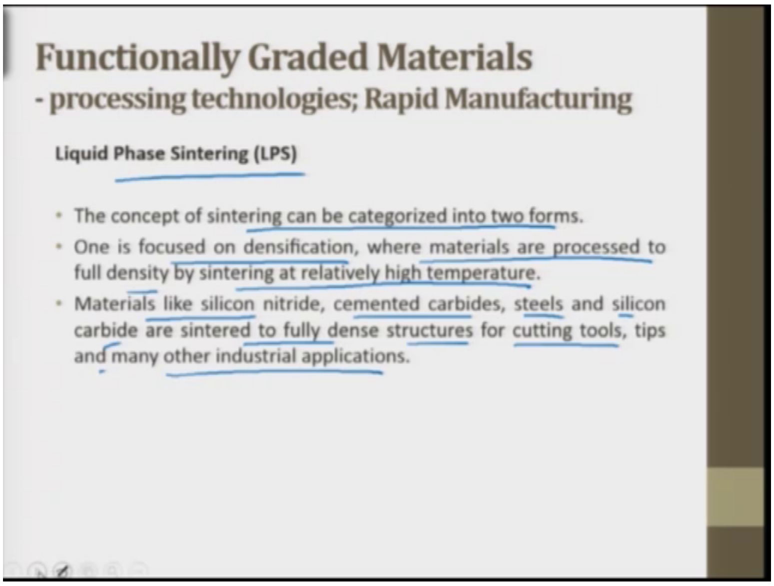

So, that two major techniques which are used and which we have discussed in the previous lectures as well, in Liquid Phase Sintering just to recall the concept of sintering can be categorized into two forms; one is focused on densification, where materials are processed to full density by sintering at relatively high temperature. Materials like silicon nitride, cemented carbides, steels and silicon carbide are sintered to fully dense structure for cutting tools, tips and many other industrial applications.

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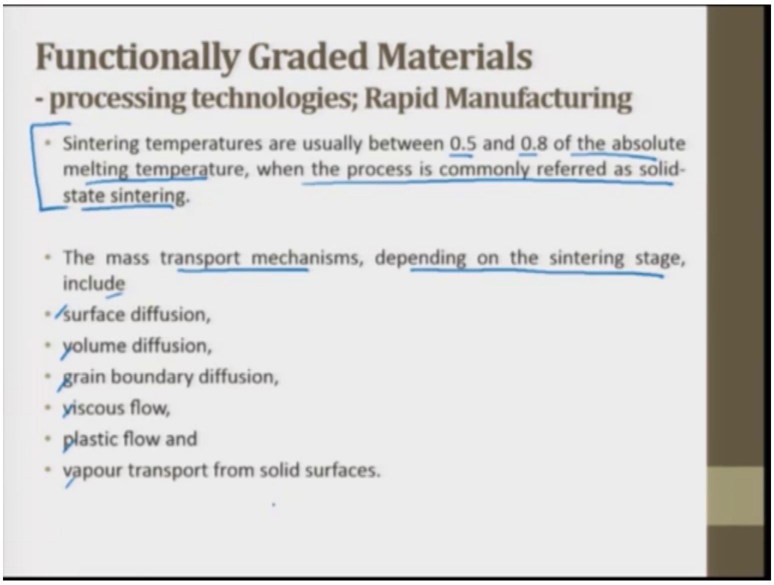

The certain factors or mechanisms that makes the process different. Sintering temperatures are usually between 0.5 and 0.8 of the absolute melting temperature, when the process is commonly referred as solid-state sintering. The mass transport mechanisms, depending on the sintering stage include surface diffusion, volume diffusion, grain boundary diffusion, viscous flow, plastic flow and vapour transport from solid surfaces. So, these are functionally graded materials I did not discussed much about them, but definitely we can provide you with the notes to read about this. So, these are the materials which are manufactured using rapid manufacturing processes as well.

So, this was all on materials in rapid manufacturing, we saw the raw materials which are there in rapid manufacturing, we saw the properties of the rapid manufacturing parts and the materials which are there and we saw what are functionally graded materials. In the next lecture we will discuss post processing concerns. Pre processing is before actually manufacturing the product, that is some processings that has to happen; we have to prepare powders, we have to maybe ground a powder to the smaller sizes; those are of pre processing, during processing is all the rapid manufacturing processes that we have discussed or processing part.

Then post processing is sometimes defects are there. First I will discuss about defects those are there in rapid manufacturing parts, then to counter those defects and to get good surface finish, to enhance the properties then to enhance aesthetics or appearance; the certain post processing methods so those will discuss in the next lecture.

Thank you.