Metal Additive Manufacturing
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Lecture 05
Metal Additive Manufacturing, Glossary (Part 2 of 2)

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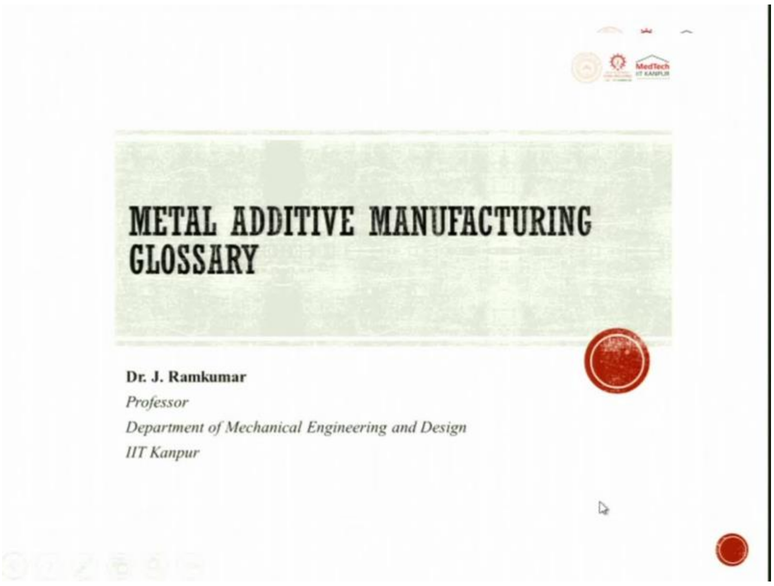

Welcome to the next lecture, which currently we are discussing on the glossary, we have seen in the last lecture up to E, continuing from E we will start going.

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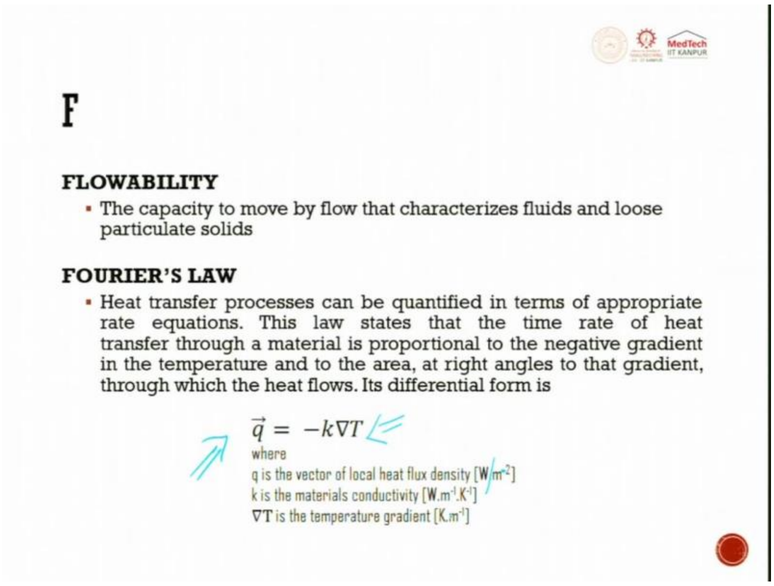

So, F is flowability, flowability is a very important property, when you are trying to use a wire and this wire is melt or it is taken to a molten state and then from there it is allowed to droop down on the table to develop our piece. Here flowability plays a very important role, the capacity to move by flow that characterizes fluids and loose particulate solids are called as flowability in all the metal additive manufacturing there is always a heat transfer.

So, we will always try to start with Fourier's Law. Heat transfer process can be quantified in terms of appropriate rate equations, this law states that the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area at right angles to that gradient through which the heat flows. So, this is called as Fourier's Law, I will not ask you in the examination to memorize and write the definition, but I can ask you some basic questions going around this Fourier's Law, the law states that the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area at right angle to that gradient through which the heat flows.

$$\vec{q} = -k\nabla T$$

where

q is the vector of local heat flux density [$W.m^{-2}$]

k is the materials conductivity [$W.m^{-1}.K^{-1}$]

∇T is the temperature gradient [$K.m^{-1}$]

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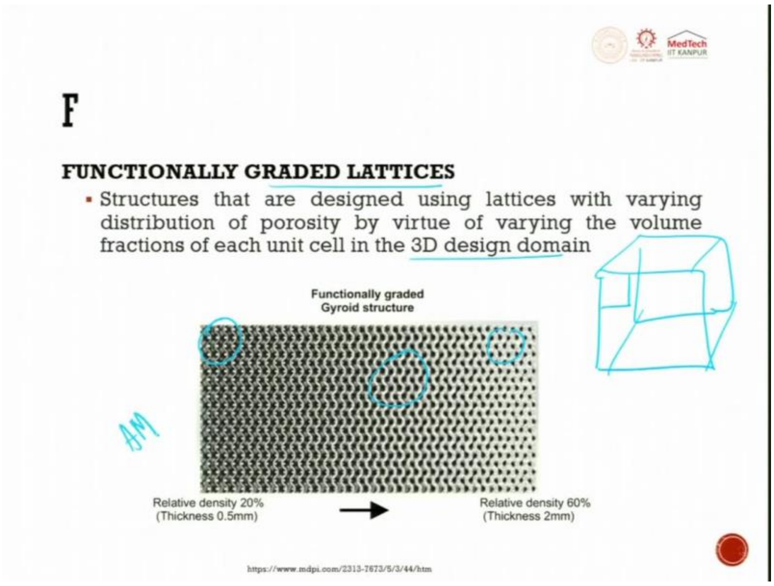

Functionally graded lattice, so, when we start looking into building up a solid object, we will now divide the solid object even in material sciences to unit cells. So, now, if you start playing with the properties changing the properties of lattice, so, this unit cell is called as lattice right. So, if you are trying to play or change this lattice, then you are trying to get functionally graded lattice structures that are designed using lattices with varying distribution of porosity by virtue of varying the volume fraction of each unit cell in the 3d design domain.

So, rather than see you see here it is not dense here it is very light. So, maybe here it is much lighter. So, you can see here relative density from 20 goes down to a relative density of 60. So, it was thickness is 0.5mm, here the thickness is 2 mm like this, if you want to develop some functionally graded lattice, functionally graded structures, and functionally graded materials, AM is the only process which gives you this flexibility.

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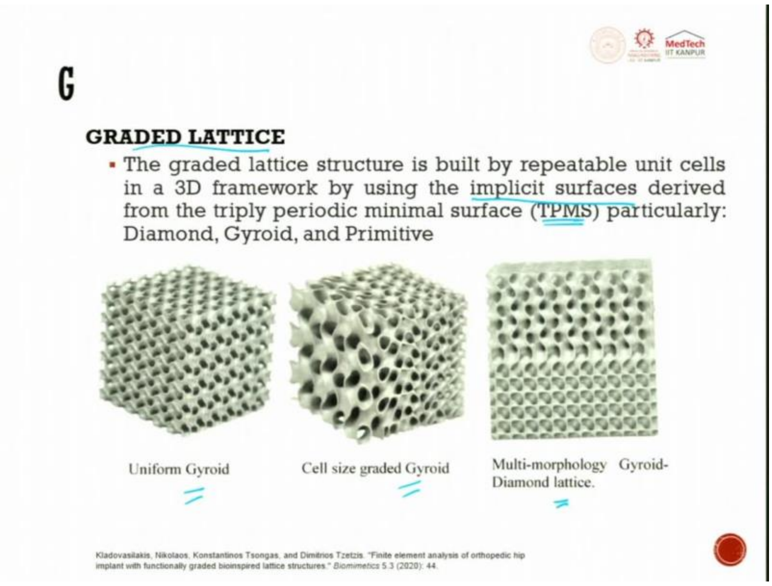

So, these are some of the more examples of graded lattice you can see here uniform Gyroid is there, cell-sized graded Gyroid, then you will have multi morphology Gyroid-diamond lattice. So, these are all varying graded lattices, which are used today in reducing the density of the material. The graded lattice structure is built by repeatable unit cells in a 3D framework by using implicit surface derived from the Tri ply periodic minimal surface which is nothing but TPMS triple or tri-ply periodic minimal surface particularly diamond Gyroid, and prismatic. So, you can see these are all varying graded lattices.

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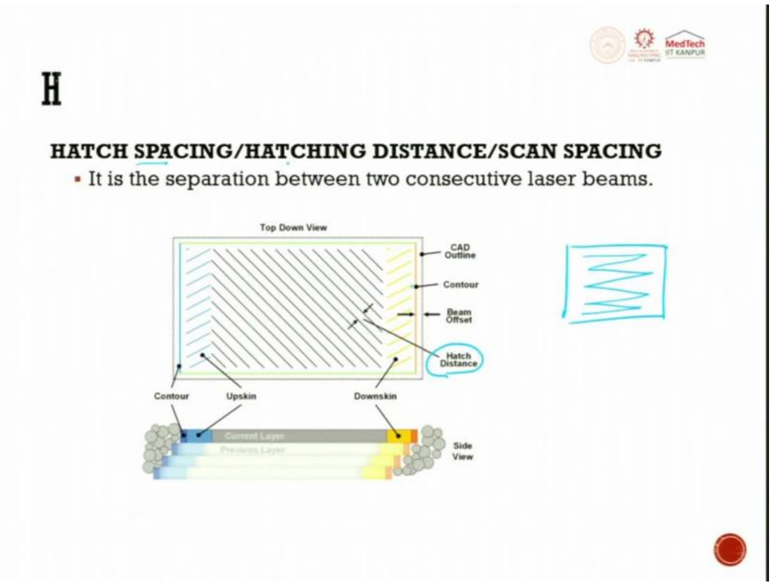

Hatch pattern, when I try to divide a layer inside a layer, the manner in which I am trying to fill the material is called as hatch pattern. So, between these two hatches the distance is called as the spacing. So, this is called as hatch spacing or hatch distance or scan spacing. So, all these things are talking about hatch lines and the distance between or the space between the hatch lines, this is the hatch distance you see here between the two hatch lines, so, beam offset is done then you have a contour then you have a CAD outer line. So, here this is called as the down skin and this is called as the up skin, the center portion is the current layer which is made. So, this is very important as far as strength or time of manufacturing is concerned.

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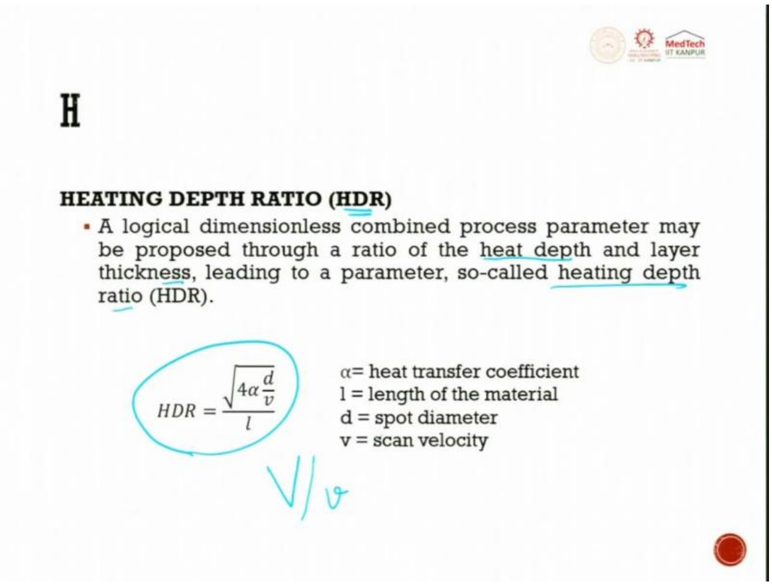

Heating depth ratio which is another important one which is called as HDR it is again a logical dimensionless combined process parameter may be proposed through a ratio of heat depth and the layer thickness, effective layer thickness, nominal layer thickness here, there is one more heat depth by layer thickness. So, this is another parameter so-called heating depth ratio. So, this can be derived by this formula.

$$HDR = \frac{\sqrt{4\alpha \frac{d}{v}}}{l}$$

α= heat transfer coefficient
l = length of the material
d = spot diameter
v = scan velocity

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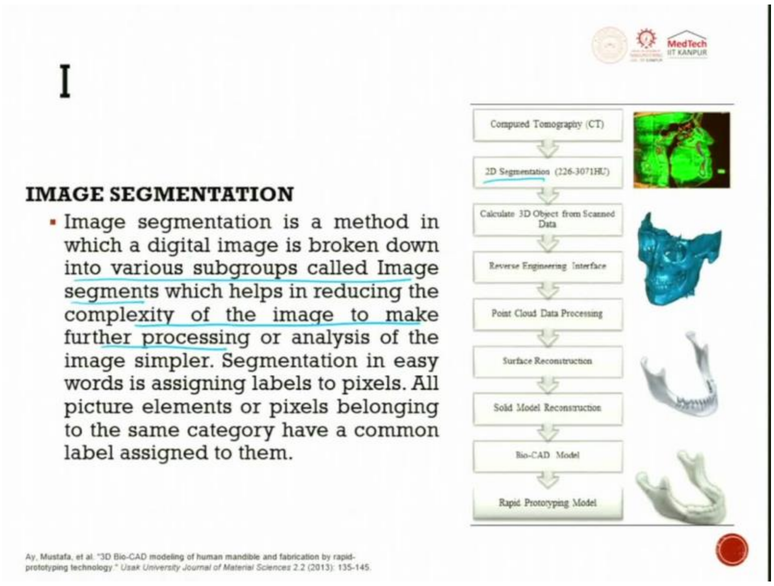

Image segregation, image segregation is a very important topic where in which the object is segmented to get some information from the image such that it can be used to for removing the errors in the surface. So, image segmentation is exhaustively used in reverse engineering you did CT from the 3D you did 2D segmentation, then you calculate a 3D object from scanned data then you try to do a reverse engineering interface then you try to get a point cloud data process then surface reconstruct happens then solid model reconstruction happens Bio-CAD model is there then finally, what you do is rapid prototype model.

So, here you can see image segmentation is a method in which the digital image is broken down into various subgroups called as image segment with the help of reducing the complexity of the image of making further processing or analysis simpler. So, you have an object you divide the object into small segments, so, that the segmentation in easy words is assigning labels to pixels. All picture elements or pixels belonging to the same category have a common label assigned to them.

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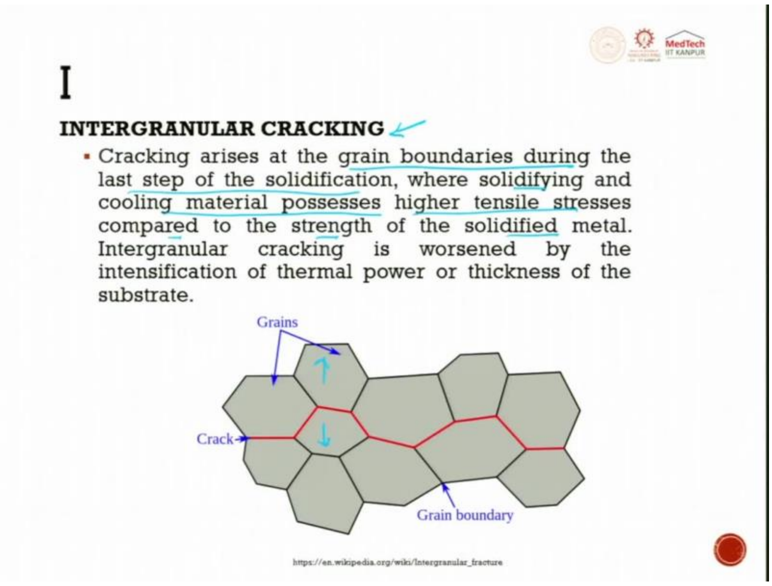

Intergranular cracking- intergranular means with this insight, inter means between two grains it is cracking, cracking arising at the grain boundaries during the last step of the solidification, where solidifying and cooling material possesses higher tensile stresses compared to the strength of the solidified metal. This is very important grain boundaries during the last step of certification were solidifying and the cooling material processes higher tensile stress compared to the strength of the solidified matter. So, because of that, this fellow and this fellow will try to pull each other and it will try to break. So, intergranular cracking is worsened by the intensification of thermal power or thickness of the substrate. So, here intergranular cracks are also common phenomena when metal additive manufacturing processes are used.

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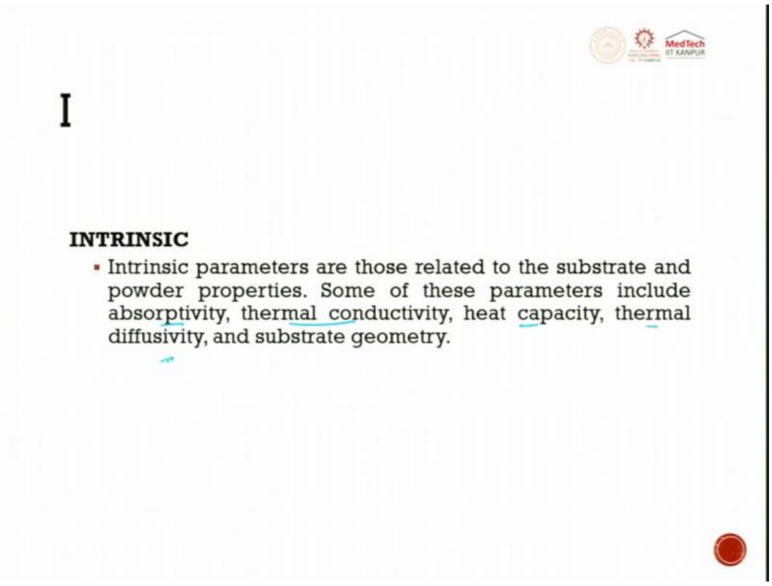

Intrinsic properties. For any given material there are extrinsic properties and intrinsic properties. Intrinsic parameters are those related to the substrate and powder properties. Some of the parameters include absorptivity, thermal conductivity, heat capacitance, thermal diffusivity and substrate geometry.

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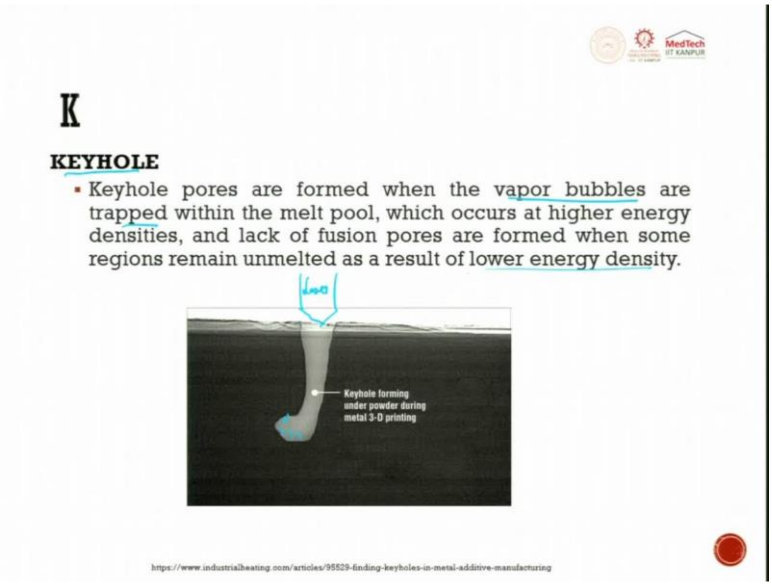

While the laser interacts with the material, we always have something called a keyhole process. This is a laser, which is hitting the surface, laser hitting the surface. So, keyhole pores are formed when the vapor bubbles are trapped within the melt pool, which occurs at a higher energy density and lack of fusion pores are formed when some of the regions remain un-melted as a result of low energy density. This is the keyhole pores which are getting formed.

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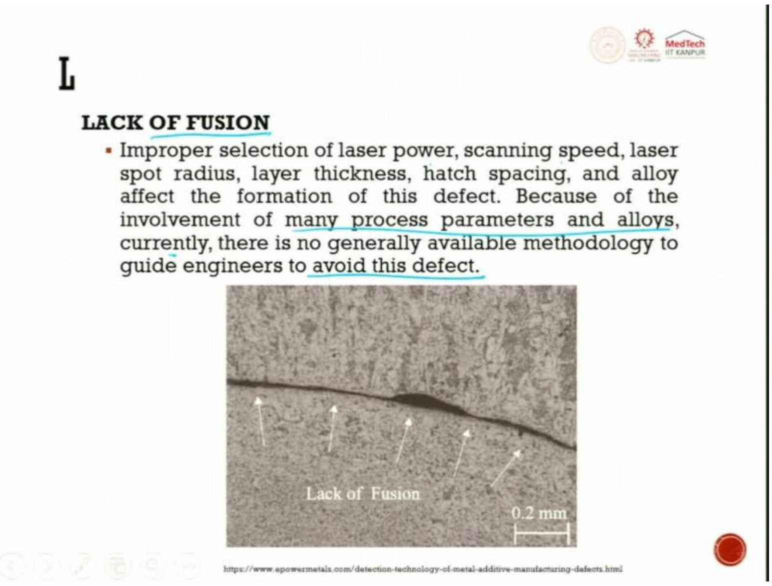

Lack of fusion, improper selection of laser power, scanning speed, laser spot radius, layer thickness, hatching spacing, alloying affects the formation of this defect, because of the involvement of many process parameters and alloys. Currently, there is no general available methodology to guide engineers on how to avoid these defects. Lack of fusion is another major thing which happens due to process parameters in laser.

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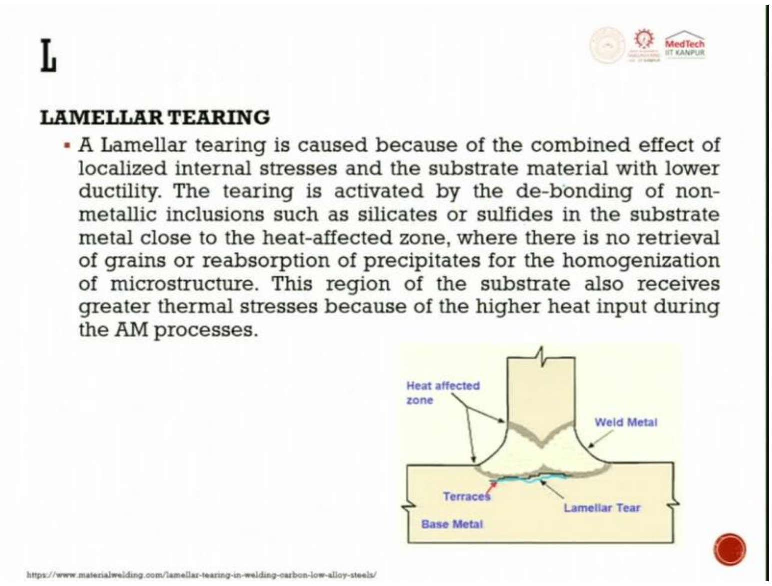

What are Lamellar tearing? Lamellar tearing is caused because of the combined effect of localized internal stresses and the substrate material with lower ductility. This tearing is activated by de-bonding of a non-metallic inclusion such as silicate or sulfide in the surface. So, these are the Lamellar tearing, these are traces, tearing is caused because of a combined effect of localized internal stresses and substrate material with lower ductility.

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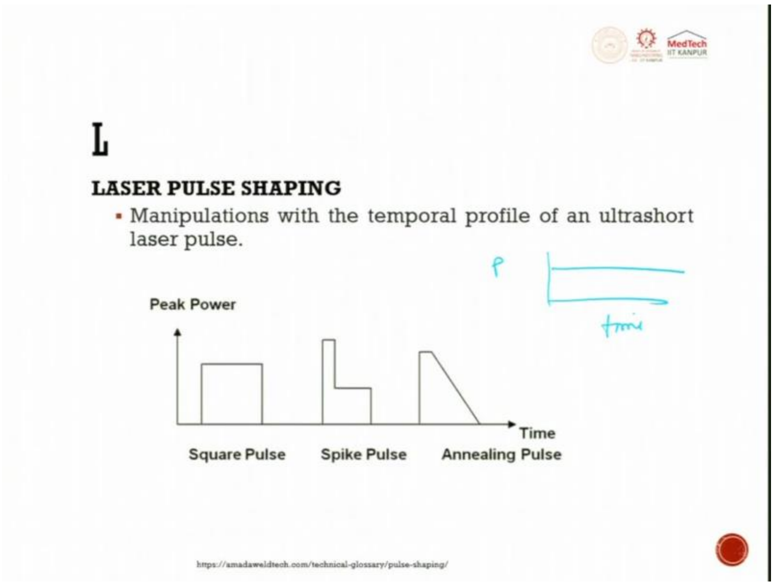

When we talk about laser, there are two types of lasers, one is called as a pulse laser the other one is called as a continuous laser, pulsed lasers are nothing but manipulating the temporal profile of an ultrasound, these are you have a peak power versus time, if you have a same amount of output coming out of the laser it is called as continuous laser, if I try to chop it and then try to have these are all pulsed laser, you can play with a pulse shape to meet out to requirements, it can help you in producing quality, defect-free product.

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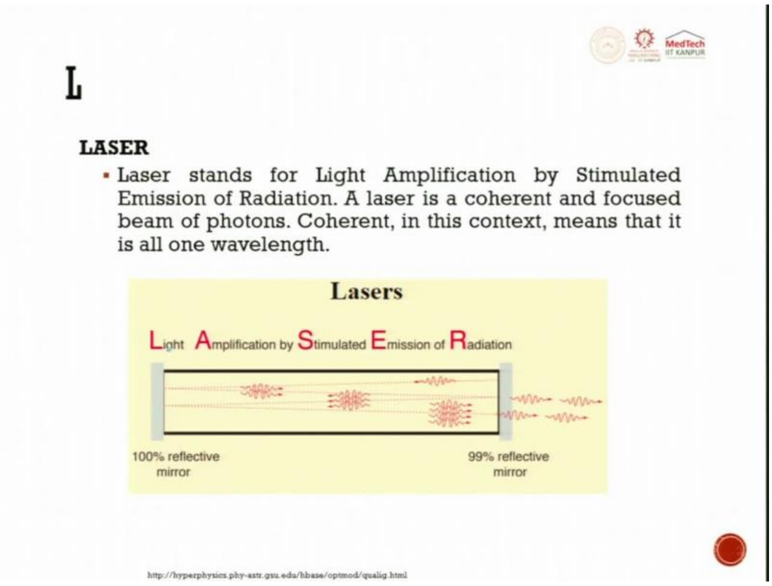

When we talk about laser, laser stands for Light Amplification by Stimulated Emission of Radiation.

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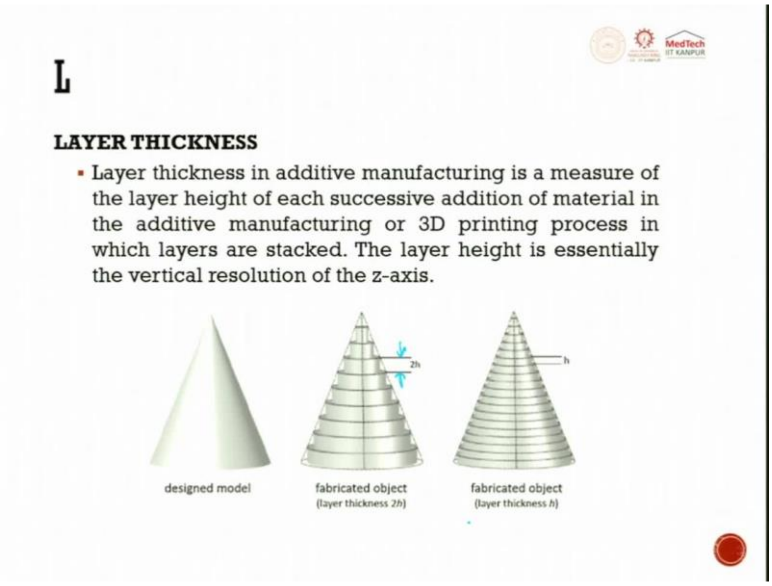

Layer thickness- layer thickness you can have varying layer thickness in additive manufacturing as a measure of layer height of each successive addition of material in additive manufacturing or 3D printing process in which layers are stacked. So, layer thickness is what is the layer thickness it has, you can have the same layer thickness all across the component, and you can have varying layer thickness across the components. So, that is called as adaptive slicing methods.

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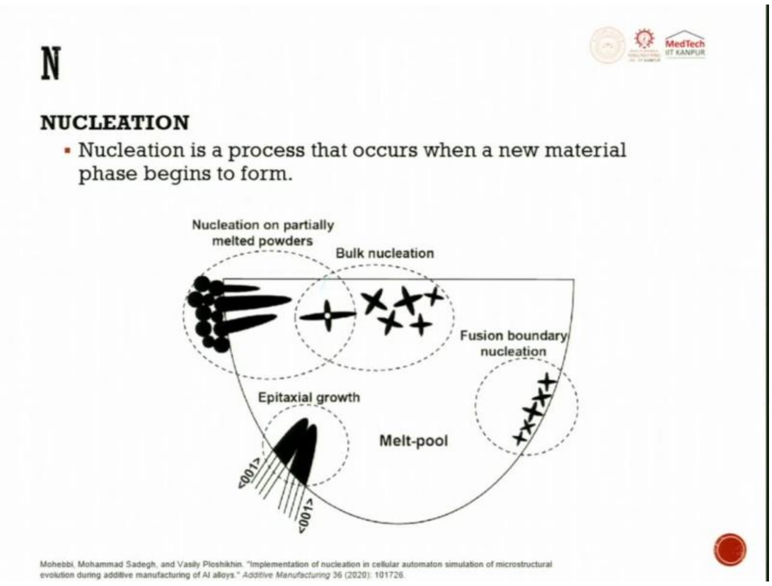

These are nucleation, nucleation is a process I said in the undercooling curve. So, you will have the temperature going down. Nucleation is a process that occurs when a new material phase begins to form. So, you can have these are bulk nucleation these are all fusion nucleation, fusion boundary nucleation, these are epitaxial growth nucleation and these are all some of the nucleations on partially melt powders.

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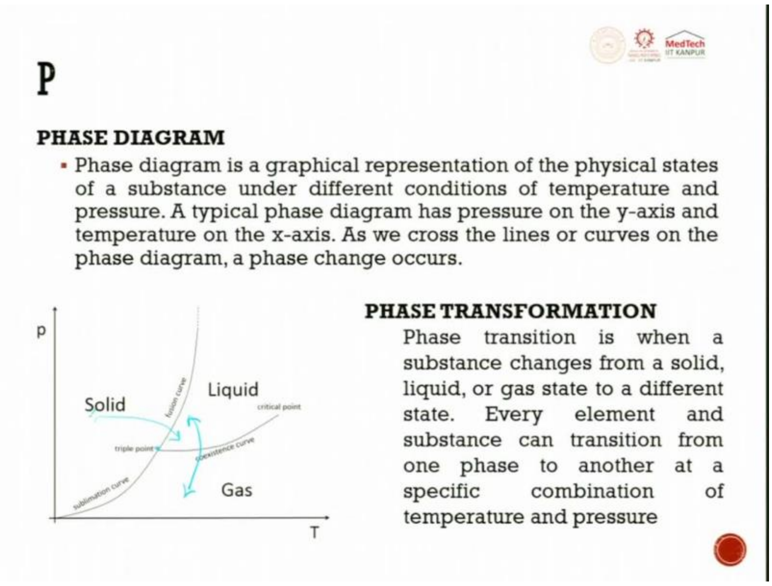

Phase diagram is very important because when we look at any the alloying system where temperature and pressures are involved and you are trying to change the phase from solid to liquid, a phase diagram is one thing which comes in your way which you have to go through it to identify the phases which are getting formed in the final end product. Phase diagram is a graphical representation of the physical states of a substance under different conditions of temperature and pressure.

A typical phase diagram has pressure on the y axis and temperature on the x axis. You can see here solid so this is a fusion curve. This is a triple point where it meets and then you have a liquid you have gas. Phase transformation is nothing but a phase transition that is when a substance changes its phase from solid to liquid or from liquid to gas or vice versa, so this is called as transformation in phase.

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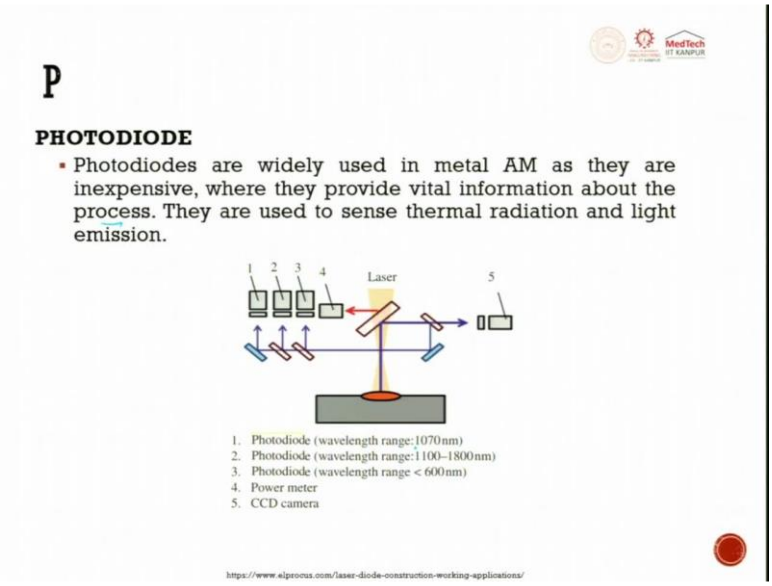

Photodiodes, photodiodes are widely used in additive manufacturing, as they are inexpensive when they provide vital information about the process. So, photodiode talks about the intensity of the profile, all these things are wavelength, intensity of the profile, then the peak distribution, all these things are directed by the photodiode.

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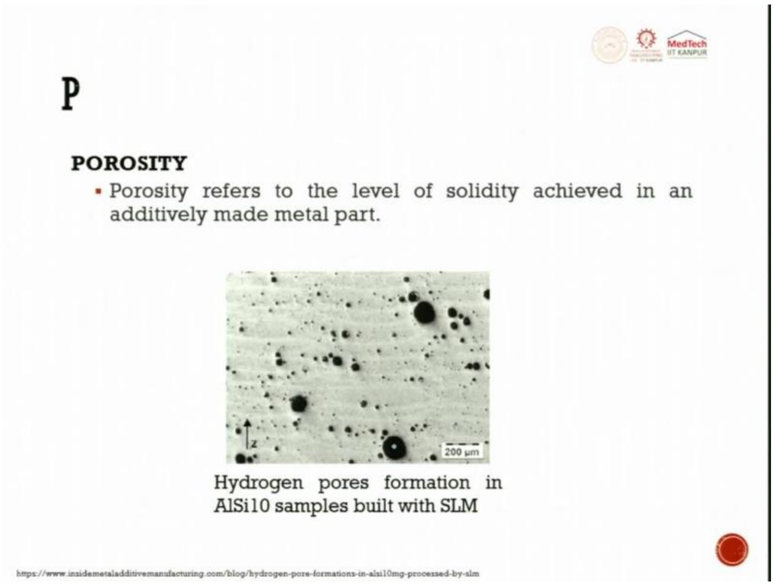

Porosity- Porosity refers to these all holes which are getting formed to the level of solidity achieved in the additively made metal parts. So, you can have porosity because of hydrogen per cent or any other foreign material which are present.

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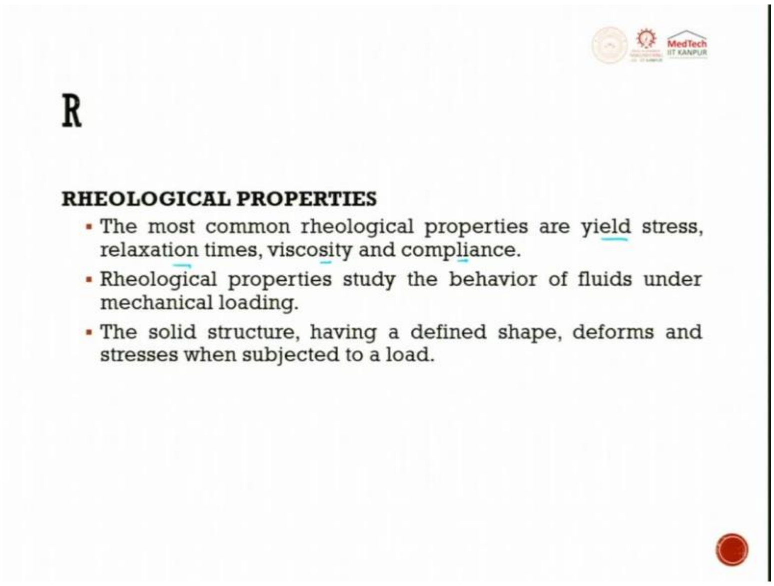

Rheological properties are very important as far as the polymer is concerned, yes, metal rheology properties are also important. So, the rheological properties such as yield stress, relaxation time, viscosity, compliance all these things are very important rheological properties, but this is effectively used for polymers, metal also undergoes this change.

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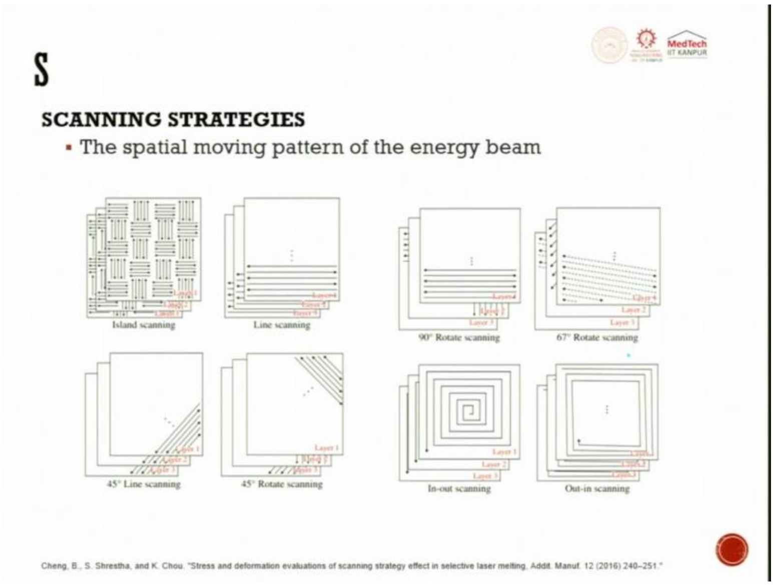

These are all scanning strategies, you can have varying strategies like this to meet up to your requirement in terms of strength and build time.

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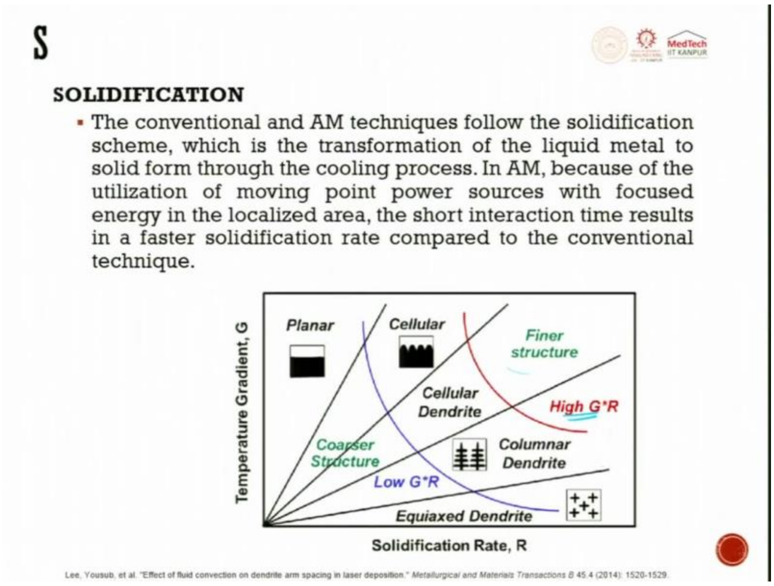

Solidification- the conventional and additive manufacturing technique follows a solidification curve. So, this is the gradient of temperature G and this is the solidification rate R if you try to plot between G and R you will try to see if when the line goes like this, you will try to have equiaxial dendritic structure when the line goes like this you will have columnar dendritic then cellular dendritic, then cellular that you have a coarse structure you have a fine structure and your higher G star R should be very high when it falls in this zone. The conventional and additive manufacturing technique follows the solidification scheme which is the transformation of liquid metal into a solid form through the cooling process. Solid solidification means converting from liquid to solid.

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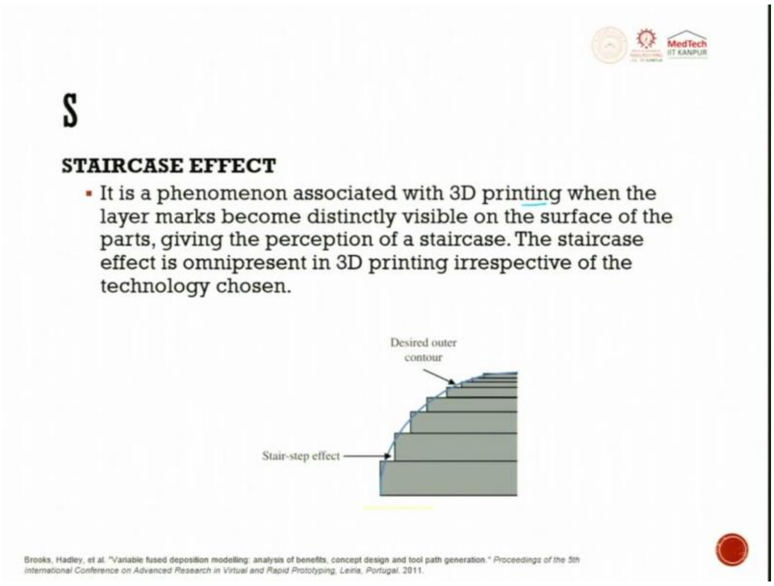

When we are trying to do layer by layer approach you will always have here something like a staircase which is getting formed. So, this defect is called a staircase defect or effect, it is a phenomenon associated with 3D printing when the layer marks become distinctly visible on the surface of the part giving the perception of the staircase. So, this is called the staircase, the staircase effect is omnipresent in 3D printing irrespective of the technology chosen.

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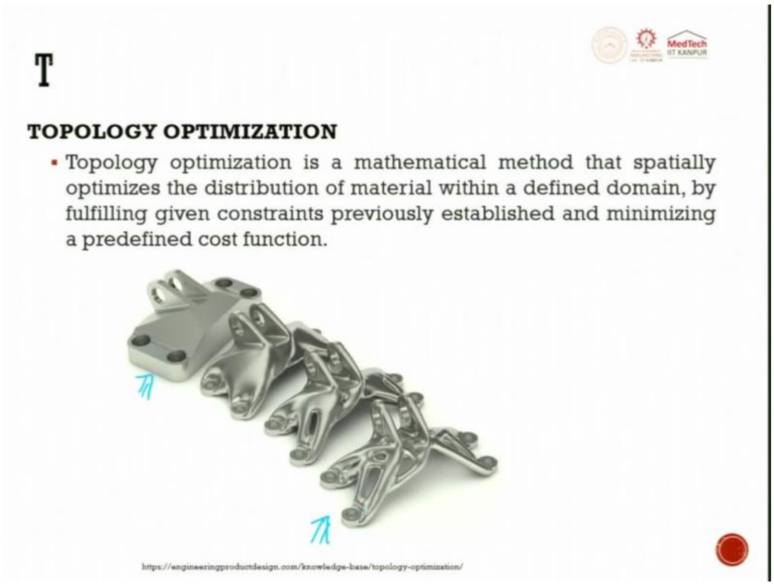

Topology optimization you see, this object finally is converted into this object by doing topology optimization with respect to shape, size and pores, so, a solid block and this is where today additive manufacturing is preferred to use. Convert the solid body product which is they're made out of the subtractive process in this way keeping design for manufacturing and assembly into account. So, now, what you do is you try to look at these objects and when you do topology optimization, you see what amount of reduction and this entire thing is a single part.

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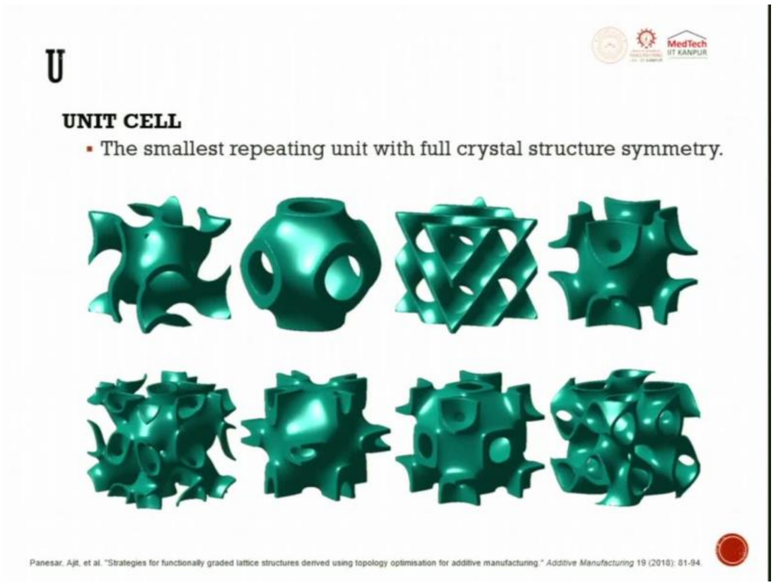

So, unit cells- the smallest repeating unit with full crystal structure symmetry is called as the unit cell. you can have unit cells of all these things, you can have a combination or you can have individual all these things depend upon the build time as well as the strength of the built object.

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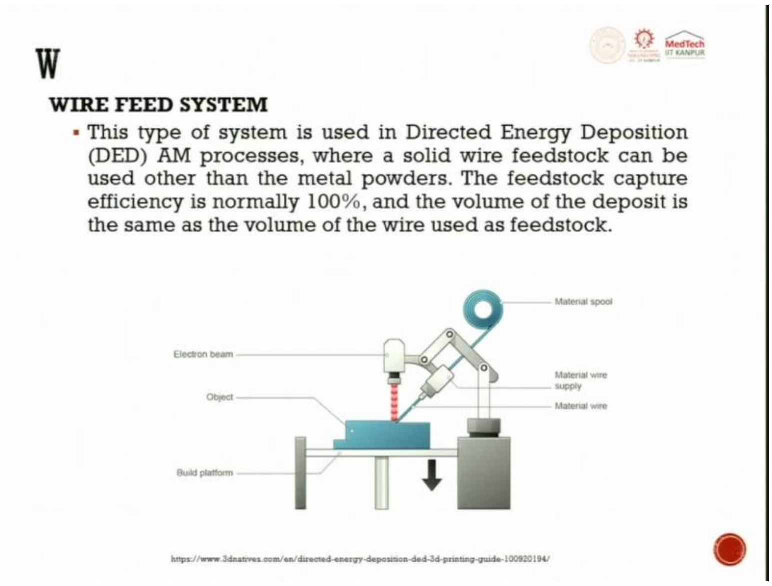

Wire feed system wherever till now, we were talking about powder you are today using wire. So, it is easy for you to transport the wire and melt and deposit it. So, a wire feeding system is nothing but feeding a wire instead of a powder and using laser for melting and trying to adhere to form parts.

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So, with that, we have come to an end to the Glossary. So Glossary, I did not cover 100 per cent. So, wherever you have some little bit of science, I have just covered it superficially. Now I will explain these concepts as and when I start explaining individual processes. So, till now, whatever you have studied, at least in these last two chapters, try to understand all these individual things and try to look forward for more properties about laser, we will not cover in detail what are the different kinds of lasers and all, just for your understanding, it is better you start doing self-learning and understand what are the different types of lasers, class A, class B, class C, Class D or class one, class two class three, what are they? How are they done? And how is it going to affect the quality of the product if you can start browsing and trying to make small notes on it that will help you to prepare for your exams. Thank you so much.