Fundamentals of Materials Processing (Part–1)
Professor Shashank Shekhar
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur
Lecture Number 01
Introduction

Welcome to this NPTEL (())(00:14) course on 'Fundamentals of Material Processing Part – 1'. So most of you I am hoping would have already seen the introductory video. So, having seen that video, you would have realized what this course is about. This course is about understanding the various fundamental processes that are involved in various manufacturing processes. Okay? So, let us start this course with a case study. We all know 'cans' which are used in so many different things, right.

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Now this can (pro) making process has been in use since nineteen sixty three, for example in US alone, if you count the total number of cans which have been produced, it is of the order of ten to the power eleven, which is something like hundred billion cans which have been produced and this data is some few years old, so you may add maybe some, you can make it ten to the power twelve. So that is the order of magnitude we are looking at in terms of manufacturing of these cans. So what does this mean? It means two things: One that the can, the overall manufacturing of the cans must be cheaper than the content that it carries, and it carries content like your soft drinks and all those things, so it must be cheaper. The overall production process must be cheaper than that. Second, if you look at the scale, you can realize that if we, if we are able to save even a penny on each of these cans, you can save really millions and millions, and that is what exactly happen when people understand the basics of processes that are involved.

For example in this can making process, what we do? We take a small pellet, which is then kind of superplastically deformed into cup shapes like this, and then further deformed and deformed and finally you get shapes or sizes upto which you want. Now you see there are kind of rings, not rings but ears, kind of, which have formed onto the edges of these cans. A lot of research went into this because what will happen to these ears, they will be shaved off, they will be cut off and that kind of money that was involved in processing, will all get wasted along with the material. And, so after looking are the (varial) or the and the fundamentals of the process, understanding the texture, there is a, we are talking about not the surface texture but a crystallographic texture. The crystallographic texture that is involved during the deformation of this process told people what to be done or what kind of texture to use to ensure that these kinds of ears are not formed.

And finally people, the companies which make these cans were able to use this and they saved off something of the order of US dollar three for thousand pieces. You would say that is not a really big amount; but look at the number of cans that are produced, and you can understand that it is a significant savings for the manufacturing companies. So this gives you an idea that if you understand the process and the science then you can modify the manufacturing process to basically optimize and get maximum outcome from that.

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Here is another example. What are you looking at? You are looking at some brass sculptures. You know where these are manufactured? These are manufactured in Moradabad city of UP. So Moradabad city is famous for these kind of sculptures and these were formed using what? These were formed using brass, because brass has very good fluidity. Now slowly over last several decades, the price of brass has gone up, and therefore, what did people needed to do? If they understood the if they understand the processing very well, then they can (in) get higher fluidity in other low cost material like what people have done over here.

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This is to a small company that I went over there, which is a very small scale, you can say cottage scale industry, but it exports these kind of things, these are saucer and pans where you put tortillas and so sauce on (to) on top of it, and they are able to export it. This is actually manufactured only for the purpose of exporting and it is made by what? It is made by aluminum.

So one, they were able to get fluidity of they they were able to change the composition of the material, some aluminum alloy, so that they get very good fluidity, and then, not only that, they are able to get seamless component. You see this is this looks like two component, and it is indeed two components but the way they have joined it by welding, they are the the welding is not actually visible and that all those things are possible only if you understand the processing, the science of the processing; and therefore it again emphasizes the importance of this course.

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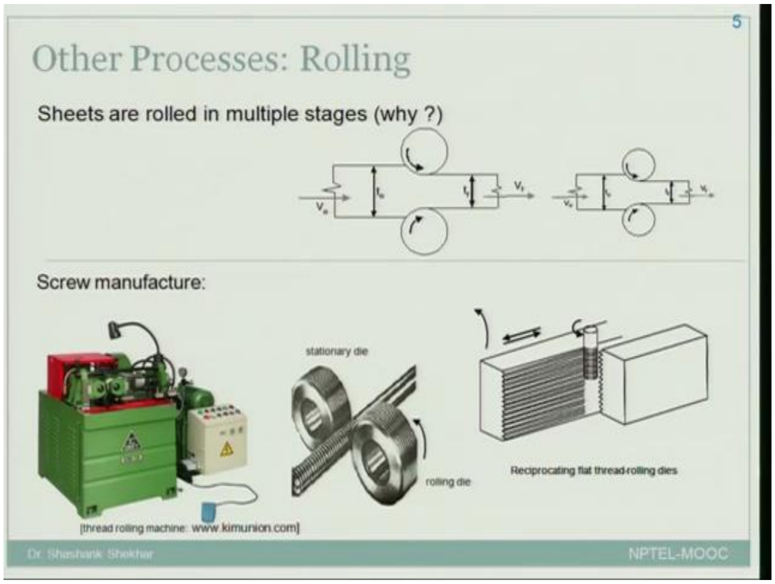

What are some other processes and what are the science that will be involved over here? One another process that you may be very well aware of is rolling. Rolling is extensively used in several industries, yeah, including the steel industry. You know why (they are) sheets over there are rolled in multiple stages? There is a reason behind it. So and and , outcome of that is that you are able to get very flat sheets and of very high accuracy; you wouldn't be able to do that if you were, wanted to do that in single stage. So that is an understanding about the stress-strain behaviour of the material, how the deformation is taking place, all all those things if you understand, then you will be able to understand what are the different or on how many stages you should deform or roll the material.

Another thing is, for example, screw, the threads on the screws are the bolts that you see. They can be manufactured in two different, atleast two different ways; one is, by rolling, like this, which is called screw rolling, sorry the thread rolling. So you see there are two dies, there is a rolling die and there is a stationary die, and in between the rod is kept and it is rotated so that the thread is formed. Now you can also create this kind of thread by machining. But why and which process would you select? Now this selection of process and material would most of the time depend on the inter-relation between material as well as the process. It is not a very straight forward guess, but in many a cases, the if you know, or there may be some overriding factors which will explicitly determine which process to use.

For example, in here, rolling at the when you do the rolling, you ensure that there is some amount of work hardening on the surface, and therefore, material gets hardened, and you want the thread to be stronger. If you do this process by machining, you would not get strong threads and therefore, this kind of rolling the thread rolling using the die is a preferred route to create this kind of threads.

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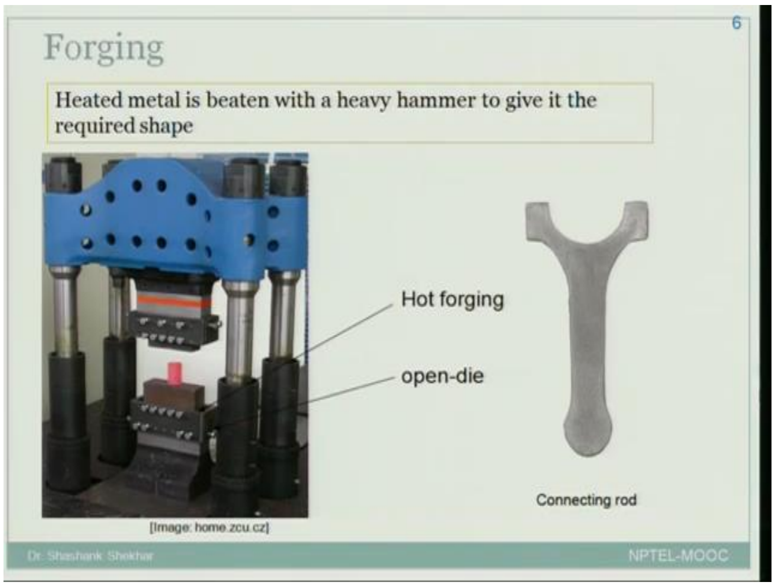

Let us look at still another process which is 'forging', which is widely used in automobile industries. So what is forging, first let us look at the definition. In this what you do is heated (me) you take heated metal, and you beat it using a hammer. Now this is not a simple hammer, this is but a kind of press, where you, where this hammer comes from the top and beats onto the surface. Now this drawing the or the image that is shown over here, it is called a 'open-die', meaning you do not have any preferred shape given into the die, but at the same time there are other methods or sorry the other dies; for example 'close dies', where you can get desired shapes. For example you get these kind of connecting rods which are widely used in your automobiles, in two wheelers. These rods are again manufactured using forging but using close die forging.

Now again, why what are the signs or (under) basic understanding that you must have about forging. Now you, if you wanted to manufacture this kind of shape by, let us say machining, again machining would be another possible route, but you do not create by machining. Why? Because when you look at the microstructure, look at the strain, the stresses and the strain, then you would realize that the microstructure that you get in a, in a component like this obtained from forging.

There is a grain flow along the edges of the valve, or along the edges of the surface, and because of that it provides it higher strength or higher toughness against crack propagation, and that is again another overriding factor which ensures that you use, if you have, if you need higher toughness, then you will have to use a process like forging. Apart from that, what is the kind of stresses that are acting, whether the material can be deformed to that extent; all those things you need to note.

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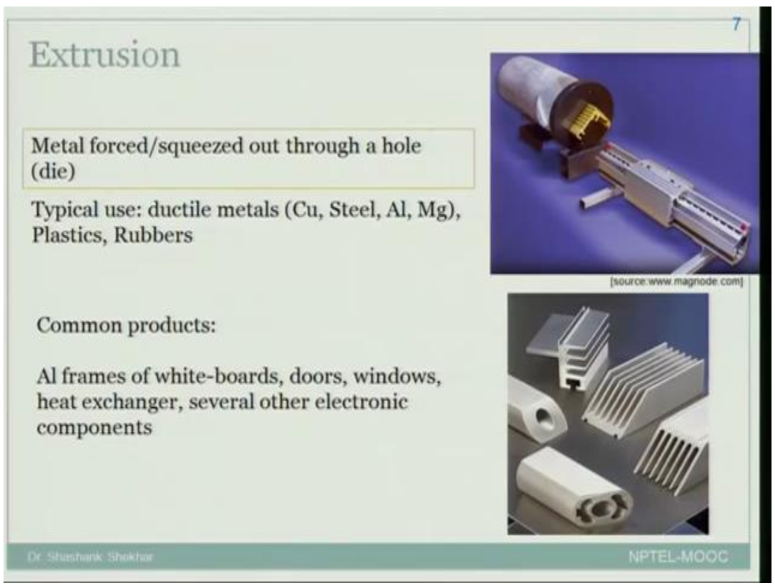

Still another metal forming process is ‘extrusion’. In here, you can say actually the material or the metal is squeezed through a die or a hole, and you get long two dimensional shapes. It is typically used for ductile materials obviously because you can realize that it is the material is very nicely flowing through the die holes, and only a soft material can flow through it. So it is used for materials like, metals like copper, steel is also very not so frequently used, but mostly copper, aluminum and magnesium; and other than metals, this is also used for plastics and rubbers. Some common products that you will see when using extrusion or aluminum frames, for example for the white boards, doors, windows where the doors or windows slide; those aluminum frames, these are those are manufactured using extrusion. Then heat exchanger, where you have lots of fins, though those fins can be manufactured using extrusion process. Several other electronic components can be manufactured using extrusion.

So , again now the question is, what are the science that are behind it, that one may be required to understand. So first and foremost, stresses and strains required because now you are using ductile materials to flow through these. Now are these materials ductile enough, how would you know? So those are the, those are the things that you will be able to answer only if you understand the basics of metal working.

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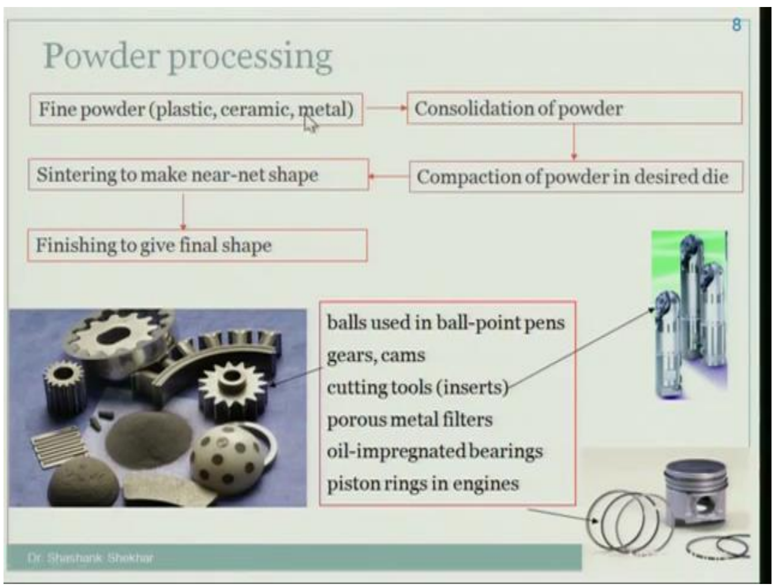

Still another process is ‘powder processing’, and this one is also called as ‘powder metallurgy’ but it is not only confined to metals, it is you can also use plastics, ceramics for powder processing. What you do is you take very fine powders, you consolidate the powder, and then compact it into the shape that you desire, and then you center it. Why do you need centering? Again there is, centering is a big science, that one needs to understand to be able to get desired properties, and then you give it the final shape. So some of the components that are manufactured are, for example balls used in ball point pens, gears, cams, cutting tools, for example if you have ever been to a lathe machine, the cutting tool inserts that you see those are manufactured using powder metallurgy technology or powder processing technology.

Now powder processing, those of you have ever came across, you would also know that it always leads leads behind some amount of porosity. Now this porosity can be looked as a disadvantage, but at the same time, in some application, you can make good advantage of it and one of these is porous metal filters. Some filters where you want only certain size of materials to pass through, then you will, if you know what is the porosity size, you can use them as a porous melted metal filter. Another application for this porosity can be oil-impregnated bearings. Now if there are some porosity, and you put in the oil over there, the oil would stay inside those pores and now when you apply it or remove it against another metal, then that oil can act as lubricant. You do not need to leave some extra space for that oil. So that is another advantage if you are using powder processing.

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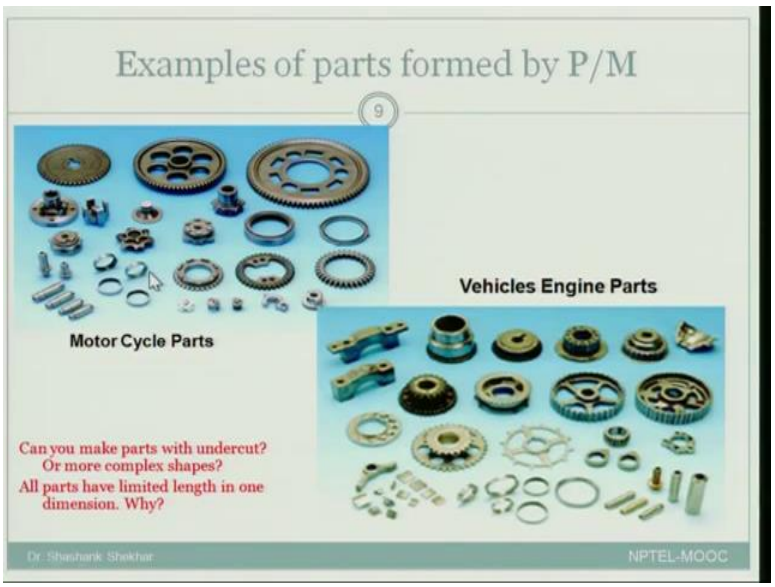

Then there are some other applications like piston rings in engines and several other, in fact let me show you some more of large variety of components in motorcycle as well as vehicle engines are produced using these modern metallurgy technique. One thing that you would see here is that these parts have one commonality, and it is that they are all in 2D, they do not have third dimension.

Again if you understand the process very well, then you would be able to understand why we have only 2 dimensional, in fact it is called 2 point 5D, meaning you can have any shape in the 2 dimension, and third dimension it will have some limited length, that will depend upon the material property like strength etc and the pressure that you can apply. And another thing is that, you you would see, you do not have any undercutting, undercut components, meaning a part coming back onto itself; that kind of shape is disallowed, and that is again if you understand the geometry of the dies that are used, you will be able to appreciate why you cannot have undercuts in powder metallurgy processes.

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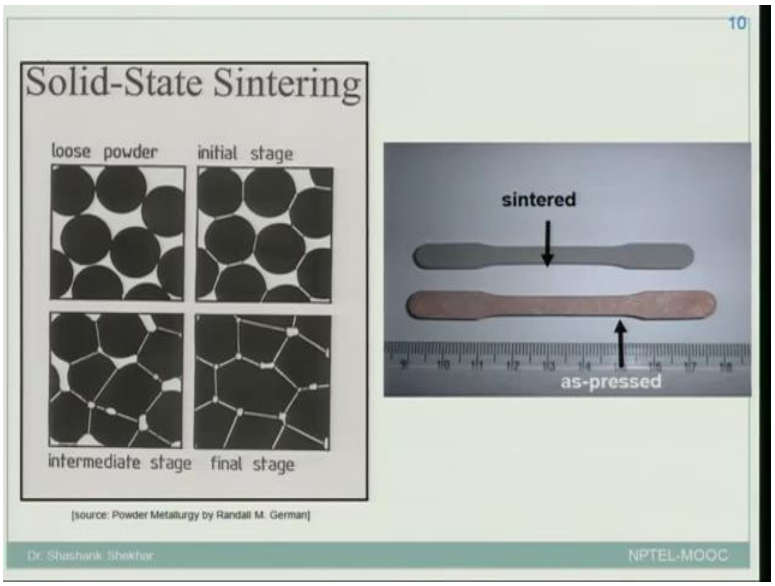

Now in powder metallurgy processes, you may have heard that it is a (())(13:39), but do you know that if you take a consolidated material or a component; so let us say we have a die which made a dog bone like this. Now if you sinter it, its size actually reduces. So the size actually gets reduced and this you will be able to predict if you understand the fundamentals over here and this is reducing because if you look on the left side over here, you start with loose powder, then you put them together into consolidated stage, which is the initial stage and then you start sintering, and when you start sintering, then these bonds between the particles start to join, and the gaps become smaller and smaller.

At this stage you would think that if I apply enough pressure enough time and enough temperature, I would be able to get rid of all the porosity. But then again, only if you understand the science, you would get to know that ‘no, this is not really two; there may be some pores which are closed pores which can never be get rid of, got rid of, and you will have to apply some special techniques or special different methodologies in sintering to your to be able to get really close to 100 percent density.

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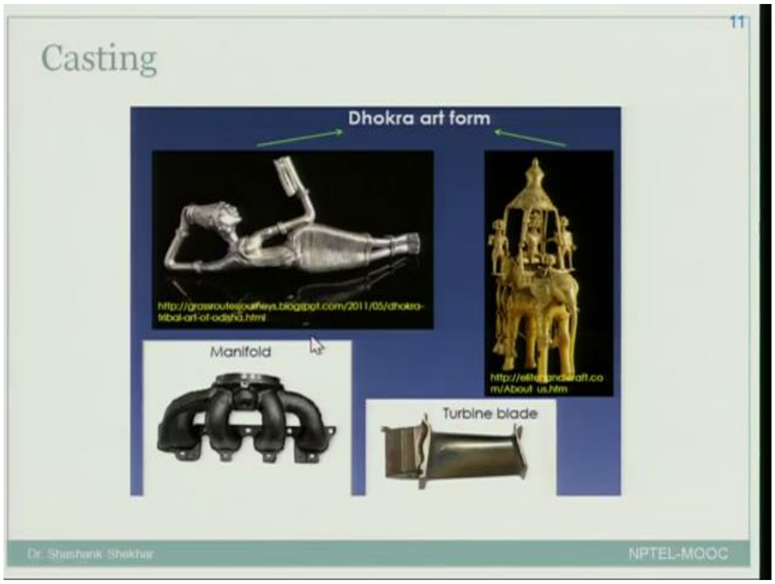

Another very well known technique is 'casting'. Now you this casting is, has been in use from time (im) immemorial, because our ancient civilization were very well versed with these kind of techniques for manufacturing or even for art form. For example, these are 'Dhokra' art forms, which are made using what is called as lost wax forms. So these are something for a decoration, but at the same time, casting is also for utility purpose; you can make manifolds, turbine blades; turbine blades is a solid casting, but you know special kind of casting where you get single crystals, or where you use only single crystals to get the casting structure.

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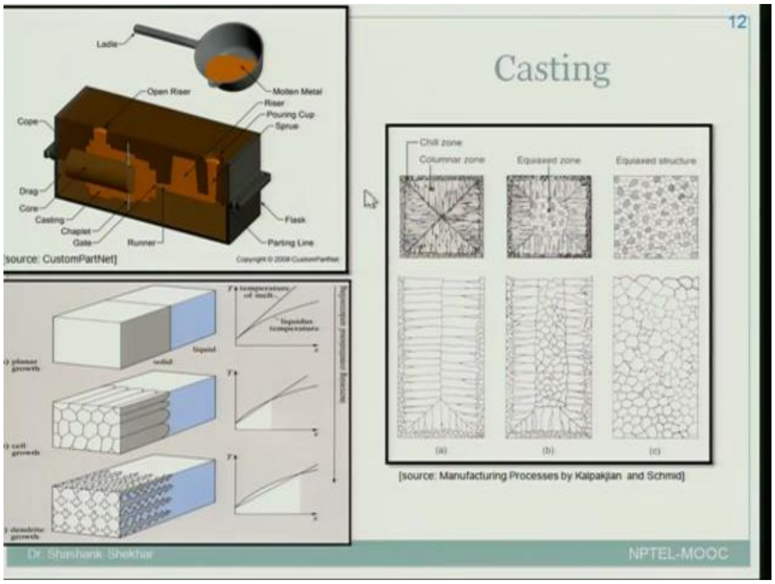

Now, what are the science involved in it? So let us look at simple casting process. Over here you will have a mould cavity, you can put a core and you can pour in the liquid metal. Now the liquid metal, (how) what is the temperature of the liquid metal? How fast the heat is being extracted? That which will depend on the liquid metal temperature, as well as on the properties of the insulating material or the mould material; those will determine what is the kind of your temperature and distance plot, and that is what will determine whether you will get planar growth, whether you will get cellular growth, or whether you will get dendritic growth, and based on that you can, and not these are the not the only factors, you may also depend on or the, the other factors that may determine the micro-structure are, for example how the different components of the alloy are getting separated.

So you can get huh something like this, where on the walls you have completely equiaxian structure and in the inside you have completely columnar green structure or in the middle you have some amount of equiaxed zones, or you can have completely equiaxed zones, depending again on not only the material and the type of casting you are doing, but also on other parameters like what is the rate of extraction, what is the kind of alloy you are using, how they partition and so on.

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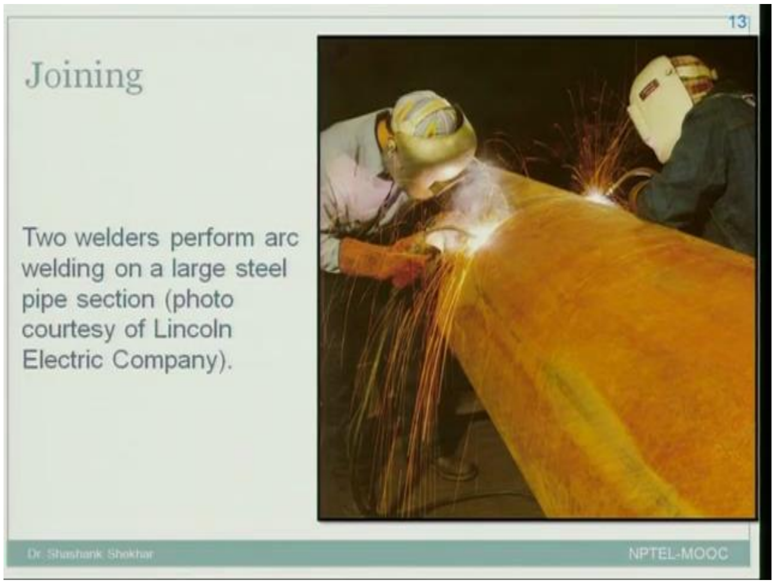

And another manufacturing technique which is not really well appreciated as a manufacturing technique comes in the class of 'joining'. For example 'welding'. let us imagine, you know the IPI pipeline which is the Iran-Pakistan-India pipeline; so if this pipeline becomes a reality you will have oil and gas coming all the way from Iran into the into our country. But you cannot manufacture those large something of the order of 1 meter pipes, and in 1 component. What will you do? You will make or manufacture small components and then join them.

So in there, joining again becomes a very important manufacturing technique and you need to understand what are the fundamentals going on over there. So for example, in here, the picture that is shown over here, people are welding 2 pipelines, most likely of the oil and gas pipelines. So this was again another manufacturing process or manufacturing technique whose fundamentals you must know, again why? Because when you are joining, now the properties, the micro-structure, again depend on the kind of process that you are using, whether you are, you know, what the kind of temperature you are using, what is the material that is being joined, and so on.

And so their properties, for example, would they be able to bear the same kind of toughness and strength that the original base material was able to do, or they, would they be able to have the same kind of functional properties, like corrosion resistance and oxidation resistance; those things can only be answered if you understand the micro-structure, which will depend on the process and the parameters used in the process. So again, the, this is to emphasize that you need to understand the process.

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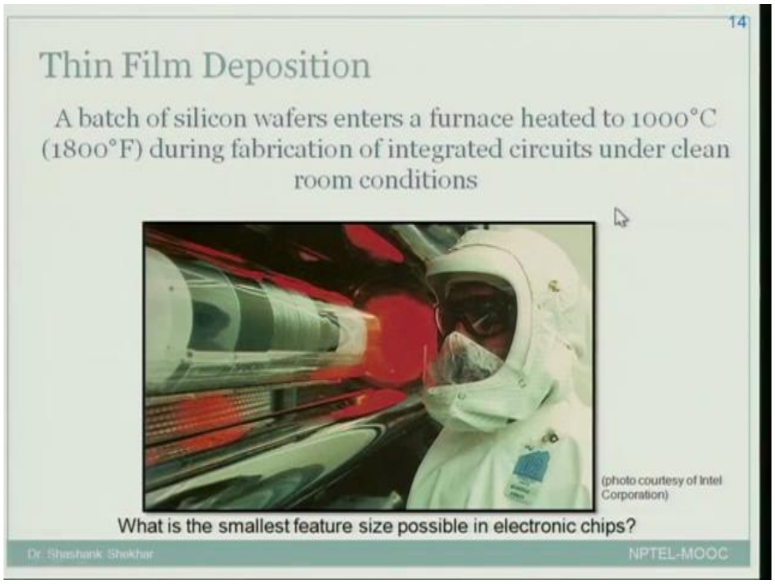

Not halting in too much on those processes, let us just look at some other process, something like 'thin film deposition'. Now, where do you use thin film deposition? Now all the electronic components that use, from smartphones to laptops to TVs; they have electronic chips, which were formed at some stage using thin film deposition. What we have in this thin film deposition? First you take a silicon wafer and then you probably dope it with boron or phosphorous, depending on whether you want P-type or N-type, and then you may even have to deposit copper as a interconnect, or silicon polycrystal for interconnectivity between the different small components inside the chip.

So this process is also a manufacturing process, but the fundamental, most of it will remain same. For example, the silicon wafer. Now the silicon wafer is a single crystal remember, and this single crystal has to be manufactured using one of the casting or the solidification technique which is the just like in the , you remember we talked about that turbine blade, it has a single crystal, similarly here also we have a single crystal which has to be manufactured. Now we are that we are talking about thin film deposition, do you know what is the smallest feature size that you can obtain electronic chips? It is actually of the order of 25 nanometer, even less probably, by the time here this video. And that is all possible because of understanding of the processes involved, so that you can finetune it, you can optimize it and get the desired properties.

Now when we are talking about the processes, it is not just the processes perse, it is also the materials which are involved in it, which make a difference to the properties. So for example, what are the kind of properties material and what are the properties that make a difference? Material wise, you we know that there are three different, three important classes: metals, ceramics and polymers, and the fourth you can consider as a combination of all these two, all these three. So, these are the main classes of materials, but what are the properties that we may be interested in?

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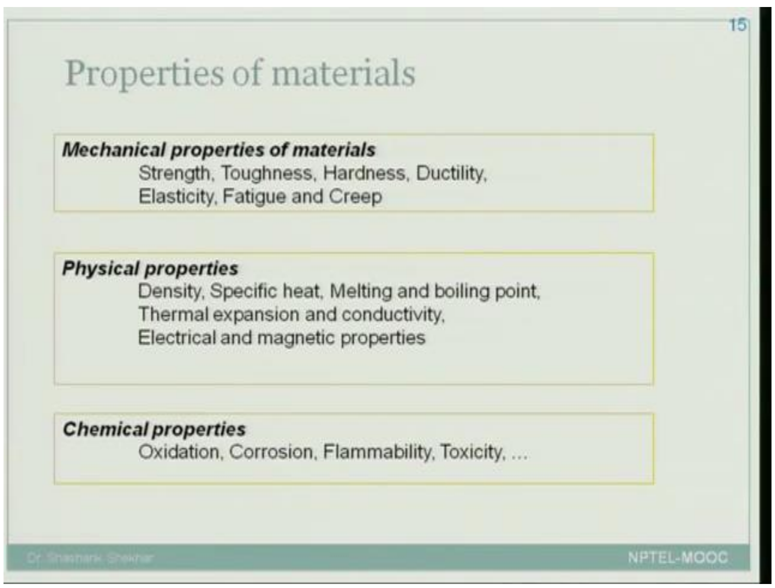

So, we may be interested in mechanical properties; for example when we are talking about metal working, it is very important to understand and appreciate the properties like strength, ductility, toughness, hardness, elasticity, fatigue and creep. Now when we are talking about, let us say solidification like processes, we are interested in physical properties like density, specific heat, melting and boiling point, thermal expansion, and conductivity, and in some cases, where we are, for example in the silicon, we are even interested in the (electro) electrical and magnetic properties.

Apart from this, we are also interested in properties, like chemical properties, which will also be important in understanding the overall science of the process. So what are the kind of chemical properties we are talking about? For example in the case of pipeline, we discussed oxidation, oxidation resistance, corrosion resistance; similarly other properties, chemical properties that may be of importance are flammability and toxicity.

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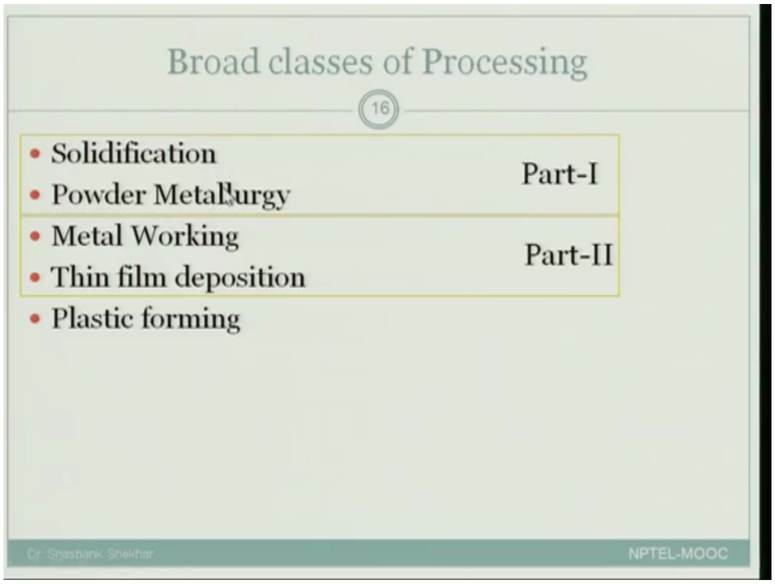

So based on our understanding and discussions so far, we can say the there are some broad classes of processing; solidification, under which you saw casting technique, and even welding would be considered amongst the solidification technique. Then we have powder metallurgy technique, or powder processing rather, because it involves not only metals, but ceramics polymers as well as metals and may be even a combination of these, if you want to create something like inserts in the tool. Another broad class of processing is metal working; so we saw examples like rolling, forging, extrusion, and apart from that, there are several more metal working processes which which come under this category. And then, these are the, you can say, large classes of manufacturing.

Then, for smaller components or electronic components, you have thin film deposition techniques, which are, which you can say is a separate class of processing. And there is still another class of processing which has not really been taken into account in the above four which is ‘plastic forming’. So, actually the plastic forming will you can say, it comes under some of these (cate), work categories, but if you which it will be much more better if we use plastic forming as a separate process, separate broad class of process to understand what are the fundamentals involved over there. Now this first part of the course is about solidification and powder metallurgy, and the second part of the course will discuss the metal working and thin film deposition.

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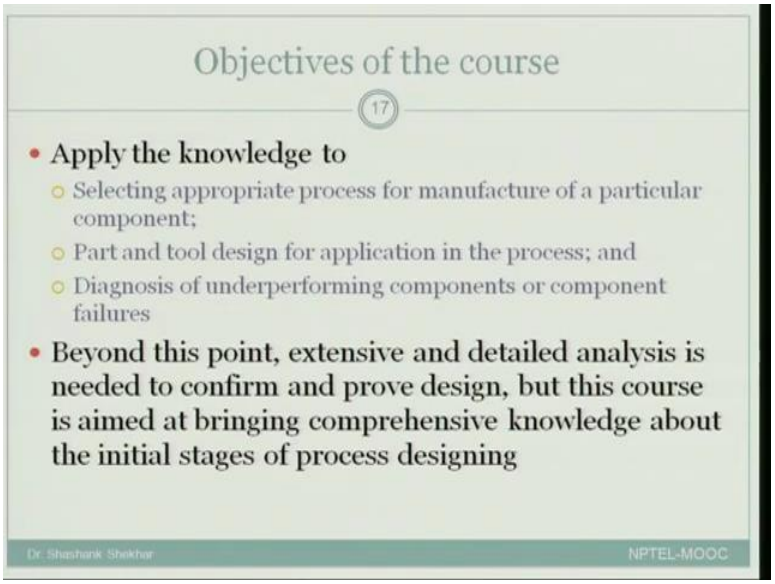

So now based on, based on our understanding so far, we can say that the objectives of this course are threefold; one, what we gain from this we apply that knowledge to selecting appropriate process for manufacture of a particular component. For example you saw the thread, (())(23:57) out the thread making in screws and bolts. Now you can have, you could have applied machining over there, or you could have as well applied rolling. So, if you are able to understand what is going on, what is the fundamental science involved over there, then you can select appropriate process. Then, knowing this, or having this knowledge, you can also apply this knowledge to design part and tools, which will be involved in the component, or which will be involved in the processes which will make the components.

For example, what kind of die to make for the powder metallurgy components, or even if we are talking about casting products, what should be the heat rate, and based on that what is the heat rate you can design appropriate mould; and similarly, if you are looking at whether you want to avoid micro segregation, which is a big problem in casting, then what what can you do? What are the things that you can do that you will be able to understand if you understand the science of a shear. Another example would be shrinkage. Now shrinkage is a big problem again, in casting.

So how to avoid that shrinkage? You would be able to appreciate that, if you or you will be able to apply that knowledge into designing proper moulds and proper selecting proper materials, if you understand the science involved over here.

Now diagnosis of underperforming components or component failures. In some cases you may have manufactured a component, which may be underperforming. You may have used and designed a process, but it is not performing to your desired to what you desired. And why could it be? It could be because at some particular step, at some particular process which you took into account is not is not giving the desired results. So you are not, in effect we can say process; there is three things: process, then the microstructure, and the properties.

Now there is the process, first part, now; in this, is this process giving you the desired microstructure? Is this microstructure giving you the desired property? So you have to find the link, which is the link that is missing? And that again you would be able to understand and appreciate if you understand this course. So that is another objective; to be able to diagnose to diagnose the underperformance, the reasons for the performance of components or component failures.

Now beyond this, you may also be interested in extensive and detailed analysis of your plant design, but beyond the, if you want more than that, then you probably will have to delve deeper into the subject. The idea of this course is not to give you a, and it is not possible to give you all, knowledge about all the different kinds of manufacturing processes and how to optimize them. The idea is here to give you the science behind it, so that you can delve into the process and then optimize the process accordingly.

So next class, we will be discussing on to the solidification. We will start with a little bit of introduction on what are the two important classes of solidification, which are casting and welding, and then, we will move on to the science behind these processes. Thank you.