Introduction to Machining and Machining Fluids
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Lecture - 27
Advances in Metal Cutting_ Machining Processes-2

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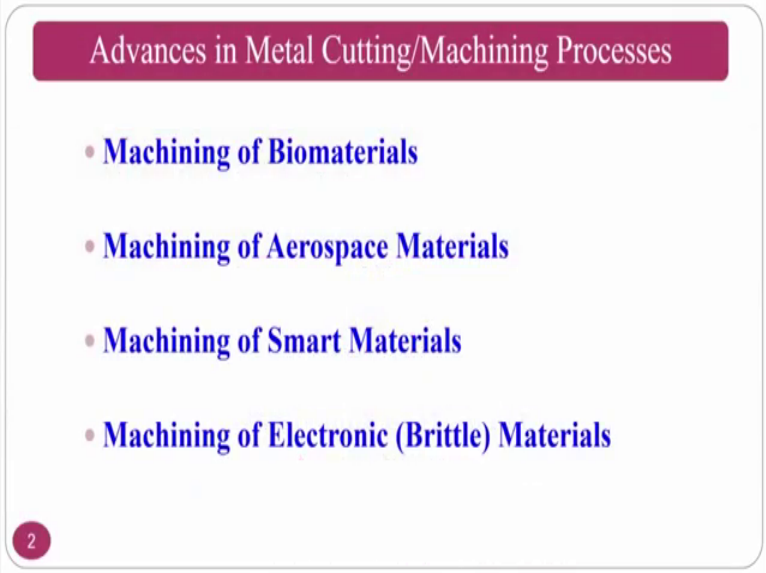

In today's class, we are going to study about machining of advanced materials. What are the advanced materials that we are going to see is few materials only, especially we are talking about machining of biomaterials, machining of aerospace material and machining of smart materials. We take one-one example and deal with the conventional machining process, because the most of these advanced materials are machined by the advanced machining process, but very little amount of work is done in the conventional machining process, especially in the electronic materials.

Normally, electronic materials you cannot directly do the machining operations. You have to do using some hybridisation then you have to do like, laser assisted machining and all those things. We will see in particular about each and everything. So, first we will start with machining of the biomaterials. Today's world people are moving around the biomaterials and it is application, because many things are happening to the people. So, they need bone materials to the vascular materials to the artificial muscles and all those things. Since, the biomaterials that can be machined should be either metal or the ceramic materials that is why we look into the, mostly we look into the orthopaedic materials.

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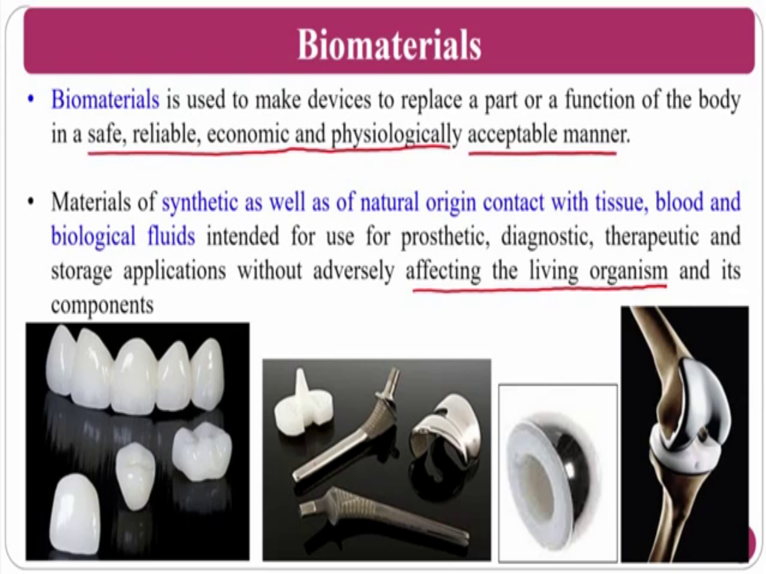

What is the biomaterial? Biomaterial is used to make the device to replace a part or a function of the body in a safe reliable economic prisoners in a acceptable manner. So, it is the biomaterial, is used to make a device to replace, a part or a function of a body in a safe reliable economic and physiological acceptable manner that is a common definition for a biomaterial.

The materials of synthetic as well as a natural origin contact with the tissue blood and biological fluid. Normally, it can be a synthetic material or it can be a natural material, whenever you place inside the body, it goes in contact with the tissue blood and the biological fluids.

Whenever it is in contact, with this type of fluid, it should be safe ok, it should not cause any damage to the cells, it should not make the blood to not flow or something, it should be either, it should be inert or it should do the positive aspects to the body. Normally, in the forms of diagnostic therapeutic are the storage applications without adversely affecting the living organisms and it is components; that means, that body fluid, there are white blood cells.

Red blood cells at the same time tissues osteoblast cells and all those things are there.

This whenever you are going to put a particular material things at a body, it should not damage or it should not affect in a adverse manner that is what the biomaterials has to do.

If you see the first and foremost material; normally, whenever you deal is a dental materials, dental ceramics are there. You have to do the casting operation, when you have to do the finishing operation then you have to do the polishing operation and all those things. So, next orthopaedic implants, the hip implants, knee implants and all those things.

The acetabular socket, it is also known as the acetabular cup. So, it will have a multiple layers or a single layer or normally it can be made out of composite material or a single material and all those things. So, knee implant materials and other, these are the some of the examples, where conventional machining process play a major role. There are stands and all the things, where the advanced machining processes, such as a laser micro-machining and all those things will play a major role.

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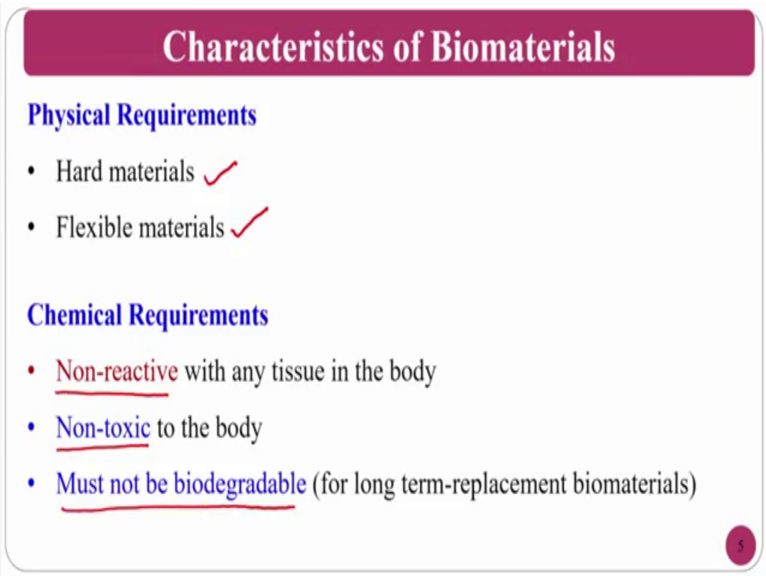

The characteristics of biomaterials physical requirements, it should be hard materials depend on your replication. It can also be a flexible material. The chemical requirements, it should be a non-reactive with any tissue of the body; that means, that it should be bio-inert material, non-toxic. It should not cause any type of toxic elements or any damage to the surroundings, it must not be biodegradable.

People nowadays, are coming up with respect to the biodegradable also. I mean to say, it can be biodegradable. It cannot be biodegradable depend on your application, if I want a implant to be permanently placed inside the body, in that circumstances, the implant should not degrade, if I want to heal certain thing, assume that you have a bone fracture, I want to put a plate or pin or something. It should be degradable, because after 2 months or 3 months, after getting the healing, what you should not go for the secondary operation to take up this plate in that circumstances.

If it is degradable normally, it will be better. So, it is application oriented, what is the requirement oriented biomaterials are there. So, for the long-term replacement biomaterials, it should not biodegrade for the long-term replacement. Normally, the material should not be degrade the main, a features of the medical applications.

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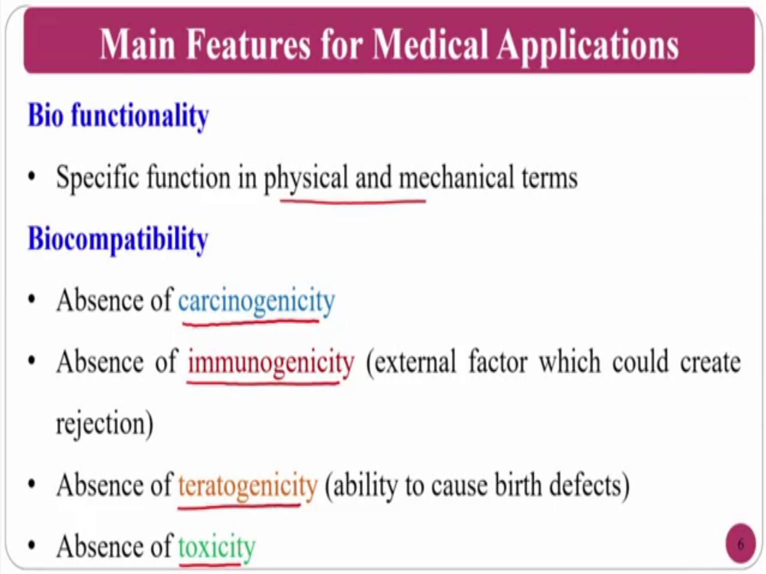

It should be, have bio functionality that is specific function in physical and mechanical terms. The bio compatibility normally, biocompatibility mean it should have absence of carcinogenicity; that means, a cancer should not cause immunogenicity, absence of immunogenicity and absence of teratogenicity and absence of toxicity.

These are all things is required for a particular biomaterial. Now, you may be getting, why we are studying all these things, the problem is whenever we are going to do the machining operation with the parent material, assume that I am going to machine, a titanium, which is a bio-inert material. What will happen?

The temperature rises and the metallurgical changes will come. Where? Where the metallurgical changes will come into a component? It may, I am saying, it may create problem by, it is elemental change ok. So, it may become carcinogenic. It may act as a toxic things and all those things that is why whenever I am going to put a particular material, it is property, should be checked, before you are placing inside a human ok.

So, further purpose, whenever you want to machine particular material, the problem is you should make sure that you are input conditions and you are tool selection should be such a way that, that the work piece should not change. It is elemental properties or it should not experience any heat affected zone recast layer and all those things. So, what I mean to say that bottom line of the story is, it should maintain it's parental form applications of biomaterials.

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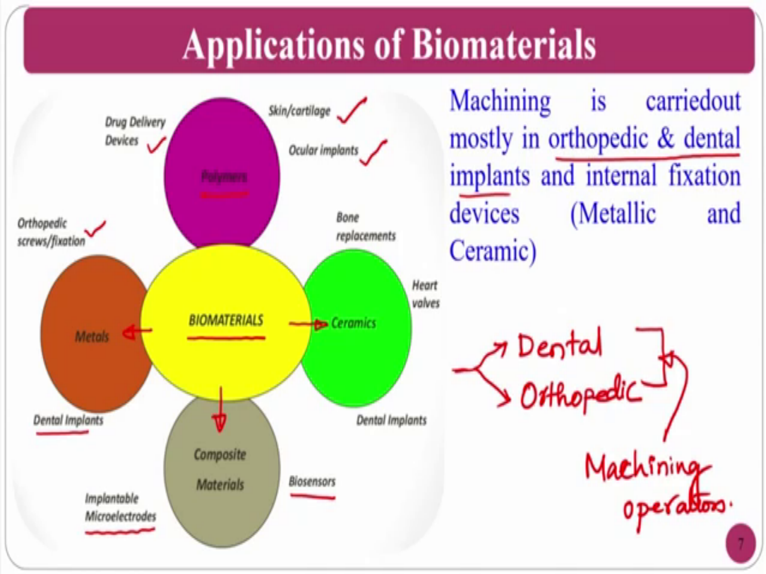

If you see the biomaterials, there are varieties of biomaterials are there. For example, ceramics, you have the heart valves, bone replacement, a dental replacement and all those things, if you see the composite materials, you will have biosensors and implantable microelectrodes.

If you go for the metals, you will have again dental implants and orthopaedic screws and fixations, whenever you go for the polymers; you have a drug delivery devices skin or cartilage and osculate implants and all those things. These are some of applications of biomaterials in different varieties of forms that is ranging from polymers to ceramics ok.

So, machining is carried out mostly in the orthopaedic and dental implants for the internal and external fixation devices ok. So, because the machining normally, as a mechanical engineer, what we do is, we talked mostly about machining of metals ceramics and polymers and all those things.

That is why, in this particular course, we are not dealing with any advanced things, such as a laser beam machining or very complicated shapes finishing or something. We are not going to talk, we are just going to talk about the simple some of the materials or the metals or the ceramics, which are biocompatible and which you can use inside a body for the mostly dental as well as orthopaedic application.

I mean to say, we are going to look machining in terms of dental and orthopaedic ok. These two, we are going to study ok. Since, these two involved mostly the mechanical machining; these two involve mostly machining operations. So, that is why, we deal with these particular biomaterials, which are machinable.

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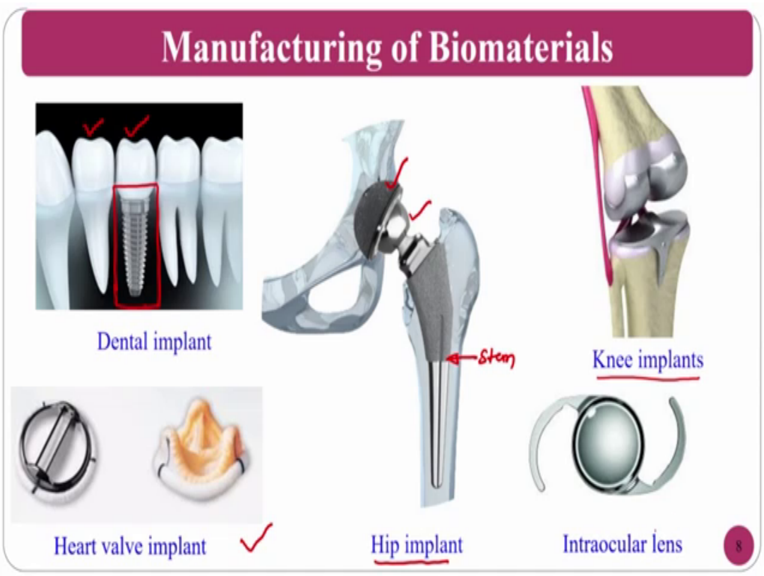

So, if you see the implants, you clearly see normally, the dental things our teeth inside, it will be look like this; So, the similarly, we are also going to develop or the people, who are doing the research will also develop in the similar trend for you, need to fix it. So, the external portion should be same that as the internal thing or whatever, you required to a particular patient, but the internal situation should be like screw that is to be fixed into the jaw.

These are to be fabricated very precisely and it should be biocompatible and all those things.

Similarly, for hip implant, plant also. So, hip implant, you will have acetabular socket. Acetabular head will be there and the stem, hip stem will be there and all those. This is the knee, knee implant, if you see, you have a knee, upper side, lower side and in between, you will get the cartilage are, that is as artificial cartilage and all those things normally, artificial cartilage materials will be developed with ultra-high molecular weight materials and all those things ok.

Apart from the orthopaedics, there are other implants for the heart applications that is heat valves and all those things and intraocular lenses for the eyes and all those things will also be developed, but this involves very less type of conventional machining processes, that is why we are not going to deal with this type of sophisticated implants, just we are going to talk about mostly orthopaedic oriented.

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Machining of Biomaterials

Normal Machining	Biomaterials Machining
1. Medium precision is acceptable	1. Ultra high precision is required.
2. Surface finish is acceptable upto 500 nanometer	2. Surface finish is acceptable upto 50 nanometer
3. Product surface textures doesn't have much significance	3. Product surface textures helps in cell growth and bioactivity
4. Generally high feed & high depth of cut machining.	4. Low feed and low depth of cut

Now, we have to see what is the difference between normal; that is the conventional machining and machining of a particular material; Normal machining, I mean to say machining of common materials like mild steel and all those things even though component is medium precision, you can accept, but in terms of bio, you need not to take any tolerances, because I mean to say exact, I cannot say 100 percent, but the only thing is that you should go for high precise components, in micron gap also plays a major role.

Surface finish is acceptable up to 500 manometers, but here the surface requirements are too high that is 50 manometers that is why the cost of bio implants normally, goes up. The product surface structure does not have much significance, but here surface texture plays a major role, if it is a hydrophobic surface, if it is a hydrophilic surface, it plays a major role.

Normally, you have seen a dental crone in the previous slide; you need to have the hydrophilic surface, because it should interact with the osteoblast cells or the nearby cells. So, so that, what will happen? Protein exchange will takes place. At the same time, the cell will easily occupy the space and it will tight your particular teeth, that is placed inside, if it is a hydrophobic then what will happen? The cell culture on that, one may not be the, because it is the, phobicity will be there.

Generally, high feed and high depth of cut will be given so, but here low feed and low depth of cut will be given, because you require very great precise components. That is why, you always go for the better surface finish. Normally, better surface finish, you will get with respect to low feed rate and all those things, if you are going to use more depth of cut, what will happen? Temperature generation will be slightly higher, because your material removal per unit time will be very high, that is why the temperature may damage the work product ok. So, the workpiece should not damage for that purpose. You should always play with low depth of cut and low fluid rate.

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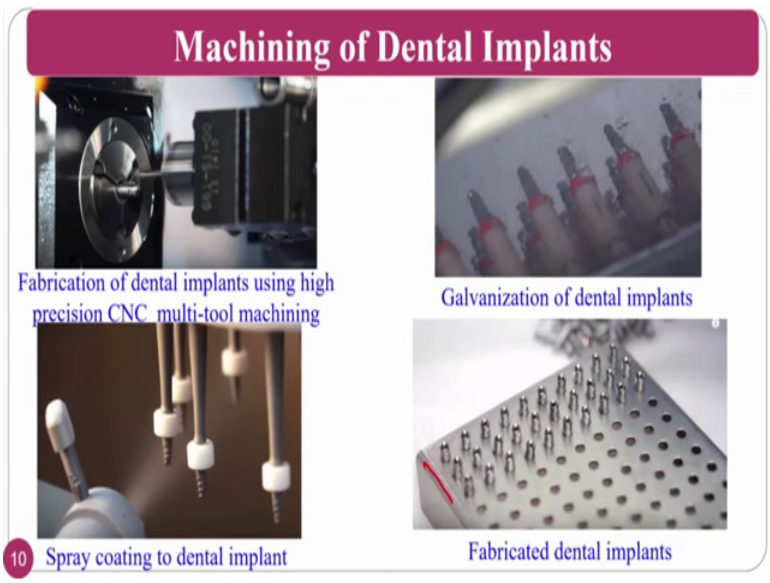

So, machining of dental implant; the procedure goes like this. First, you just fix the dental implant material. Normally, this will be done on the titanium, then using a CNC multi-tool machining process; just you do the turning operation. Normally, patterning operation and all those things, then you generate the threads as per your requirement, then you can do the post processing like coating and all those things also.

So, then you can do the galvanising of the dental implants followed by the spray coatings of the dental implant, because whenever you want to coat the biomaterial then it will be good for you, because you are cells, which are there nearby compatible to the biomaterials, then you are dental implants are ready. So, you can see how the dental implants are ready here, for the deployment in to a human machining of knee implant.

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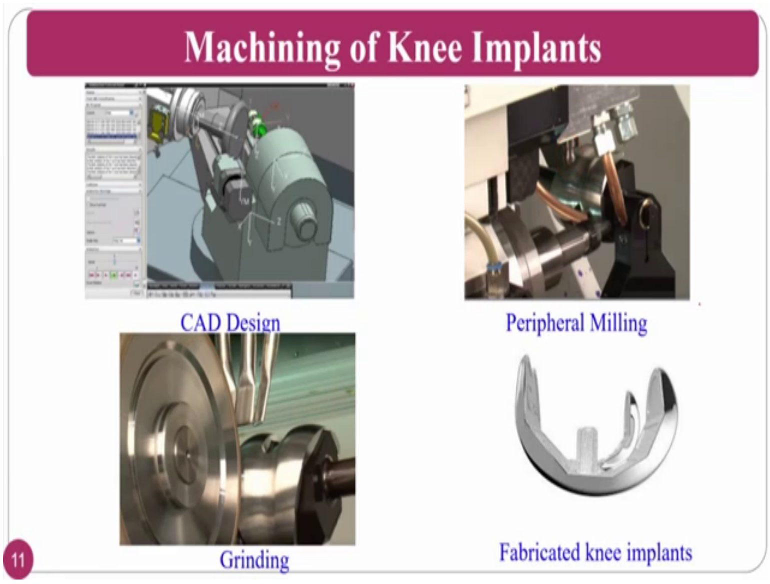

If the first procedure will be goes like this. First, you have to design, a CAD design model then, you go for the machining operation, you can see here, the peripheral building is done at the same time. You can clearly see here, it is ball; end type of milling is done. So, that the surface finish will be better, then you can go for the grinding operation and you can see the final product, how it can be fabricated?

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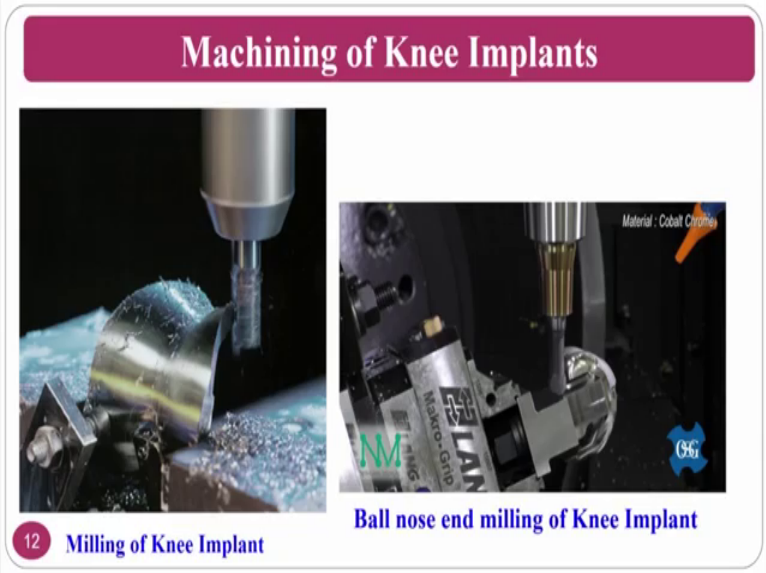

So, milling before what you have seen, the peripheral milling like, ball and all those things. Normally, this implant will be machined like this, then it will be do the peripheral milling operation with the ball end and all those things, or you can directly go for the finishing. There are some technologies like ball end magneto rheological finishing processes, people who are interested in the advanced finishing processes, they can go through this one.

So, there you can use instead of peripheral milling process directly, you could go for the polishing, using a ball end magneto rheological finishing process, which is developed by IIT Delhi professor, professor Sunil Jha. So, you can see the process and if it is suitable to you, you can do your research for the nano finishing of bio implants and all those things.

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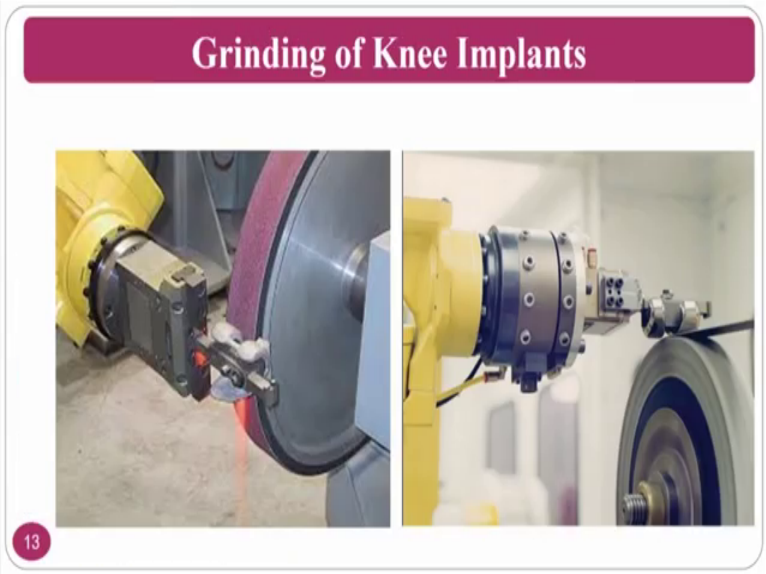

So, at the same time, if you want to fabricate, the component are the knee implant at the minimum price. You can go for the belt grinding or buffing operations also ok. So, advanced finishing processes like what I said MRF or magnetorheological finishing or ball end magnetorheological finishing, this type of processes assume that these are going to be costly for you, then you can design your own belt grinding process and all those things like, what is given here.

You can go for this type of processor also; that means, you are going to do the machining process, then you are going to do the profiling, then you do the finishing operation to make a knee implant.

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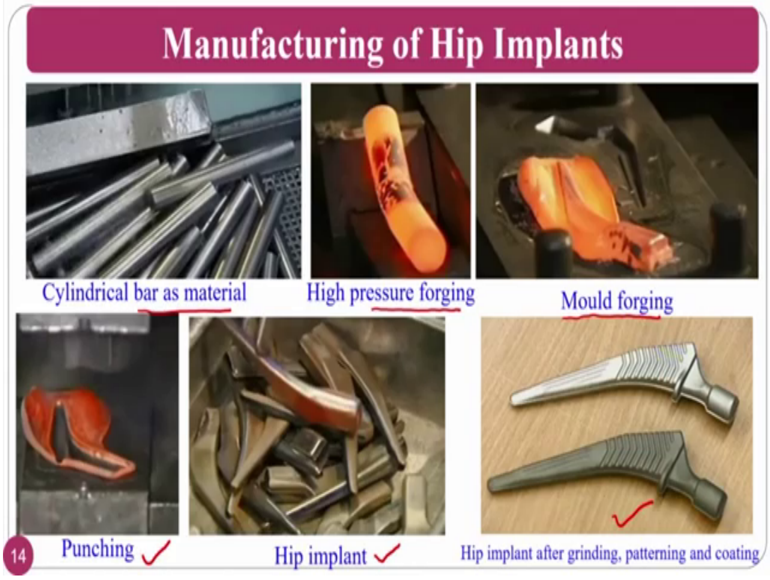

If you want to do the hip implant basically, if you see the hip implants first, cylindrical bars as a materials, you can take, then high pressure forging will be done for the giving shape, then mould forging will be done. That is the, whatever the shape of the mould, that you can generate, then will be the forging operation, then you can do the punching to an extract that component.

So, that you will get a hip implant then you can go for the grinding operation or patterning then followed by the coating operation and all those things, you can do on a hip implant, so that you can sell your product.

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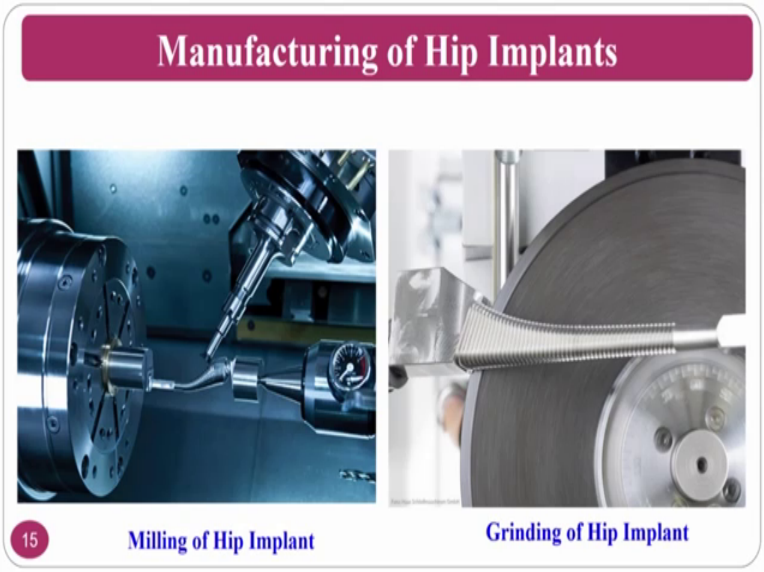

Hip implant also can be manufactured by the machining process, the whatever you have seen in the previous one is a forming process here. You can also do this particular, hip implant by the machining process. You can see here, the profile milling is taking care by the machining operation, followed by. You can also do the grinding operation; you can see the grinding wheel, which is very thin. Grinding wheels are used to generate the some profiles on the hip implants.

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So, now we have seen about in the previous slide. We have seen about the stem of a hip implant. Now, we need to see how the acetabular socket is fabricated. Acetabular socket can be done by the machining operation first, then followed by the finishing operation. Finishing operation is done here and the machining operation done here and you can see clearly, how the machining is taking place.

How the chips are coming out of this particular material. Normally, this type of materials are fabricated from the ceramic materials or you can also fabricate from titanium based alloys. This is about the acetabular socket or acetabular cup machining using the conventional processes ok.

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At the same time, laboratory people are talking about the 3D printing. So, instead of going for the top-down approach, you can go for the bottom-up approach also, whatever you have seen in the previous slides, those are all, are the top-down approach. You just make a particular component similar to the, you make a raw shape then, you just do the machining operation to your required shape. That is the, one is a top-down approach, but material waste will be always there, that is why people nowadays, are working on the bottom-up approach that is called the 3 D printing.

You can see the selective laser sintering that is manufactured skulls. At the same time, you can also see a skull plate, you just draw the 3 D CAD model, then you just put into a 3 D printer. It will print and give you. You can also do the knee implant, not only by the top-down approach that is milling grinding then followed by the polishing and all those things, you can do by the 3 D printing, but only thing that you have to see 3 D printing, do not give you a very-very good surface in that circumstances.

You need to go again for the micro-machining applications and polishing applications also. That is why people nowadays are working on the surface roughness on in the 3 D components or the 3 D metallic as well as ceramic component. That is why it here also conventional machining or the slightly advanced machining, that is called the micro-milling and all those things, micro machining process play a major role, even though you have, you are developing a three components.

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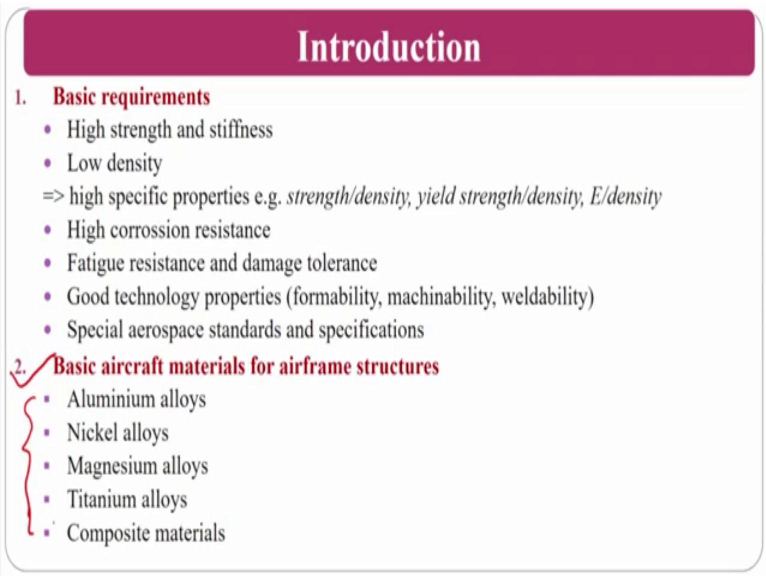

Now, we move on to the machining of aerospace materials. So, aerospace materials; the basic requirements goes like many things and the basic aircraft materials here from structures and all those things. Normally, these are the materials that are used in this one, a properties of the superalloys.

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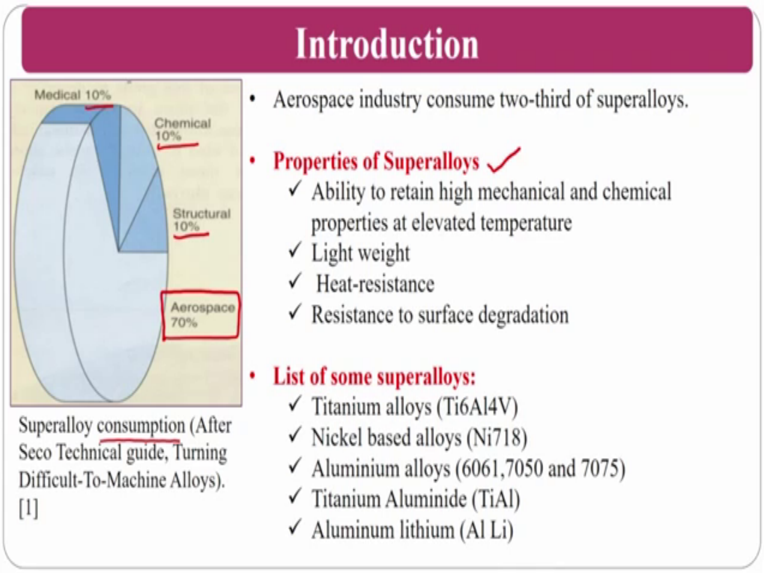

Mostly, super alloys are used in the aerospace applications, if you see super alloys consumption in the market, the structural application is 10 percent, chemical industry 10 percent, medical industry 10 percent, but aerospace industry is 70 percent. That is why super alloys like, nickel based alloys and all those things are play a major role in the aerospace industry. That is why we see how to machining the super alloys? What are the problems and we also see the other materials also.

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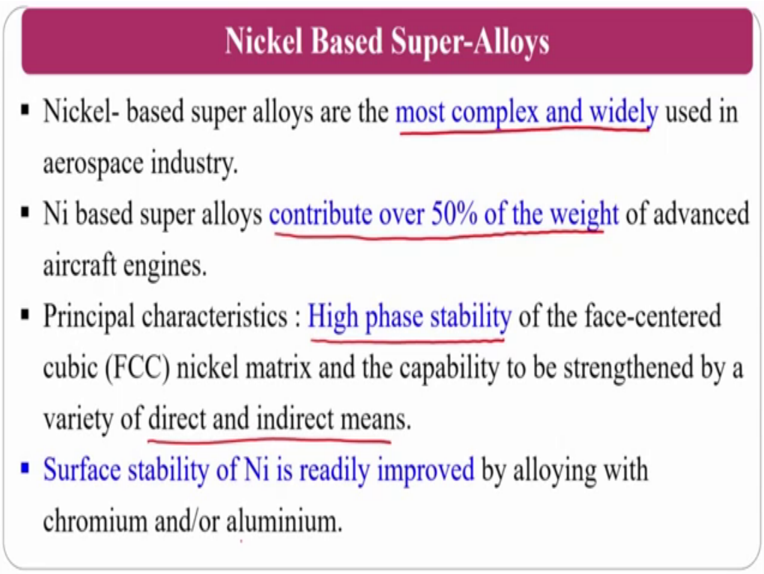

Nickel based super alloys, nickel based super alloys are the most complex and widely used in the aerospace industry and nickel based super alloys contribute over 50 percent of the weight of the advanced aircraft engines. Especially, these materials are used in the aircraft engines basically.

So, principal characteristics, it is high phase stability and of the face centred cubic nickel matrix and capability of the strengthening by variety of direct and indirect means and the surface stability of nickel is readily improved by the alloying with the chromium or aluminium. That is why; you can improve the properties as per your requirement.

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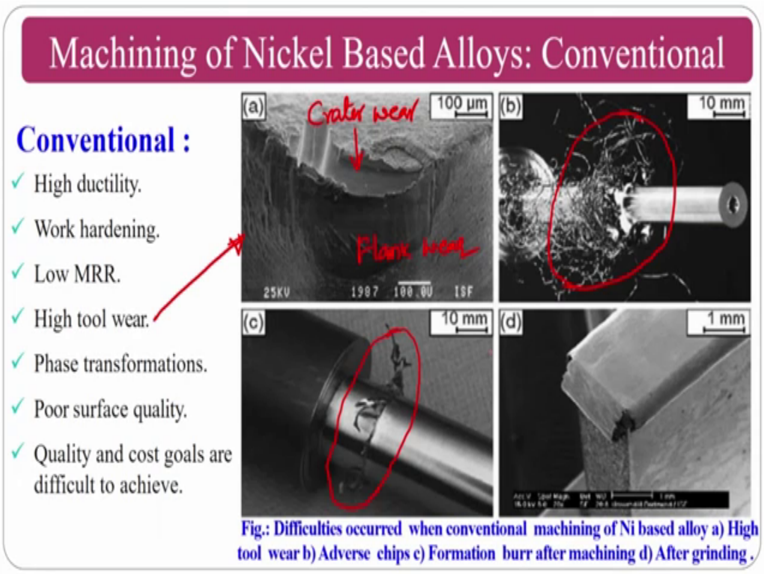

The machining of the nickel based alloys conventionally. So, high ductility work hardening low material, removal rate high tool wear. Basically, it is a super alloy material in that circumstances, the tool wear will be very high, the phase transformations will takes place quality that you are going to get on the surface is very poor and the cost goals are difficult to achieve quality and all those things ok.

If you see particular thing, that is what I was talking about, the tool wear and all those things, if you see here tool wear. So, this is the tool wear that is observed on the cutting tool. So, the crater wear also, you can see here and you can see also flank wear.

So, at the same time you can also see the basic problem is adverse chip formation here, itself. The chips are entangled in the machining region itself ok. So, this is one of the adverse effect, at the same time formation of burrs. So, whenever I am doing the machining operation, the burrs is nothing, but the pieces bits and pieces that are not dismantled from the work piece. You can also see these problems will hamper the final product that is, why you need to machine very precisely, very efficiently?

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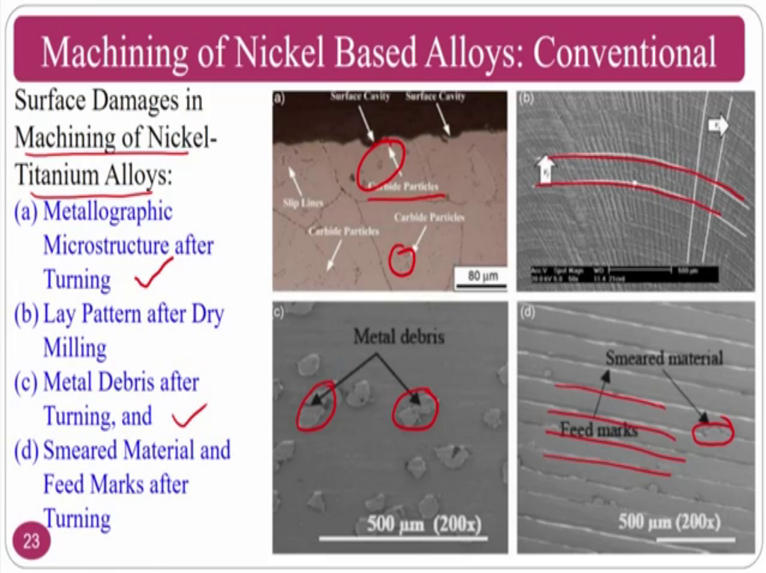

Here, you can see the conventional machining. The basically problem is the surface damage in machining of nickel titanium alloys; metallographic microstructure after the turning operation, you can see the carbide particles are there and all those things; that means, that whenever you do machining with a carbide base cutting tool, there is will be a diffusion taking place on to the surface; that means, the tool material higher concentration to the lower concentration. That is the workpiece material is transferred. That is why, carbide particles are seen here.

So, lay pattern after the dry milling, the predominant direction or surface roughness is clearly observed at the same time metal debris, after the turning operation how the metal debrises are still there on the surface smeared material and feed box. The smeared material is here, at the same time, these are the feed marks that are observed during the billing of these super alloys.

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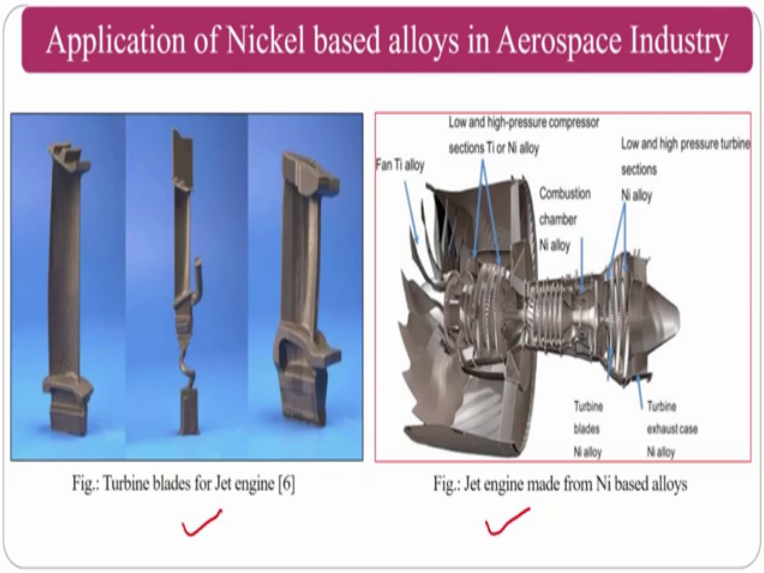

Applications I said that this is the mostly important material for the aerospace engine. This is a engine and this is the turbine blades that are made and this is the engine. You can see 50 percent on the literature. It is evident that the more than 50 percent are approximately, 50 percent will be used in the aerospace engines or the other material, which is mostly used in aerospace industry, is the titanium and the titanium based alloys.

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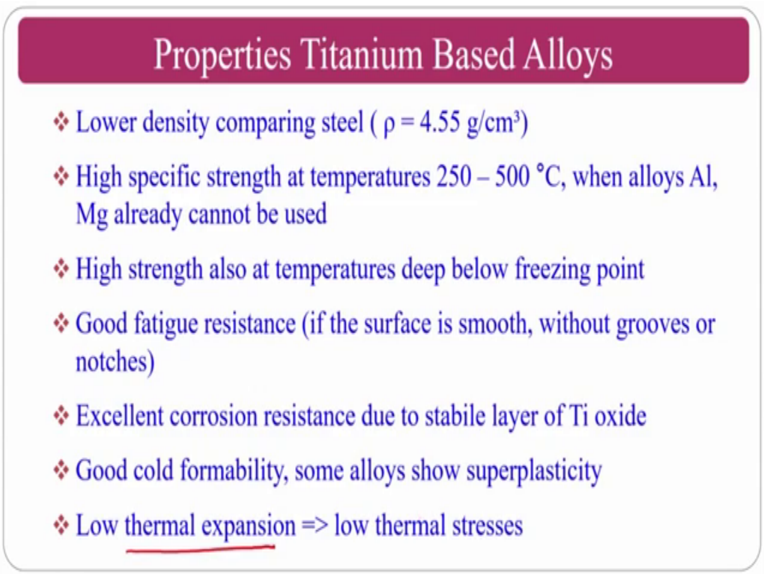

The properties it will have a lower density, comparing to steel high specific strength at elevated temperatures, also high strength at temperatures below the freezing temperature also good static resistance, excellent corrosion resistance, due to stability of the Ti oxide layer. Good cold formability of this particular material and low thermal coefficient of expansion, these are an lower thermal stresses also. These are the beautiful properties that one can see in the titanium based alloys.

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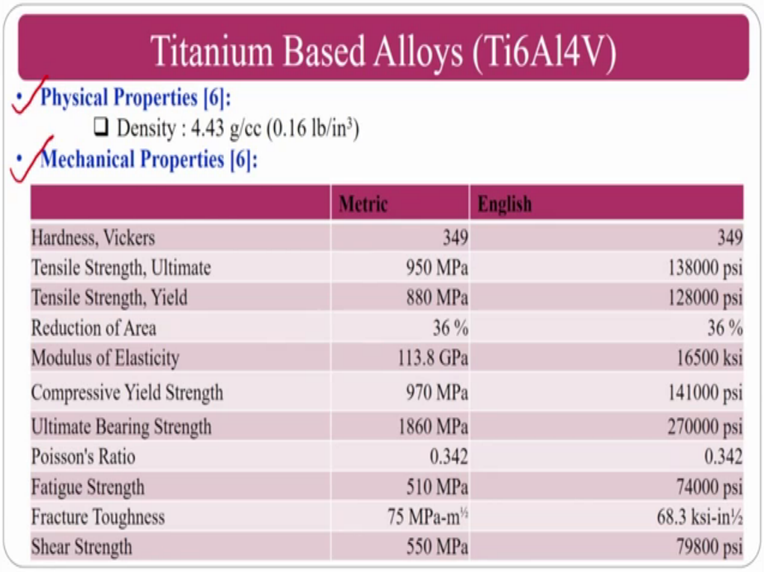
Titanium Based Alloys (Ti6Al4V)

- Physical Properties [6]:
  - Density : 4.43 g/cc (0.16 lb/in^3)
- Mechanical Properties [6]:

	Metric	English
Hardness, Vickers	349	349
Tensile Strength, Ultimate	950 MPa	138000 psi
Tensile Strength, Yield	880 MPa	128000 psi
Reduction of Area	36 %	36 %
Modulus of Elasticity	113.8 GPa	16500 ksi
Compressive Yield Strength	970 MPa	141000 psi
Ultimate Bearing Strength	1860 MPa	270000 psi
Poisson's Ratio	0.342	0.342
Fatigue Strength	510 MPa	74000 psi
Fracture Toughness	75 MPa-m$^{1/2}$	68.3 ksi-in$^{1/2}$
Shear Strength	550 MPa	79800 psi

These are the physical properties as well as the mechanical properties of the titanium based alloys. You can go through the table for your convenience, what are the various values like hardens tensile strength modulus of elasticity and all those things.

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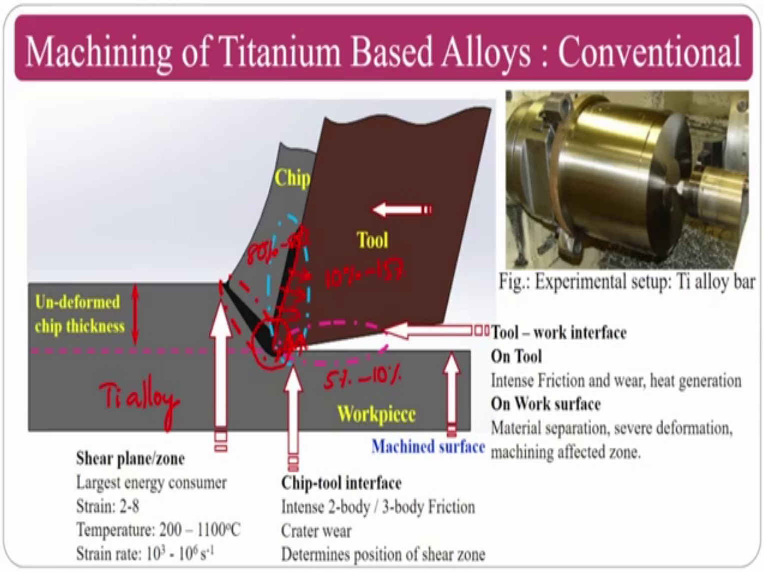

If we see the machining process, it is looks like a ductile and material, because it is a soft material. Even though it is a super alloy type of material, but it, it is a basically a ductile material. That is why, you always see a thick zone ok. You people have studied already thin zone models and thick zone models. If the shear plane is like a line, it is thin zone model.

But here, if you see a black thing, this is an area that is occupied, that is nothing, but it is a thick zone is forming here and between the thick zone is formed between the undeformed thickness to the chip thickness. So, chip tool interface, the basic problem in machining the titanium is, it cannot conduct the temperature assume that a here 100 percent temperature is generated in this particular region. The 80 percent is carried by chip and 10 to 15 percent will be carried out tool and 5 percent will be carried by this one ok. In that case what will happen? 5 to 10 percent assume ok.

In this case what will happen? The tool is the only body where, it will absorb the temperature, because the, if it is a titanium alloy workpiece is a titanium alloy, it cannot dissipate the heat, to whatever the heat that is generated, stay on this particular portions only. So, that it will import into the tool. So, the thermal softening of the tool will takes place very fast and the tool will fail, that is the basic drawback of this particular material.

The titanium-based turbine blades also will be used, because this adverse effect, whatever I said, the temperature will stay on the surface itself, if you talk in terms of turbine blades, what will happen? Whenever; the flight takes off to the higher altitudes, what the temperature. Normally, it will be minus degrees, the whatever the heat is generated on the surface will be cooled by the way that is coming ok.

What is the advantage that you are going to get here is the, it cannot dissipate the temperature inside ok; that means, that whatever, because of the rotational speed, if there is any temperature generated on the surface, it will be cooled by incoming air ok. The adverse effect in the machining is a good property for aerospace turbine blades development and all those things.

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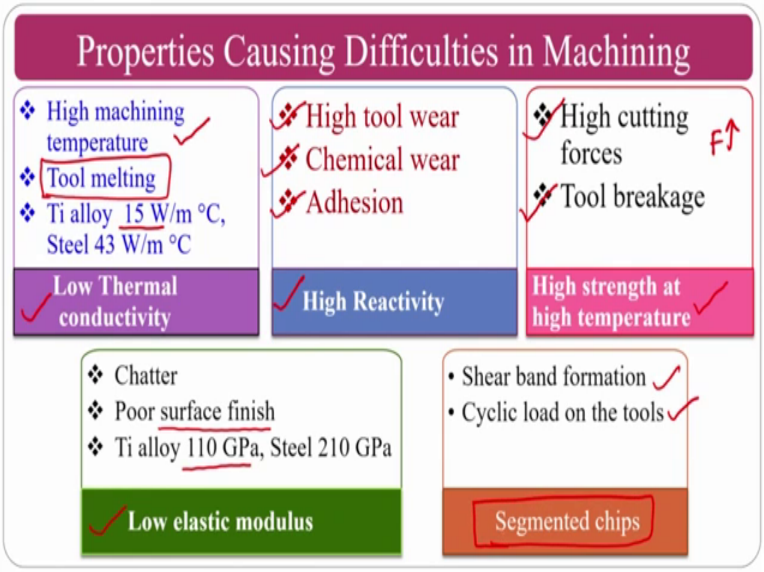

So, properties causing the difficulty in machining the first property; is as I said lower thermal conductivity; If the thermal conductivity of this particular material is 15 and high machining temperature during the machining process. If the temperature is very high, it cannot conduct the temperature inside the workpiece material. So, it will impart to the tool. So, the thermal softening of the tool takes place and tool melting will takes place thermal and tool will fail.

Another one is high reactivity. So, if it is high reactivity, what will happen? The tool wear will be very high, at the same time chemical wear; that means, that it will chemically affect with respect to the temperature gases and all those things and at the same time it also will have high adhesion effects.

So, high strength at high temperatures; that means, that whenever, you are doing the machining operation the temperature goes up, if the temperature goes up, still it maintains it strength, then it is very difficult for the cutting tool to do the machining operation, in that circumstances you will experience high forces, because the strength of that particular material even though you are at elevated, temperatures is very high. So, the forces experience will also will be high and the tool breakage will occur as early as possible.

So, now no elastics modulus, because of this normally chattering will takes place. Poor surface finish will come and at all Ti alloys normally, will have 110 GPA compared to steels the segmented chips. The type of chips that the operator is going to experience during the machining of this titanium alloys is shear band formation. Cyclic load of the tool and most importantly, you are going to get the segment type of chips, we will see what are the segment type of chips and all those things.

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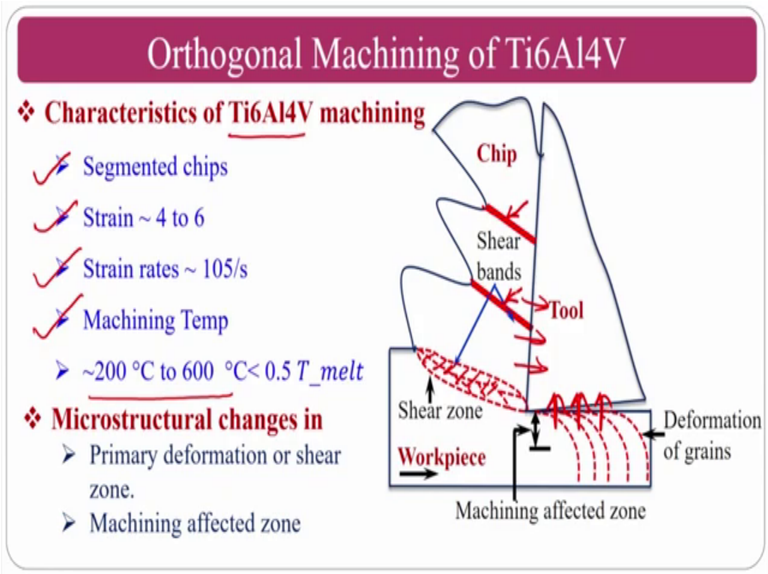

So, the characteristics of Ti 6 Al 4 V, this is the one of the common material that aerospace industry uses. So, segmented chips, you are going to get strains, are approximately 4 to 6 strain rates are 1 naught 5 for second, the machining temperature will be very high, that is 200 to 600 degrees and you can see here, the primary deformation zone and the machining effected zone.

Basically, the primary shearing zone, this is and the machining affected zone, the lot of temperature that is generated here will be important to the tool ok. That is why tool will experience a lot of temperature, that is the drawback and the tool thermally softens and fails at the same time. You can clearly observe, this is the shear bands ok. These are the shear bands; that means, that you are going to get a segmented chips ok.

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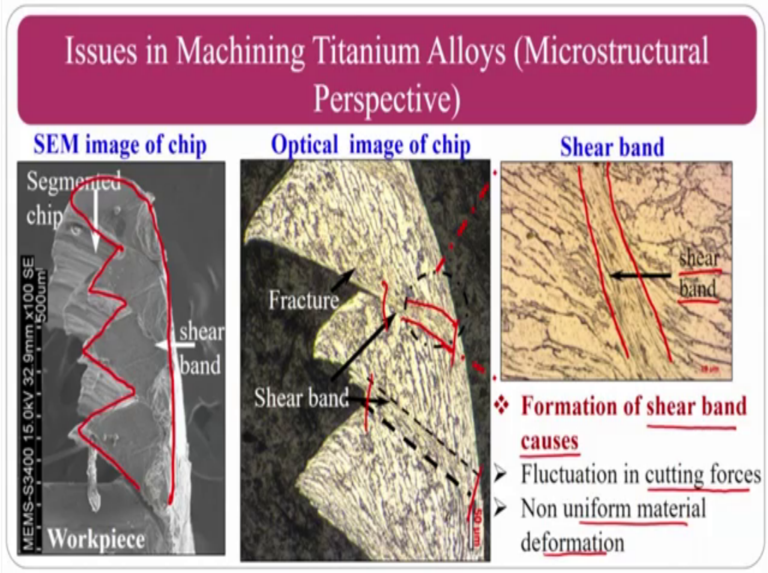

The proof for this one, you can clearly see the shear bands here. So, the segments are clearly formed here and this is a continuous one. One side; it is a continuous one, on other side; it is a discontinuous one. So, it is a segmented chips ok. At the same time, you can also see the microstructure at this particular portion that is shear bands, that are formed here. You can see here, if you, in this picture itself, you can see here the shear bands formation, in this particular portion. So, how the shear bands are formed?

Formation of shear band causes two things; one is the fluctuation in cutting forces, non uniform material distribution and all those things. So, in the segmented chips, assume that you have this much segment. In other case, this much big segment, in this one, there will be a form. There will be a disturbance in the segmental width in that circumstances, the basic problem, you will face is the fluctuation of the forces; you can see the tool wear.

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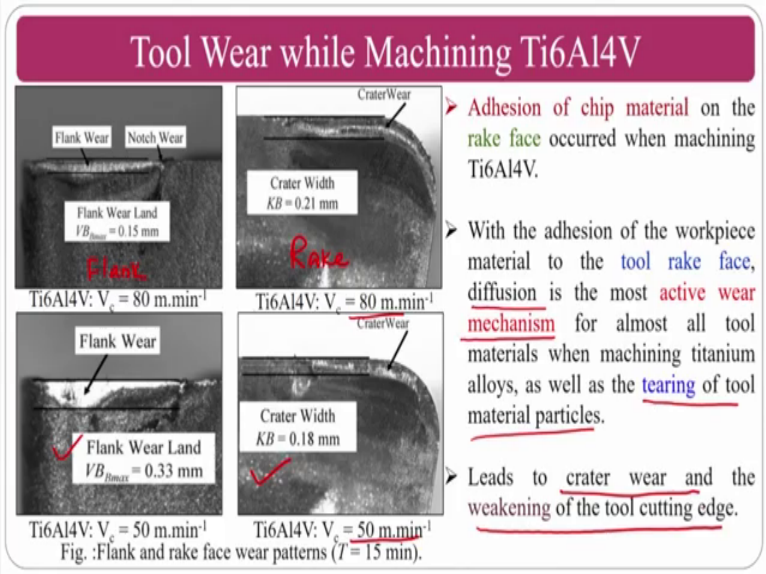

Whenever you do the machining operation here, you can see, here the flank wear and you can see here, the crater wear on the rake surface. This is the rake surface, this is the flank surface, at the same time you can see here with the different input conditions, this is the flank wear. Again this is the crater wear. Again, but compared to the previous, it is less; because you are cutting velocity is less ok. Cutting velocity, you have to take at the most important culprit that causes the temperature in the machining region or the heat in the machining region is cutting speed ok.

Here, the cuttings speed 80 metres per minute. Here, the 50 metres per minute, that is why as the velocity cutting, velocity is decreasing. What will happen? You are crater wear as well as flank wear will reduce. The adhesion of the chip material on the rake surface is occurred that is the one of the thing, if you are going to increase higher speeds with the adhesion of the workpiece material to the rake surface. Diffusion is the most active wear mechanism. Normally, you have seen in the previous lectures also, whenever the tool wear, mechanisms are explained.

There are three mechanisms; one is adhesion, abrasion and diffusion. In this particular case, the diffusion is the most one, what, what do you mean by diffusion? Diffusion is nothing, but transfer of material from higher concentration to the lower concentration. That is nothing, but the tool particles move from the tool to the workpiece or chip.

So, when this one alloys as well as tearing of the tool material particles will takes, that is what I was telling that the transfer of higher concentration tool particles to the lower concentration. That is called the workpiece ok. Tool particles gradually moved from tool surface to the workpiece surface. That is nothing, but the diffusion this leads to the crater wear and the weakening of the cutting tool will takes place ok. So, whenever the chip is going to take gradually the particles of the rake surface; that means, that the cutting tool particles, what will happen at certain point of time, the tool will become weaker.

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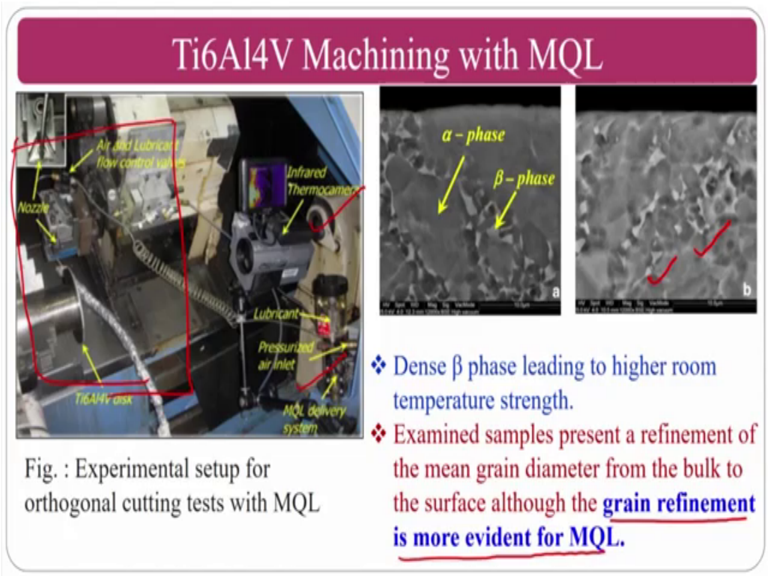

This is the machining setup. To avoid up to certain extent, people have used here minimum quantity lubrication or the minimum quantity cuttings fluid, if this is the machining zone, where the machining zone is taking place and you can see the infrared camera is focused. Lubricant pressurized is also given and all those things and dense beta phase, alpha phase, all you can see here, but the thing what the people experience are reported in this.

One is grains refinement, that is, is more evident in the MQL, compared to the normal try and normal cutting fluid application. In that application, you can find the grain refinement, in a better way, whenever you are using a minimum quantity cutting fluid, you can also reduce the tool wear and you can get the good surface finish. Also whenever you use minimum quantity lubrication that is why, this particular minimum quantity lubrication is considered to be the sustainable process at current times.

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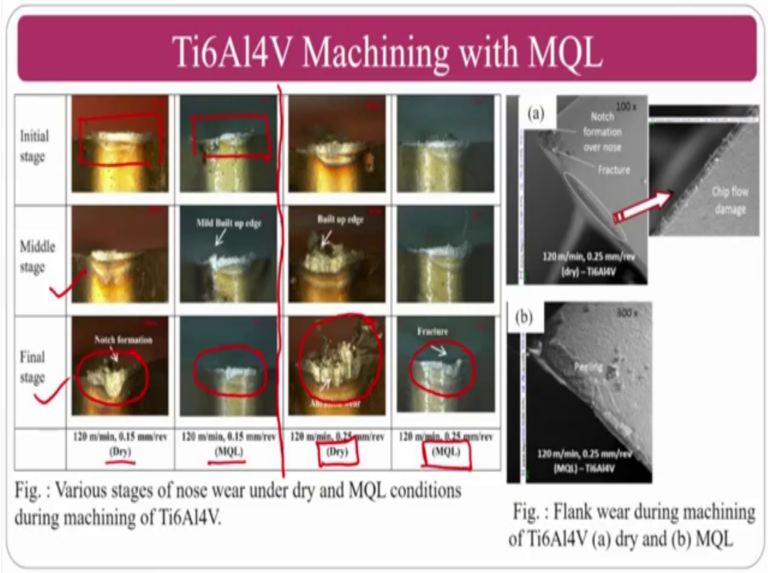

I always mention sometimes, the book about current trends, because if you may see these particular videos after 10 years or 15 years, the technologies may be varied or this particular process may not be still called as a sustainable source. That is why I always tell that currently, it is a sustainable one, if you see the initial stage normally, with respect to the dry with respect to MQL; I can drop a line like this.

So, the dry one, you can see here, at the same time with MQL, you can see very less. Similarly, middle stage and the final stage; you can see the final stage, how drastically the way taking place, because of the dry machining and you can see how much reduction is there using MQL ok. That is why particular process is much safer and you can even see here in the second stage, where you can with respect to dry and with respect to minimum quantity lubrication. This is the beauty about this particular process and those people, who want to work in this one, you can work.

That is the minimum quantity lubrication along with the sophisticated cutting tools, the machining of super alloys, for the aerospace applications is one of the title. You can give to your master, students or PhD students are, if you are a student then you can take up this as your research, but only thing is that do the proper literature survey. What is done. Keep your literature survey on your fingertips. So, it will be easy to find out the objectives. These are the applications; you can make the titanium aircraft parts and all those things.

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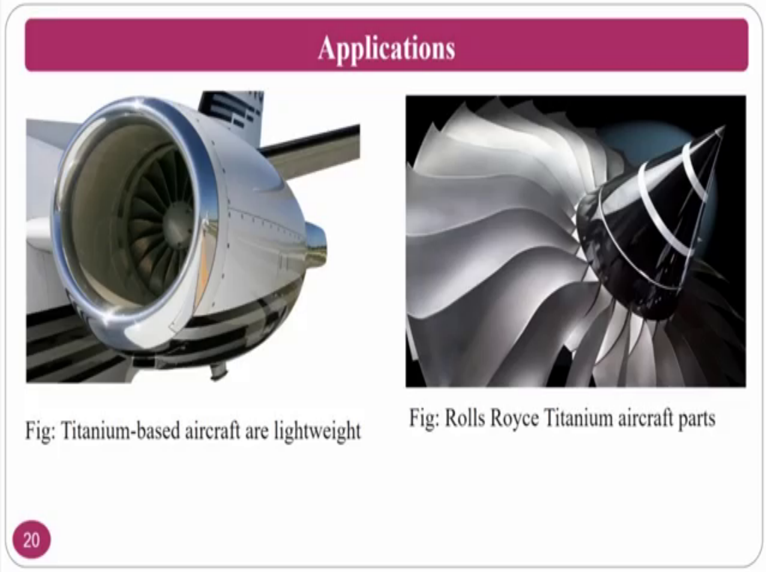

Now, we move on to the machining of smart materials basically or very sophisticated materials and most of the smart materials are done by the advanced machining processes only ok. So, very little chances are there, for the conventional machining processes. That is what we will discuss.

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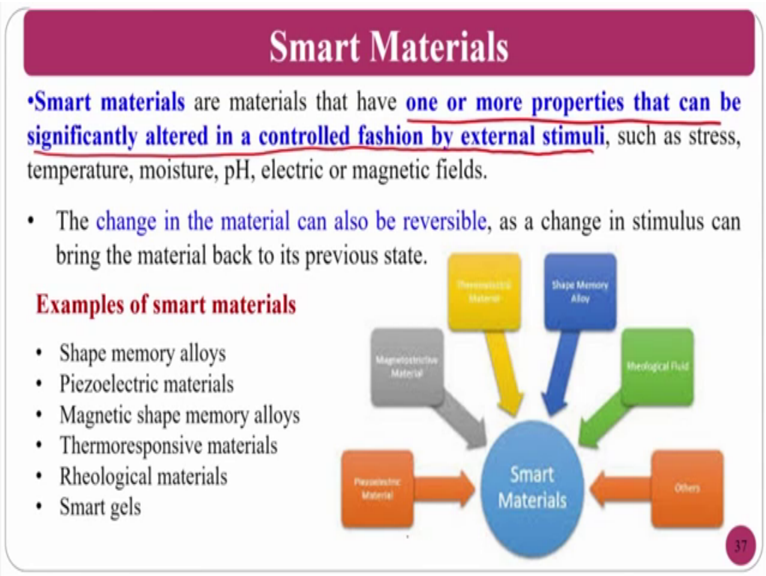

Here the smart materials are the materials that have one or more properties, that can be significantly altered in a controlled fashion by external stimuli that is, whenever you give certain external stimulus like temperature and all those things, it will change it's major properties ok. Change in material can also be reversible. It can go martensite to austenitic phase, austenitic to martensite phase, whenever.

If you, if somebody wants to study about what is smart material and all those things, you can go through some of the videos or some of the books, you can refer it. The examples normally shape memory, piezoelectric magnetic mid shape memory, many materials are there at the, say and you can also see here same thing the machining difficulties during machining of the smart materials ok.

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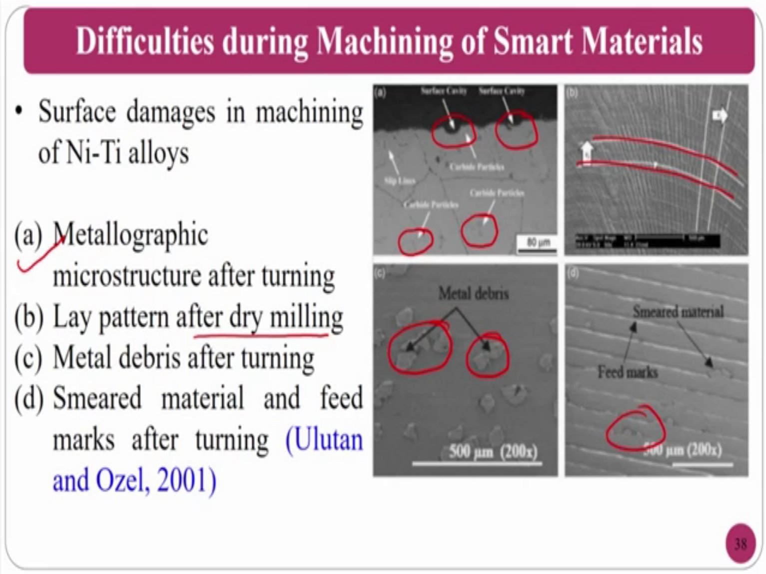

So, metallographic microstructure, after the one you can see here, wherever the surface cavities are formed and all those things and the carbide particles also stays here ok. Whenever people are using here, nickel titanium alloys are more one of the common examples for the smart materials.

These are the materials that will be used for stent applications and all those things not only stent applications, you can use for many-many applications, whenever the nickel titanium alloys, that is called nitinol or machine conventionally using the carbide tools. You can see, there is a diffusion of the carbide. Particles will take place into the workpiece that is diffusion is taking place here ok.

Lay pattern after the dry milling. You can see the lay patterns that is the surface roughness and even metal debrises are also, you can see in which, at the same time smeared material. Also you can see in this particular workpiece material as I said, there is not much scope in terms of shape memory materials, there is very-very minute area is there, because the feature that you are going to generate on shape memory materials, assume that I want to generate some features on stents, stent itself is very small in that, because it has to go into the artery of the human.

So, artery diameter is approximately 2 mm or something. So, the diameter of that one will be less than 2 mm. This, conventional machining process are less preferred for the smart material. That is why, we do not have much things, but you can do the some of the milling operations and you can generate some of the features on it

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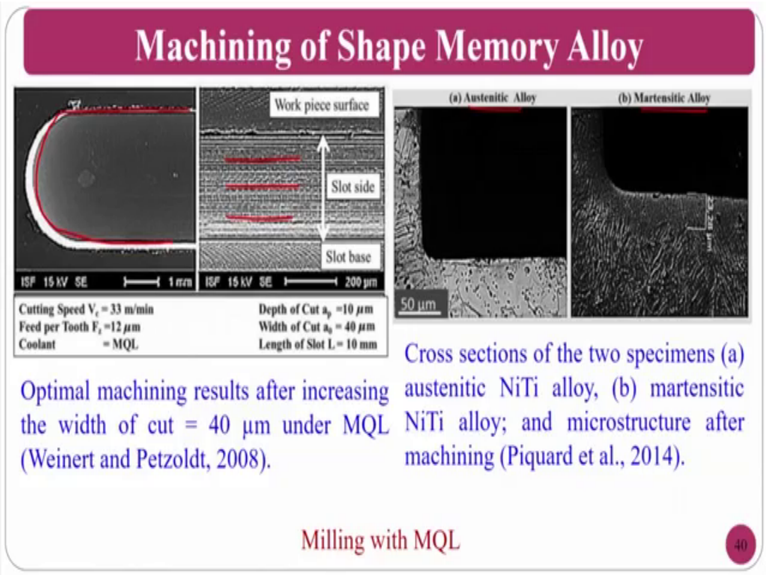

And now, you can see how the slot generation, how the surface finish is there and you can cut on austenitic steel and martensite steel and you can observe milling with minimum quantity cutting fluid, also you can do; So, that the metallurgical changes will be very less. If the metallurgical changes is there, what will happen? Whatever the phase change, you have to do or you are expecting may not be 100 percent.

Now, we move on to the electronics materials, machining of electronic materials, the electronic materials like silicon material. I am going to talk about most, which is a brittle material. Since, till now, we have seen the ductile materials and the high strength materials, super alloys and all those things. That is why; we are missing the brittle material. That is why in this particular electronic materials, I am going to talk about the brittle materials.

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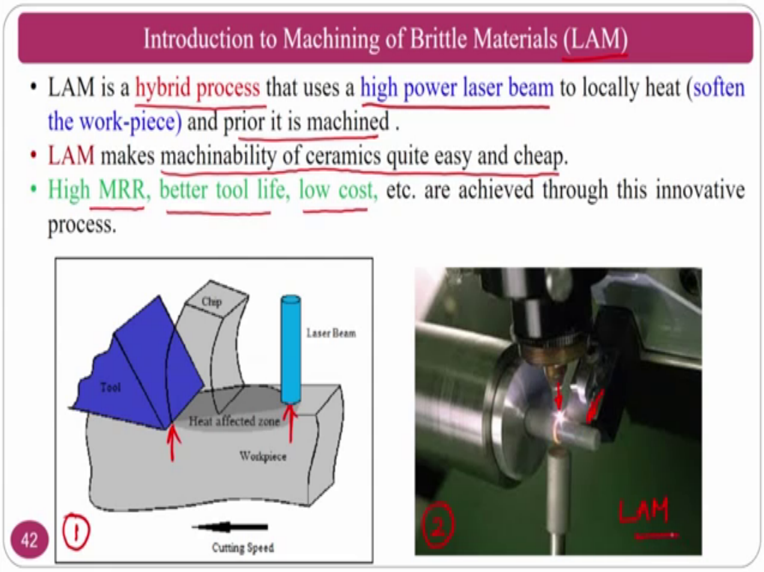

Basically if I want to do the machining of brittle material assume that I have a class, I want to do the machining using the milling operation in that circumstances. How can I do? Basically, the problem comes is, if the interaction forces between tool and workpiece is very high. It will break into pieces for that purpose, one has to do the alternative that is hybrid machine that is called here, what is proposed, is laser assisted machining process. That is called, where you are applying a laser ahead of. You are cutting tool; this is the laser ahead of your cutting tool. So, that you are making the softening of your workpiece, then doing the machining operation ok.

So, laser assisted machining is a hybrid process that uses the high powered laser beam, locally to soft, the workpiece prior to the machine ok. Laser assisted machining makes the machinability of ceramics quite easy and cheap ok, because, otherwise the component itself will fail, because of the laser softening. MRR will be higher, better to life, no cost and all these things one can achieve.

You can see here in the second picture 2. This is picture one or the figure 1 and figure 2, this is the machining operation is taking place from this direction. Laser is falling from this direction and the laser assisted machining is taking place ok.

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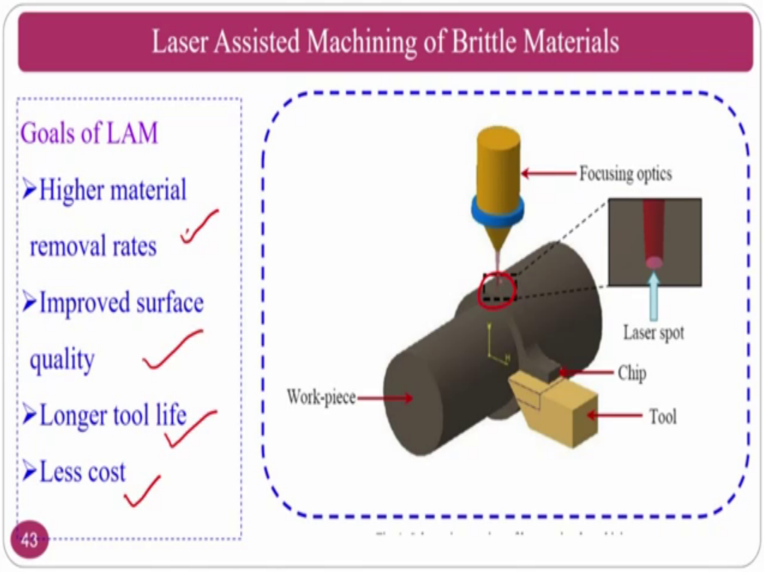

The schematic view, if you see here, the laser is falling here, this is our own picture, we have drawn especially for you. So, laser is falling here and ahead of the turning position. This particular portion is softened and, and then you are removing the material in that circumstances, the cutting tool experiences low forces. So, it can easily remove the material, that is high material removal rates improve, the surface quality tool life will improve and the less cost ok.

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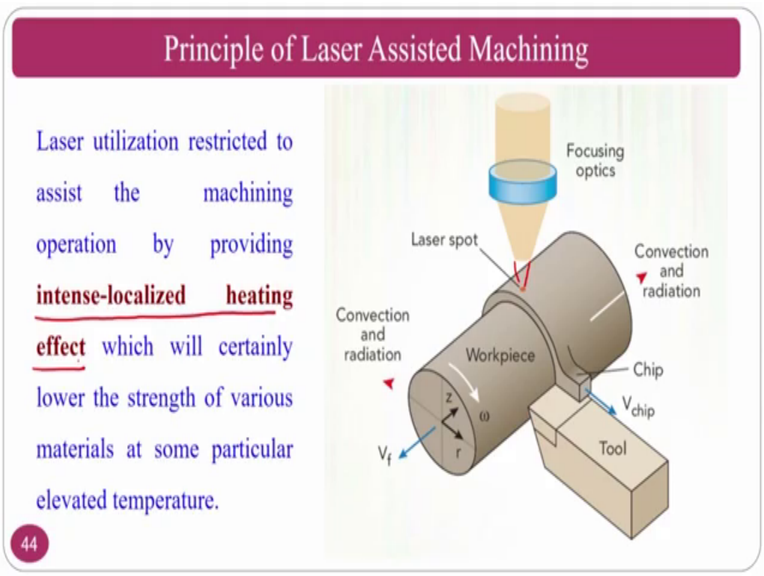

So, you can even see how the spot is generated here in this picture, the principle as you see in the previous picture also or the previous slide also, the laser utilization is restricted to assist the machining process. Why this is called laser assisted? Machining is laser, is not here to the machining operation.

Normally, you people may have done laser machining that is called, you are doing the ablation by the laser here, you are not doing, you are using very low power. So, that it will soft locally, then the cutting tool will do the remaining work that is providing the intense localised heating effect only; that means, that it is going to heat the workpiece. So, that the brittle nature of the brittle material will become a ductile material, then one can do the metal cutting operation.

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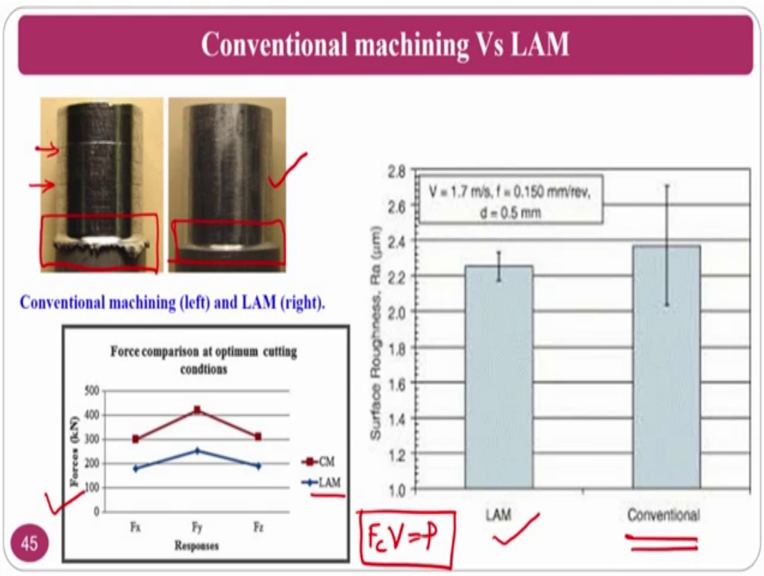

You can see here the forces or the surfaces. Normally, here you can see how the burs are formed; no burs are formed at the same time. Good surface finish is achieved, compared to this one; you have a line here, line here and all those things; that means, that surface quality in laser assisting machining is much better, whenever you are doing the machining operation for the brittle materials or very hard materials and all those things.

If you see the forces, normally forces here is less compared to the normal conventional machining process, that is why the forces, if the go down, the power requirement will go down. You all know Fc into V is nothing, but the power requirement. So, if the power forces are less; that means, that power requirement will be less. At the same time you can see the surface roughness also laser assisted machining process, you got the lower surface roughness; that means, that your surface finish is better compared to your conventional finishing process.

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Conventional machining Vs LAM

Cutting Speed	Conventional: Volume of Material Removed (cm^3)	LAM: Volume of Material Removed (cm^3)
50 m/min	6.48	15.26
100 m/min	7.00	15.38
150 m/min	$\boxed{12.08}$	$\boxed{21.13}$
200m/min	11.45	19.2

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These are the main things that one can see for the cutting speed 50150 and 200, the conventional. What is the volume of material removal, maximum is this much, but if you see here, the maximum here is 19.2, at, at the same time, if you see 150 here, slightly higher; that means, that the maximum amount that one can observe, in this particular process is 12.

Wherein, the laser assisted machining the volume of material removal is approximately 90 percent higher than what it has to be in a conventional machining process ok.

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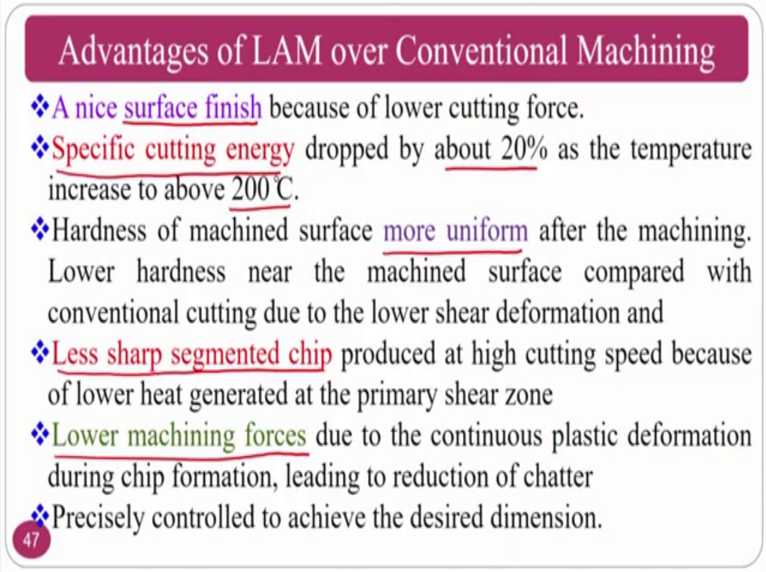

The advantages of laser assisting machining over the conventional machining process; You will get a good surface finish and the specific cutting energy will be less; that means, that approximately dropped by 20 percent. As the temperature in the machining region of the workpiece material is increased, not the tool material, because the laser is focused on the workpiece material hardness of the machine surface is more uniform, less sharp segmented chips will be form.

Normally, the continuous chips will be formed and the lower machining forces will be experienced, because the thermal softening of the workpiece only is done by the localised heating of the laser.

Not only the laser, the people who want to do the hot machining of the ceramics, you can go for your oxyacetylene flame also, because purchasing a laser may be a costly. Those people who want to do the research in this particular area, just what you need to have? A welding torches, that is oxyacetylene flame and all those things you just get the work piece and you arrange your oxyacetylene flame such a way that it will machine it, but it may not be exactly localise, but it may be slightly diversified still ok. Only thing you required is you need to do the at economic price ok. You can do a very good thesis in this way ok.

Only other thing, what you can do? You can do the cryogenic cooling, if the cost permits and if your university has for the cutting tool itself or you can do MQL for the cutting tool ok. If you do the MQL for cutting tool and you are going to do the oxyacetylene hot machining of ceramics that can be a good thesis. If you are a M. tech and PhD student ok. So, you can explore.

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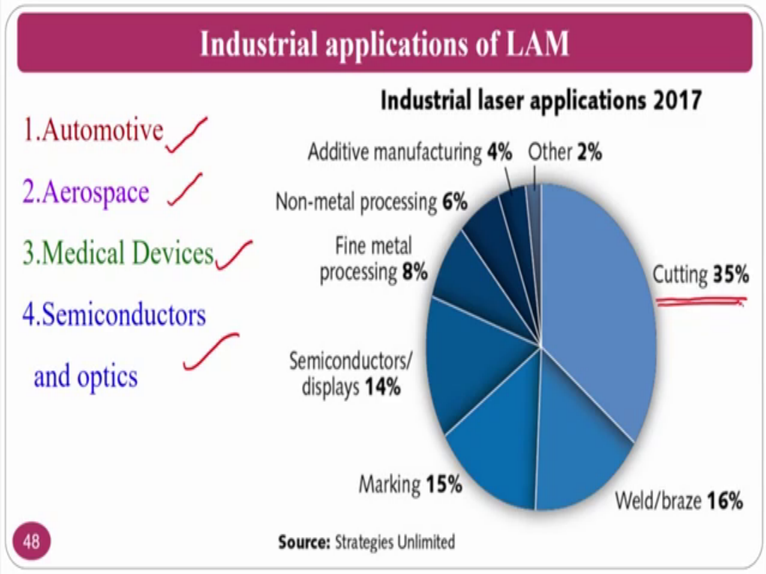

In this direction in industrial application, if you see this particular material will have automotive application, aerospace medical devices and semiconductors and all those things normally, the cutting will be 35 percent ok.

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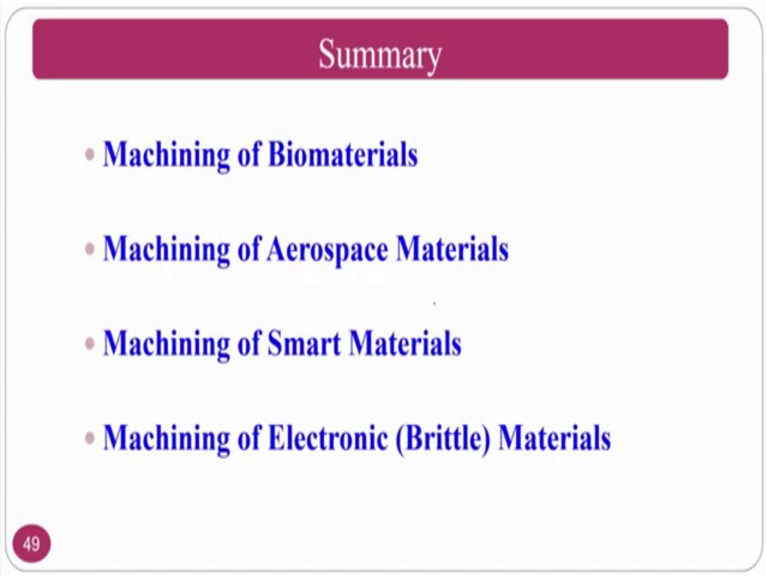

The summary of today's class, if you see we have studied about machining of biomaterials, machining of aerospace materials, machining of smart materials. In this three, we have gone through simple ductile materials to the hard materials, but in terms of electronic materials to have a variety, we have gone for the brittle nature. That is in the electronic materials.

So, we have seen a variety of materials that go into the human, that go in to the aerospace industry, that go into the electronic industry, and all those things ok. There are varieties of material, they are apart from these in terms of advanced materials, but due to time constraint and all those things, I am, talking about only few materials, those people who are interested in doing their research in machining of advanced materials, they can explore and they can do it ok.

Thank you, for your kind attention in this particular course.