Mechanics of Machining
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Lecture – 20
Introduction to Advanced Machining Processes

Hello students. Welcome to the course on Mechanics of Machining. Today is the twentieth lecture of this course. This is the last lecture. In the 19 lectures, we have studied the mechanics of machining. We various type of machining processes and about the cutting forces and surface roughness obtained in those processes. These processes you used a wedge shape tool. This type of tool we was used in all these processes which did the cutting actions so, there was a physical contact between a wedge shape tool and the material and the force was applied on the tool, then the material was removed in the form of the chips that is the basic process.

So, in that we discussed turning process using a lathe machine in that there is a tool that is called single point cutting tool. And then of course, we discussed about milling process in which there were number of a teeth in a cutter and these where doing the machining, but their also each individual tooth was like a wedge shaped tool look so, it use to remove the material in the form of the chips. Then similarly we discussed about drilling in which there were to cutting edges simultaneously cutting the material. We also discussed about the boring process, which is like turning process in which there was a single point cutting tool shaper is there which is also similar to turning process.

And we also discussed the grinding process in which instead of any one cutting tool there were number of abrasive particles and each abrasive particle can be considered as a single point cutting tool and bit with very high rake angle, negative rake angle. Suppose negative rake angle was of the order of say 45 for something like that and some grains were of course, of very round shape also.

But a still nevertheless, there is a physical contact between the cutting tool and the work piece and the tool is in a way properly guided. Because in grinding wheel also these abrasive particles they were not loose rather they are properly embedded in a bonding material. So, these type of things were there, but today I am going to discuss similar advanced machining processes which deviate from the conventional pattern. In this there are number of a different type of energy source is implied of course, there is a mechanical energy source is also there. But the type of the interaction with the tool and the workpiece is quite different from the conventional way many times suppose abrasive particles may be loosely bounded. They may be moving in a random way such type of things are there.

So, we will discuss these processes also this a only one lecture is a sign for that purpose. So, this is basically going to be introductory and intension is only to provide exposure. We will not discuss this in detail, but you can pick up this type of things are may be if you get a part you need to do another course of an advanced machining processes, then these back ground will help you a lot because you will already be knowing something about these processes.

So, we discussed about these advanced machining processes. They are little bit advanced from the conventional machining processes and they are also called sometimes nontraditional machining processes, although which is nontraditional today may become traditional tomorrow and these are also called nonconventional machining processes. But these are also becoming slowly conventional. So, anyway let us discuss various type of these processes.

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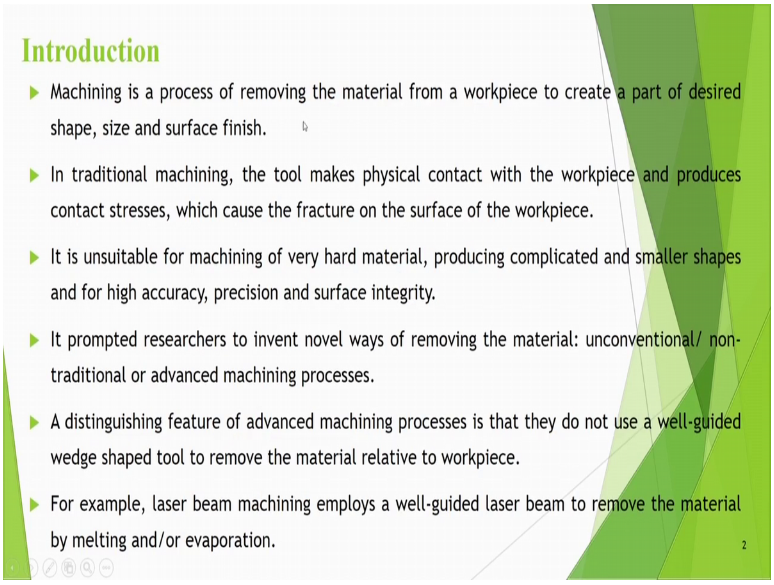

So, machining as you know is a process of removing the material from a workpiece to create a part of desired shape size and surface finish that is the proper purpose of machining that we want to make a product it should be of desired shape, it should be of desired size and it should be of desired surface finish. In traditional machining the tool makes physical contact with the workpiece and produces contact stresses which cause the fracture on the surface of the workpiece in the form of the chips material is removed. It is unsuitable for machining of very hard material producing complicated and smaller shapes and for higher accuracy precision and surface integrity.

So, we look for the new type of processes because sometimes the material is too hard, if it is harder than even the tool material, then it is difficult to remove the material. All the shape is too complicated which is very difficult to produce by conventional means or it is of very small shape. If I want to make a very small hole in a machine, suppose say point 0.5 mm diameter hole may be very difficult by the conventional drill because the drill bit will break. So, that is why we use and sometimes we need very high accuracy, which may not be possible by conventional means precision. Also if we need very high repeatability of the process and then, we need surface integrity also. It should be very good suppose I do not want any residually stresses on the surface. I want high surface finish, naturally I how to look for new type of processes.

So, it prompted researches to invent novel ways of removing the material these are unconventional, nontraditional or advanced machining processes. A distinguishing feature of advanced machining process is that they do not use a well guided wedge shape tool to remove the material relative to workpiece. So, they may use sometimes wedge shape tool, but that is not well guided. But sometimes they may use a well guided tool, but it may not be wedge shaped also. For example, laser beam machining employs a well guided laser beam to remove the material by melting and or evaporation.

So, we have a laser beam that is properly guided, it can be fitted on a CNC table when it goes x y and z motion, but it is not a tool that will make a physical contact; infact a beam is there which is traversing the way tool is moving on a lathe machine. So, such type of laser beam machining comes in the category of advanced machining process.

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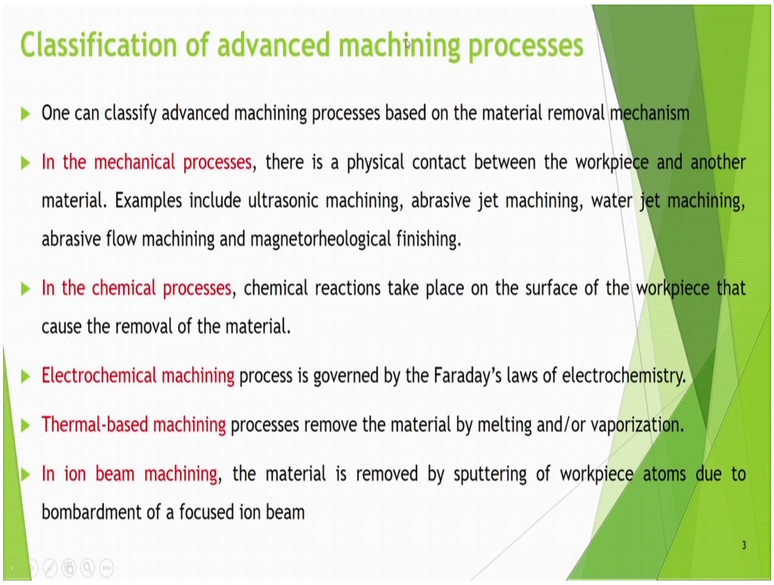

Now, let us classify the advanced machining processes. One can classify advanced machining processes based on the material removal mechanism. In the mechanical processes, there is a physical contact between the workpiece and another material means we have mechanical advanced machining processes. In this there is a physical contact between the workpiece and another material, but that workpiece and another material may removing in somewhat random fashion some example is ultrasonic machining.

So, in ultrasonic machining usually there are some abrasive particles. They undergo ultrasonic type of a motion means, they impact the workpiece because ultrasonic vibrations are imported, then these materials, these small powders may impinge on the body, but they are not very well guided like a tool in lathe machine. Similarly abrasive jet machining will be like that suppose, there is air jet in which I mix up the abrasive particles. So, air jet is beam forced on the material and abrasive particles also attack and that is how that they is machining is carried out. In water jet machining there is a jet of water that is making some contact and of course, in that I can at some abrasive particles. So, it becomes abrasive water jet machining, abrasive flow machining also there are some abrasive particles. They are imbedded in a carrier medium that is viscous and that carrier medium is moving it is flowing on the workpiece and that is how that material removal will take place.

So, these are, you can see that these are loosely bonded abrasives mostly they have been used. In water jet machining, pure water jet machining there may not be abrasive particles, but of course, this tool is a liquid actually and magneto rheological finishing in which magnetic force in some sense guides that motion. So, it is a that type of finishing is there. And in chemical processes chemical reactions take place on the surface of the workpiece that cause the removal of the material like photo chemical machining. So, it is those are chemical processes. Electrochemical machining is the process governed by the Faraday's law of electrochemistry. So, in this case it is opposite of the deposition of the coating. Suppose we do the coating deposition it is opposite of that we remove the material.

Then thermal based machining processes removes the material by melting and or vaporization. So, this is how that like laser beam is one good example, plasma machining may be plasma arc machining may be another example. In ion beam machining instead of a laser beam a beam of ion bombards the material, but the material is not removed by the thermal action are melting and vaporization rather those bombarding ions. They have got lot of weight. So, they actually cause sputtering of workpiece I atoms due to bombardment of a focused ion beam just like one ball is heat, then it can actually transfer its momentum to another ball and another ball starts moving. So, similarly the ions come and the heat atoms and the provide the movement to atoms and that is how the material is removed. So, that is called ion beam machining.

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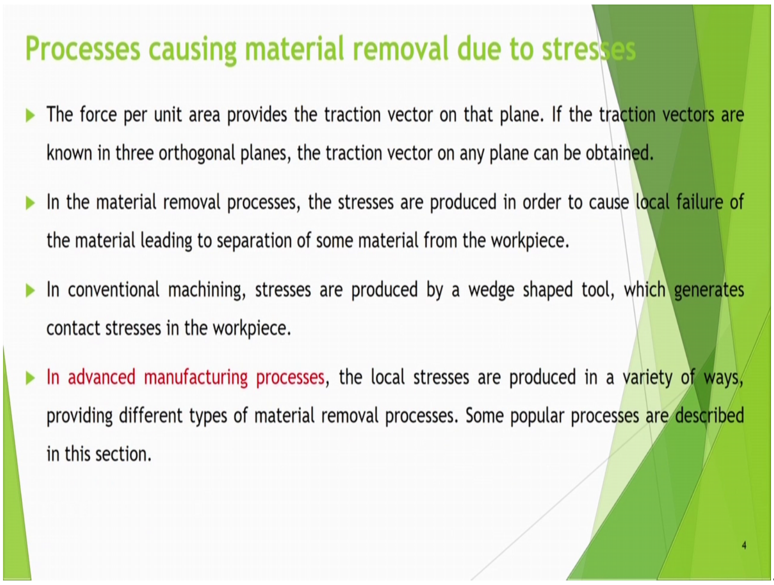

Let us discuss mechanical types of processes; that means mechanical processes or I would better name them as processes causing material removal due to stresses. That means, they in turn basically generate these stresses, whatever is the process like in conventional material is removed conventional machining material is removed by creating the stresses. Here although these are advanced machining processes, here also the stress is created, it is not like that laser beam where a there is no need to create stress rather melting is responsible. But in this process which I am going to discuss now material is removed by stresses.

So, force per unit area provides the traction vector on that plane. If the traction vectors are known in three orthogonal planes, the traction vector on any plane can be obtained this you know. So, in the material removal processes the stresses are produced in order to cause local failure of the material leading to separation of some material from the workpiece.

So, in conventional machining stresses are produced by a wedge shape tool which generates contact stresses in the workpiece. That is the thing which you know, but in advanced manufacturing process the local stresses are produced in a variety of ways providing different types of material removal processes. Now some popular processes are described.

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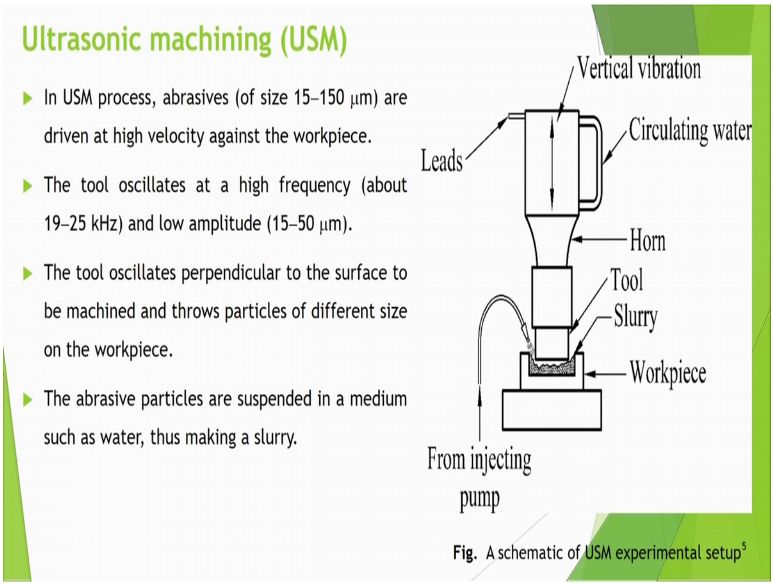

Here ultrasonic machining. Now, just see the diagram of ultrasonic machining I am imparting vertical ultrasonic vibrations. These are the leads, then I am circulating the water. Then this is a that horn the purpose is to implify the vibrations, then I have got a tool it is vibrating and then I have got a slurry of a abrasive particles and may be water as a carrier and this is vibrating. So, it is imparting that motion to those particles also and they are creating that a cavity just like replica of a tool like that here. This is a tool same type of cavity they will produce.

So, in ultrasonic USM process, abrasives of size generally 15 to 150 micrometer are driven at high velocity against the workpiece, tool oscillates at a high frequency. High frequency means it may be in the range of 19 to 25 kilohertz that is ultrasonic range, but amplitude is very low that is about 50 to 15 to 50 micrometer. Now this tool oscillates perpendicular to the surface to be machined and those particles of different sizes on the workpiece so, it actually throws particles of different sizes and these abrasive particles are suspended in medium such as water thus they makes slurry.

So, you see that these particles this water may be injected in part that slurry may be injected from a injecting pump and this is how that it is going. So, this set up you have seen.

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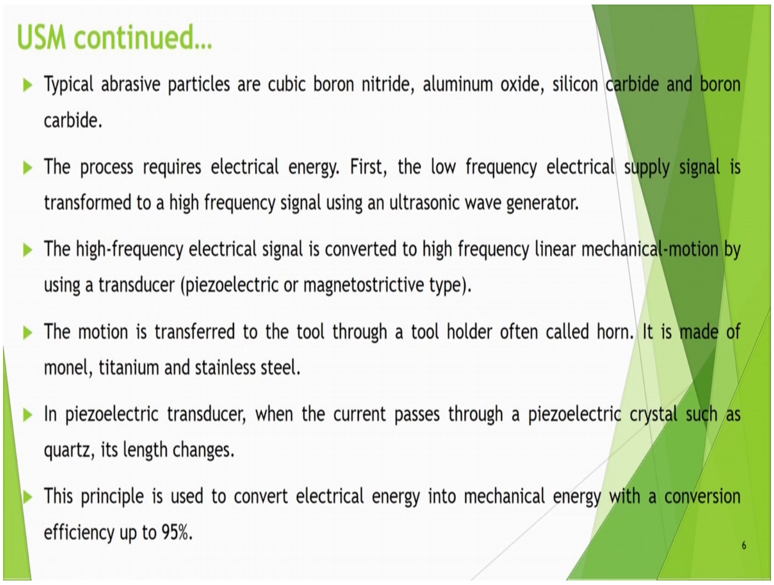

Typical abrasive particles are cubic boron nitride a very hard material; aluminum oxide, silicon carbide and boron carbide. The process requires of course, electrical energy because you how to get new ultrasonic vibration. So, first the low frequency electrical supply signal is transformed to a high frequency signal using an ultrasonic wave generator.

And then the high frequency electrical signal is converted to high frequency linear mechanical motion by using a transducer; that means piezoelectric or magnetostrictive type. Piezoelectric one is direct that if you we subject that material to electrical field; electric field, then and we supply the, we provide the charge; then it can undergo mechanical motion. On vice versa that if there is a piezoelectric materials are those materials suppose you compressive then the develop charge.

And magnetostrictive type materials are those which undergo the change in length in the magnetic field. So, the motion is transferred to the tool, through a tool holder often called horn. It is made of monel, titanium and stainless steel and you see that horn has got this type of shape. So, basically it is bigger cross section here, smaller cross section here. So, it basically amplifies the amplitude of vibrations.

Now, here most show a in piezoelectric transducers when the current passes through a piezoelectric crystal such as a quartz; its length changes. The principle is used to convert electrical energy into mechanical energy with a conversion efficiency up to 95 percent and magnetostrictive materials usually do that have that much high efficiency.

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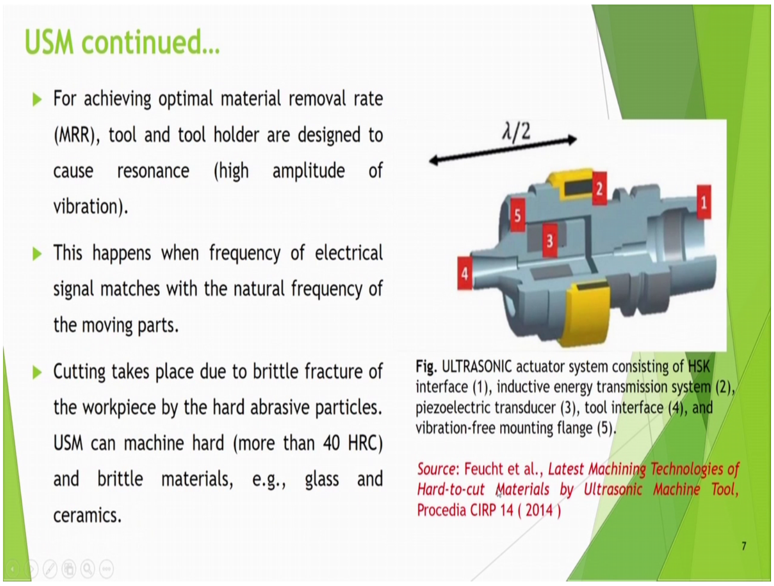

They have efficiency of only about 40 percent, but they were consider to be more reliable. Nowadays, piezoelectric crystals are also very reliable so, usually in USM machines they are widely used.

So, now for achieving optimal material removal rate tool and tool holder are designed to cause resonance, high amplitude of vibration. This happens when frequency of electrical signal machine matches with the natural frequency of the moving parts and cutting takes place due to brittle fracture of the workpiece by the hard abrasive particles because the attack the material. And USM can machine hard more than 40 HRC and brittle materials eg; glass and ceramics etcetera. But the convert easily machine very ductile material even they will not be able to cut only skill. So, suppose you put your hand may be behind become remain safe. So, this type of thing may be useful when you how to cut only the brittle material. It even if it may be surrounded by ductile material; ductile material will not be machine, but brittle material will be easily machined.

This is a ultrasonic actuator system is shown. Here inductive energy transmission system then piezoelectric transducer is here, then tool interface is this one and vibration free mounting flange is there. So, these are the components and yes. So, this is the tool interface is fourth and the third one is piezoelectric transducers and in this is inductive energy transmission system.

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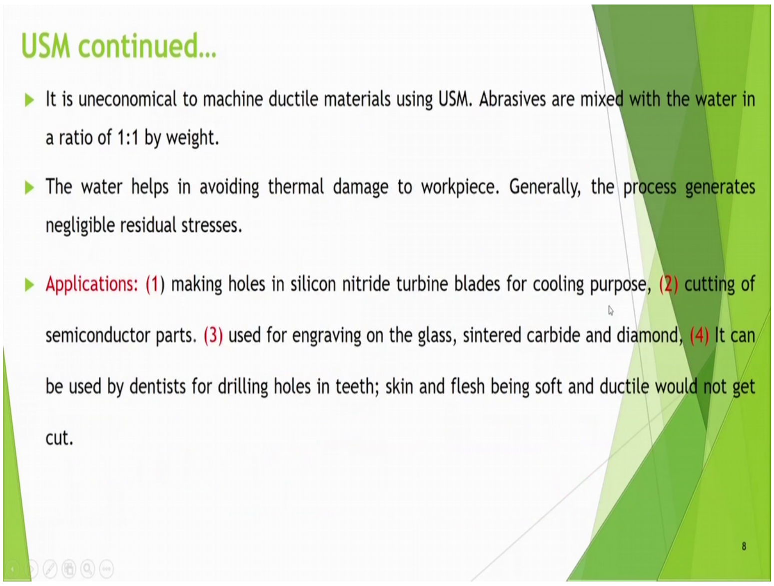

So, this I have shown, now it is uneconomical to machine ductile materials using USM abrasives are mixed with the water in a ratio of 1 isto 1 by weight. So, that is what suppose you may have 1 kg of a abrasive and 1 kg of water and you can make a slurry.

The water helps in avoiding thermal damage to workpiece. Generally the process generates negligible residual stresses. So, after machining very small amount of stresses are left on the surface applications can be making holes in silicon, nitride turbine, blades or cooling purposes cutting of semiconductor parts. It is used for engraving on the glass sintered carbide and diamond and it can be used by dentists for drilling holes in teeth skin and flesh being soft and ductile would not get cut. So, this is very easy from that point of view that you have to use that USM.

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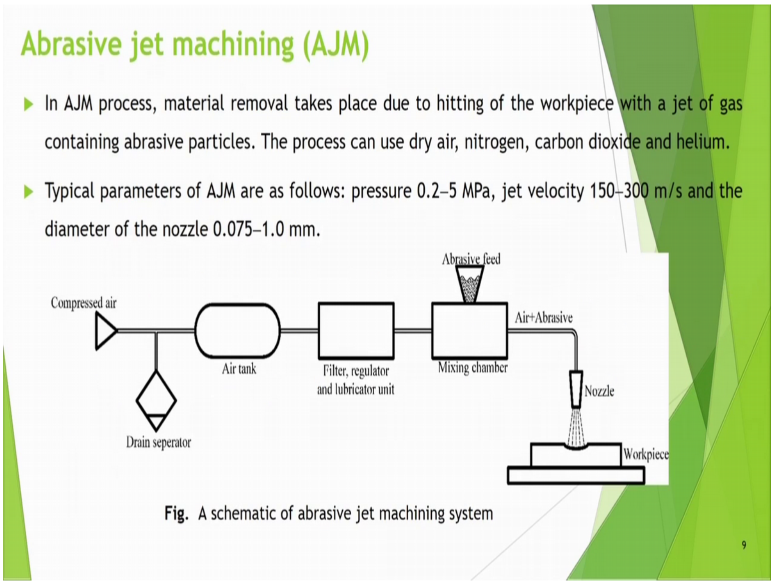

So, this one it is one process, then I tell about the other process that is abrasive jet machining. In abrasive jet machining process material removal takes place due to hitting of the workpiece with a jet of gas containing abrasive particles. Now the process can use dry air nitrogen, carbon dioxide and helium typical parameters of AJM are as follows pressure may be 0.2 to 5 mega pascal; that means, 2 to 50 bar 2 to 50 atmospheric pressure jet velocity can be 150 to 300 meter per second that is mostly subsonic range because 330 meter per second is the velocity of any sound velocity in the air and the diameter of the nozzle typically can be 0.075 to 1 millimeter.

Now, it is a schematic of abrasive jet machining is shown here. You are seeing that there is a compressed air, this is a symbol for compressor. Now there is a drain separator, if there is any moisture etcetera that is a tool separated from here, then there is a it is a stored in the some air tank even if power supply is not there compressed air will be stored in that air tank. Then filter regulator and lubricator unit is there; its purpose is to remove the dust particles and also it regulator means it regulate the quantity going there and lubricator means some amount of lubricator may be added here with the air. So, that if it is going inside the some moving parts like in a piston cylinder s o, it should not get damaged.

And then whole thing is going in a mixing chamber and from here I am feeding the abrasive feed, then air plus abrasive which coming through this nozzle and then it is machining and you have got this type of workpiece shape you have got.

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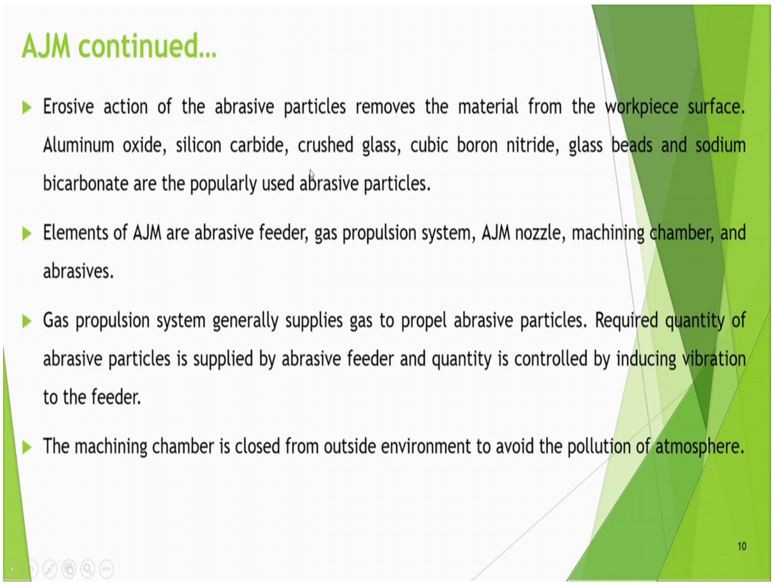

Now erosive action of the abrasive particles removes the material from the workpiece surface aluminum oxide, silicon carbide, crushed glass, cubic boron, nitride glass beads and sodium bicarbonate are the popularly used abrasive particles. So, these are the abrasive particles. Elements of AJM are abrasive feeder gas propulsion system AJM nozzle machining chamber and abrasives.

Now, gas propulsion system generally supplies gas to propel abrasive particles. Now required quantity of abrasive particles is supplied by abrasive feeder as you have seen and the quantity is controlled by inducing vibration to the feeder. If I vibrate, then the more quantity will come. If I increase the vibration more quantity will come like that I can control the quantity machining chamber is closed from outside environment to avoid the pollution of atmosphere.

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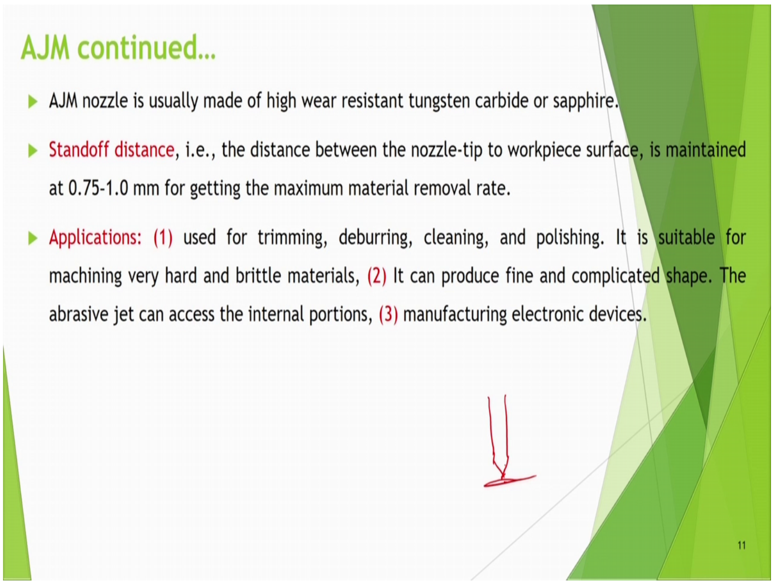

Now, AJM nozzle is usually made of high wear resistant, tungsten carbide or sapphire. Actually standoff distance that is distance between the nozzle tip to workpiece surface is maintained at 0.75 to 1 millimeter for getting the maximum material removal rate. So, standoff distance is actually very very small that is about maximum about 1 mm. Standoff distance is the distance between the nozzle tip and the workpiece this is the nozzle tip suppose like this and then this is the workpiece. So, this and this type, applications are used for trimming, deburring, cleaning and polishing. It is suitable for machining hard and brittle materials can produce fine and complicated shapes abrasive jet can access the internal portions that is another advantage. Suppose I have got many holes in and in accessible area and they how to deburrged means burs have to be removed; this may be good process. Then manufacturing of some electronic devices you use that.

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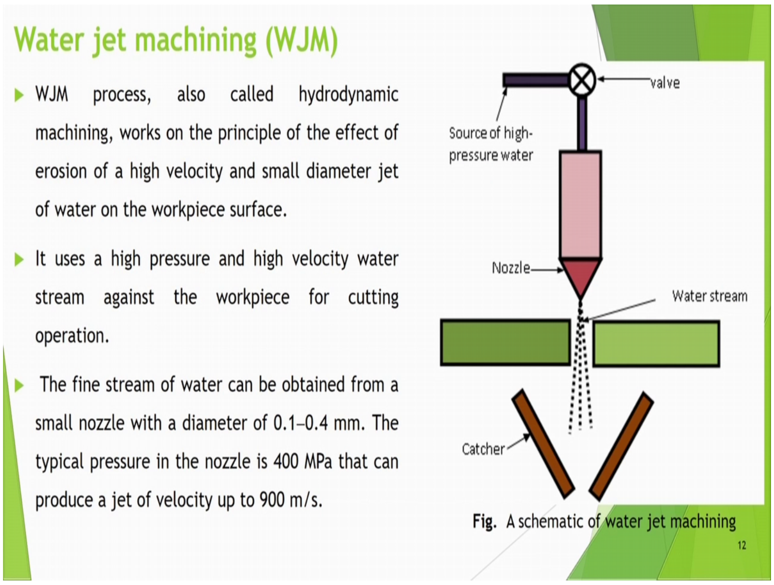

Now, water jet machining process also called hydrodynamic machining works on the principle of the effect of erosion of a high velocity and small diameter jet of water on the workpiece surface. Now it uses a high pressure and high velocity water stream against the workpiece for cutting operation. So, it is that suppose I am sending that high pressure water and then it is nozzle and then water stream is coming, then it is a catcher which catch is the water here. So, it uses high pressure and high velocity against the workpiece fine stream of water can be obtained from a small nozzle with a diameter of 0.1 to 0.4 mm.

So, diameter of the nozzle is very small just like it is a blade of 0.1 to 0.4 mm thickness. Typical pressure in the nozzle is 400 mega Pascal; that means, about 4000 atmospheric pressure can produce a jet of velocity up to 900 meter per second very high velocity that may be more than the speed of the sound.

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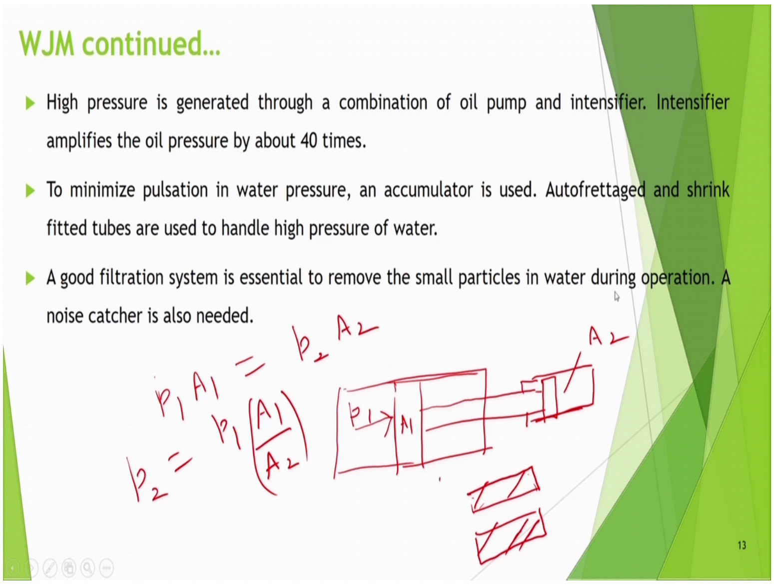

And high pressure is generated through a combination of oil pump and intensifier. Intensifier amplifies the oil pressure by about 40 times. So, it is basically intensifier is a arrangement of a piston cylinder type of thing and then it can intensify this one. You know that suppose principle is like this, suppose you have got a big cylinder with a piston and then after that it is connected with a small cylinder like that. So, it is like this. So, suppose I apply that force pressure p 1 here and this area is A 1. So, this force which gets transmitted there in this small one is p 1 A 1, but this area is only A 2. So, same force is getting transformed. So, p 1 A 1 will be p 2 A 2 and therefore, p 2 will become p 1 A 1 by A 2.

Now, A 1 by A 2 ratio I can control a suppose A 1 is 10 times than A 2 then p 2 becomes 10 times of p 1. So, this is the intensifier. So, this type of thing can be done to intensify the pressure to minimize pulsation in water pressure an accumulator is used, accumulator basically stores it is like a fly field in mechanical system. So, it just it stores that whenever there is a shortage of pressure a accumulator kind supply the liquid. And at so, it is also important that because those pipelines which are carrying that high pressure water. They have to be very strong. So, they are generally autofrettaged and shrink fitted tubes. Autofrettiging is an operation in which by means of the earlier plastic deformation, we produce residual stresses on the tube. Generally we produce compressive stresses in the inner side and tensile on the outer side.

So, pressure carrying (Refer Time: 26:56) gets enhanced. It can take more amount of opy (Refer Time: 26:58) stress and shrink fitting means that there is a tube and top of that I fit another tube. So, by a string fit. So, if I fitted by string fit. So, what will happen that because it is string fitted means it diameter was smaller more diameter of the outer tube was smaller, then the outer diameter of inner. So, it is causing a type of compression type of that material. So, that is why it is getting compressed air.

So, good filtration system is essential to remove the small particles in water during operation. A noise catcher is also needed, noise catcher is shown here.

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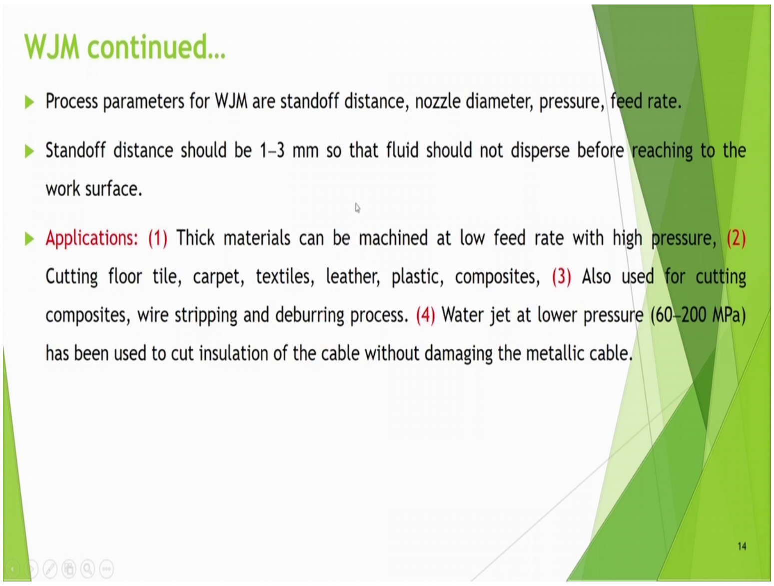

And this process parameters for WJM means Water Jet Machining are standoff distance that is how much distance is there between the nozzle and workpiece and then though nozzle diameter, then pressure, then feed rate. Then standoff distance should be 1 to 3 mm. So, that fluid should not disperse before reaching to the work surface. Applications of water jet machining can be thick material can be machined at low feed rate with high pressure, cutting floor tile in work because in the cutting of tile otherwise lot of dust is generated which may be harmful for the operator. But in this water jet will be nice thing because water will carry away those dust. And carpet, you can cut in textile industries; you can use it leather industries, you can cut the leather this one. Even one shoe industries making use of this water jet cutting, then plastic you can cut, composites you can cut and also used for cutting composite wire stripping and deburring process. Then water jet at low pressure that is 60 to 200 mega Pascal; that means, about 600 to 2000 atmospheric pressure has been used to cut insulation of the cable without damaging the metallic cable.

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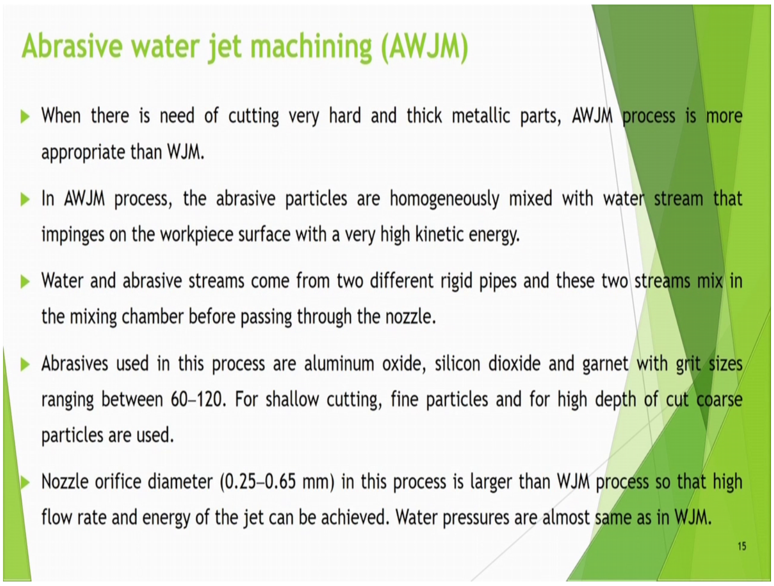

When there is a need to; there is a need of cutting very hard and thick metallic parts, then abrasive water jet machining process is more appropriate than water jet machining. In abrasive water jet machining the abrasive particles are homogeneously mixed with water stream that impinges on the workpiece surface with a very high kinetic energy. And water and abrasive streams come from two different rigid pipes and these two streams mix in the mixing chamber before passing through the nozzle.

Then the abrasive used in this process are aluminum oxide powder, silicon oxide and garnet with grit sizes ranging between 60 to 120 for shallow cutting fine particles and for high depth of cut coarse particles are used nozzle orifice diameter in this process is larger than WJM process. So, that high flow rate and energy of the jet can be achieved and water pressures are almost same as in WJM and nozzle diameter has to be slightly bigger in this case. So, that there is no plugging also of the orifice.

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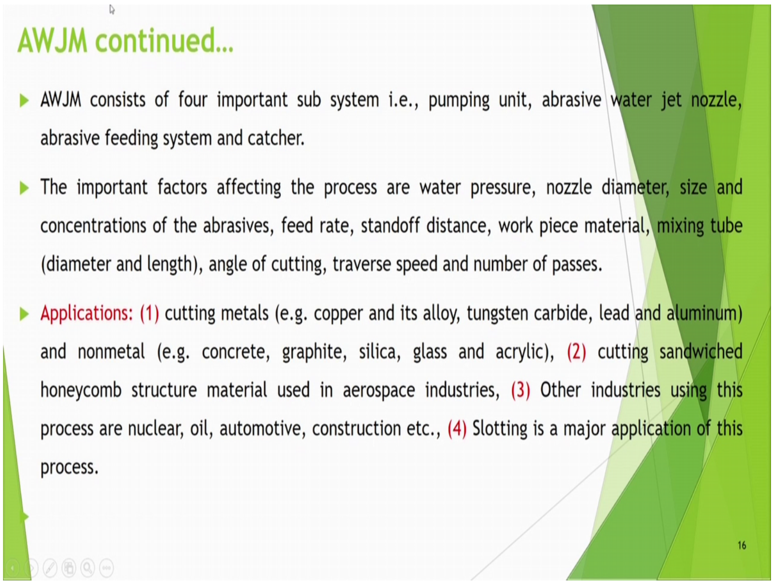

Now, a WJM consists of four important sub system that is pumping unit like in the water jet. Similarly abrasive water jet nozzle, abrasive feeding system and catcher important factors affecting the processes are water pressure, nozzle diameter size and concentration of the abrasives and feed rate, standoff distance, workpiece material, mixing tube; that means, diameter and length angle of cutting, traverse speed and number of passes.

Applications are cutting metals eg copper and its alloy, tungsten carbide, lead and aluminum. And nonmetals can also be cut like concrete, graphite, silica glass and acrylic and cutting sandwiched honeycomb structure material used in aerospace industry. Other industries using this process are nuclear, oil, automotive, construction etcetera; slotting is a major application of this process.

So, these are the abrasive water jet machining operation and advantage is that because water is there not much thermal damaged is caused it remove the heat. So, it is it does not produce much a residual stresses particularly it does not cause thermal damage.

And pure water jet also has been used in food industries. Suppose you can even cut the breads etcetera by means of the water jet machining so, this is the that process.

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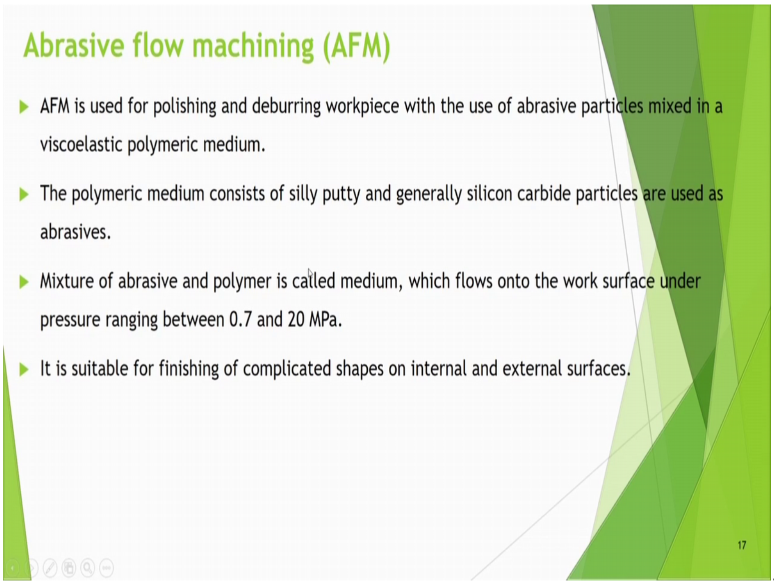

Now I am only discussing about the mechanical processes in which mechanical energy is there; that means, there is a physical contact between the medium and the workpiece. So, abrasive flow machining process is another type of such type of process. In abrasive flow machining we do polishing and deburring of workpiece with the use of abrasive particles mixed in a viscoelastic polymeric medium we can usually call it a putty.

The polymeric medium consists of silly putty and generally silicon carbide particles are used as abrasives. They mixtures of abrasives and polymer is called medium. So, which flows onto the work surface under the pressure ranging between 0.7 to 20 mega Pascal; that means 7 atmospheric pressure to 200 atmospheric pressure. It is suitable for finishing of complicated shapes on internal and external surfaces.

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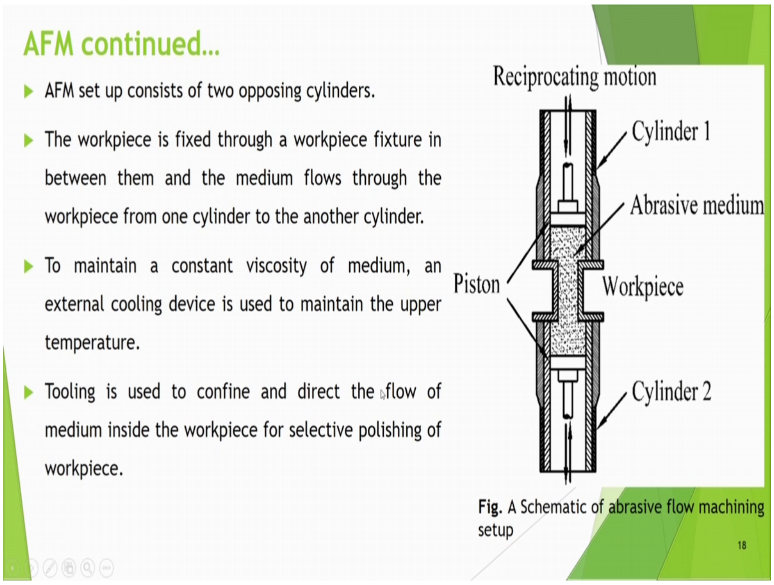

So, this is one example that suppose this is the workpiece, you are seeing that workpiece is there and there are two opposing crystals. They reciprocates so; that means, abrasive medium is reciprocating and in that process it places the both of the workpiece. AFM set consists of two opposing cylinders, the workpiece is fixed through a workpiece fixture in between them and the medium flows through the workpiece from one cylinder to another cylinder to maintain a constant viscosity of medium. An external cooling device is used to maintain the upper temperature and tooling is used to confine and direct the flow of medium inside the workpiece for selective polishing of workpiece. So, this is shown here.

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Process variables are extrusion pressure means how much pressure I need to imply, then number of cycles, then stiffness of the medium, then workpiece fixture configuration, abrasive size and concentration. And applications are rounding the sharp edges of workpiece and polishing the rough surface of a casting; it is mostly used in industries like automobile, aerospace and die making. It is used for uniform finishing of both metals and non metals for internal and external surfaces.

Now, see this is a helical gear before and after machining. Finishing by abrasive flow machining this is a nitro alloy collar. This has been also machined then this is a brass nozzle, then this is a knee joint implant before that it was finishing having this much, but after we machined it has become like this.

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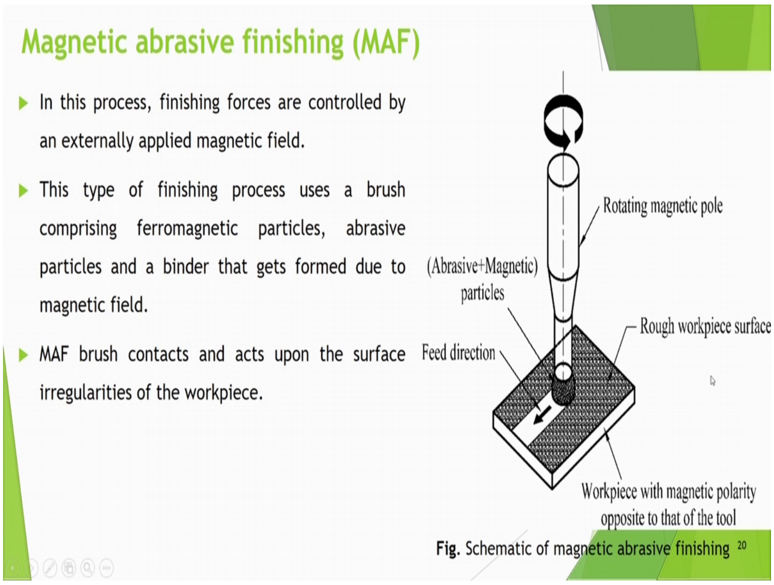

So, this is a then another process is that magnetic abrasive finishing process. In this process finishing forces are controlled by an externally applied magnetic field. So, suppose this type of thing abrasive plus magnetic particles are there and this is rotating magnetic pole, this is a rough workpiece surface and by these your controlling this thing workpiece with magnetic polarity opposite to that of tool is there. So, between two pole these particles are magnetic particles are moving and they are machining. This type of finishing process uses a brush comprising ferromagnetic particles, abrasive particles and a binder that gets formed due to a magnetic field. So, it makes small brush type of thing. So, this magnetic abrasive finishing brush contacts, and acts upon the surface irregularities of the workpiece.

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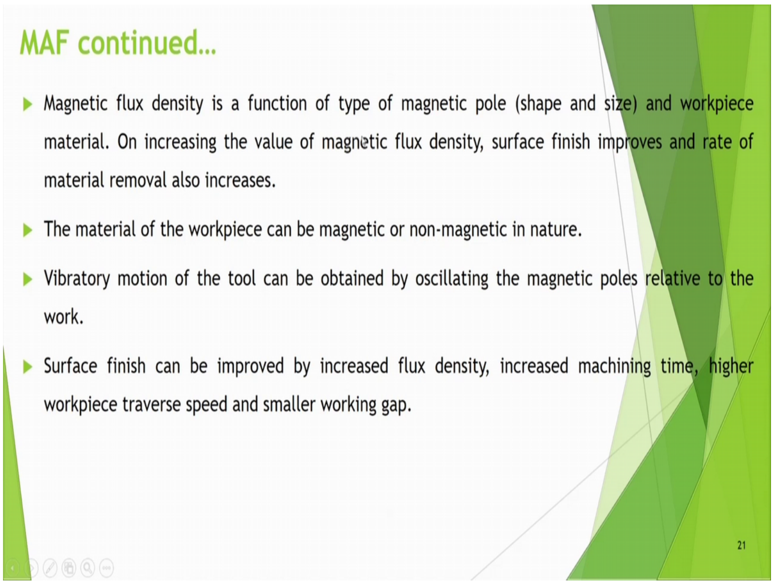

Magnetic flux density is a function of type of magnetic pole shape and size and workpiece material. Now on increasing the value of magnetic flux density, surface finish improves and rate of material removal also increases. The material of the workpiece can be magnetic or non magnetic in nature, you can actually put even if it is non-magnetic. You can make another pole of the another material and vibratory motion of the tool can be obtained by oscillating the magnetic poles relative to the work. Then surface finish can be improved by increasing flux density, increased machining time, higher workpiece traverse speed and smaller working gap.

Applications are used for polishing of balls and rollers, finishing of inner tube surface, removal of oxide layer, polishing of fine component like printed circuit board, removing the burr in gear and polishing of complicated shapes.

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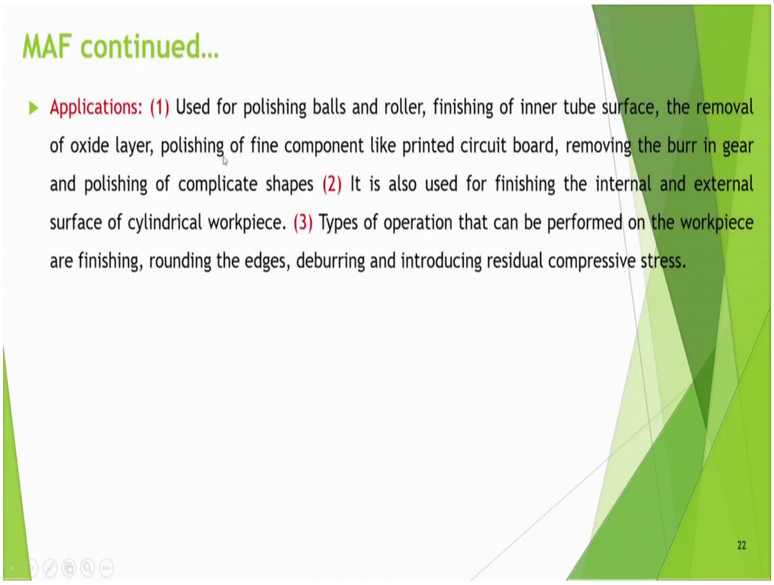

It is also used for finishing the internal and external surfaces of cylindrical workpiece. Types of operation that can be performed on the workpiece are finishing, rounding the edges, deburring and introducing residual compressive stresses.

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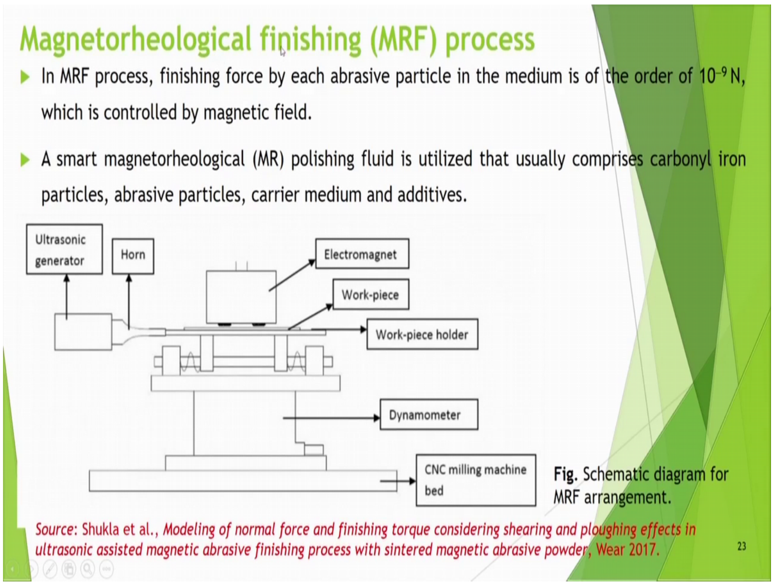

Now, magneto rheological finishing process in MRF process, finishing force by each abrasive particle in the medium is of the order of 10 to the power minus 9 Newton. So, magneto rheological finishing process will use some magnetorhelogical medium which will change its viscosity depending on the magnetic field. So, forces are of very small order. A smart magnetorhelogical polishing fluid is utilized that usually comprises carbonyl iron particles, then abrasive particles and carrier medium and additives. So, we make this type of fluid and then, this is suppose ultra we can even impart ultrasonic vibrations to that magnetorhelogical fluid. So, suppose this example is there there is ultrasonic generator that is additional item imported, but you may not have ultrasonic generator sometime. It is ultrasonic generator horn is there, electromagnet is there, workpiece is there, workpiece holder is there, dynamometer is there and then CNC milling machine bed is there. So, this is how that is there. So, it is that type of process.

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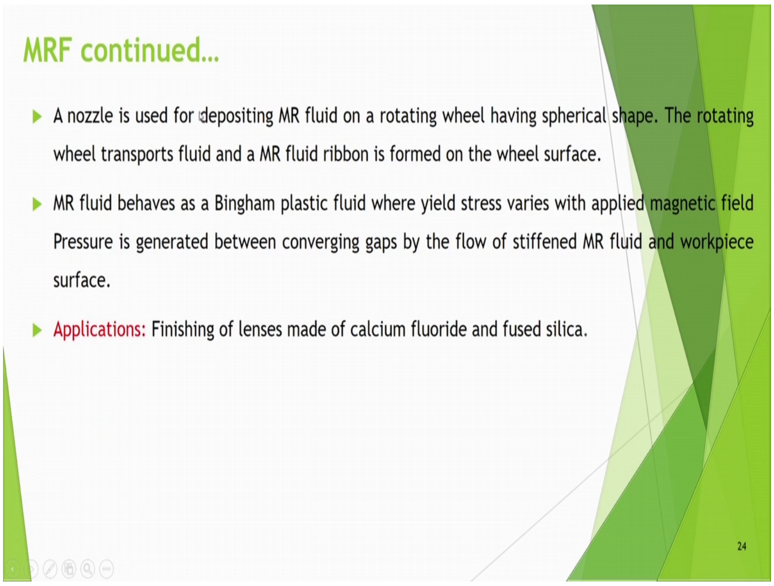

So, a nozzle is used for depositing MR fluid on a rotating wheel having spherical shape. The rotating wheel transports fluid and MR fluid ribbon is formed on the wheel surface. MR fluid behaves as Bingham plastic fluid where yield stress varies with applied magnetic field, pressure is generated between converging gaps by the flow of stiffened MR fluid and workpiece surface applications are finishing of lenses made of calcium fluoride and fused silica that is common application, then magnetorheological abrasive finishing process.

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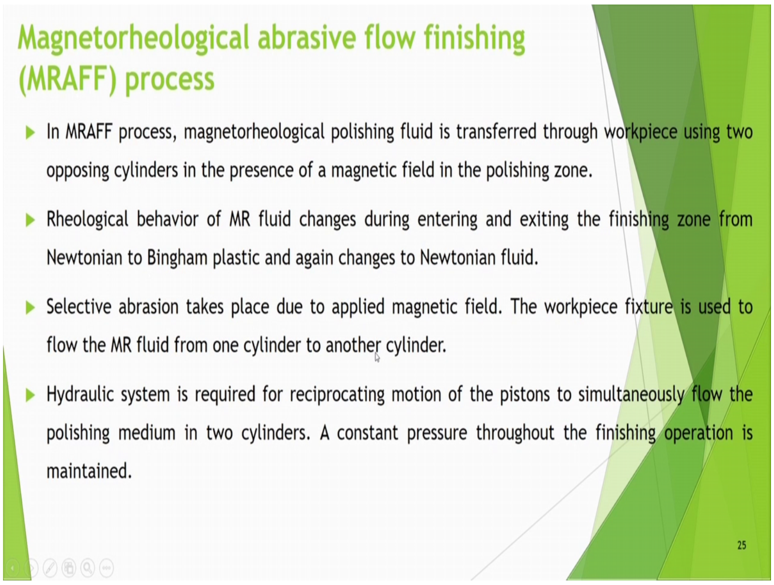

So, this is this one this figure actually this is normal considering shearing in ultrasonic assisted. This is actually magnetic abrasive finishing process. So, this is actually really not magneto rheological finishing it is because I have not shown anything this is basically magnetic abrasive finishing only, but there is a I am giving the ultrasonic vibration, but this one is a magneto rheological finishing and in this magneto rheological abrasive flow finishing process. In MARFF process, magneto rheological polishing fluid is transferred through workpiece using two opposing cylinders in the presence of a magnetic field in the polishing zone.

So, that means, magneto rheological fluid is also there and abrasives are also there. Rheological behavior of MR fluid changes during entering and existing the finishing zone from Newtonian to Bingham plastic and again changes to Newtonian fluid and selective abrasion takes place due to applied magnetic field the workpiece fixture is used to flow the MR fluid from one cylinder to another cylinder. And hydraulic system is required for reciprocating motion of the pistons to simultaneously flow the polishing medium in two cylinders. A constant pressure throughout the finishing operation is maintained.

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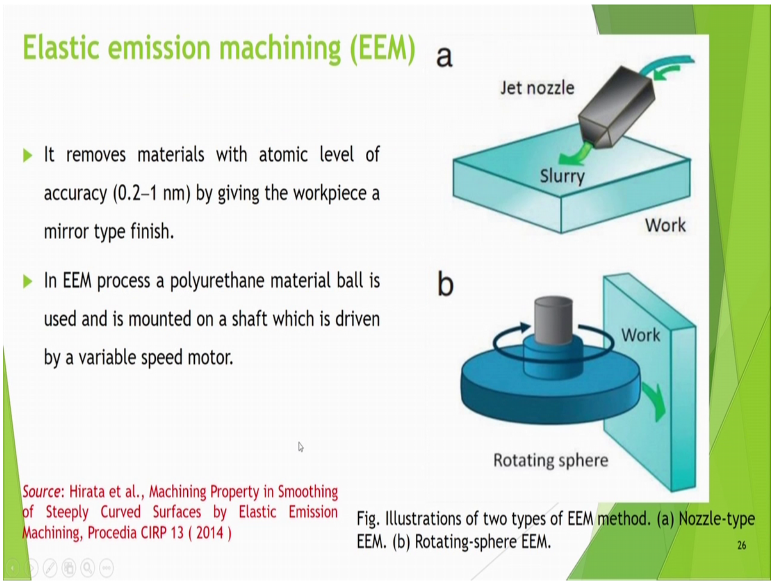

So, these are the processes and another operation is elastic emission machining. This is so called is elastic emission machining. It was about a teas that it was invented. It removes material with atomic level of accuracy by giving the workpiece a mirror type of finish. Usually that very small sized a powdered particles are there and they are doing the cutting with a small force acting on that. So, it is machining is by means of elastic fracture. So, in elastic emission machining, a polyurethane material ball is used and is mounted on a shaft which is driven by a variable speed motor.

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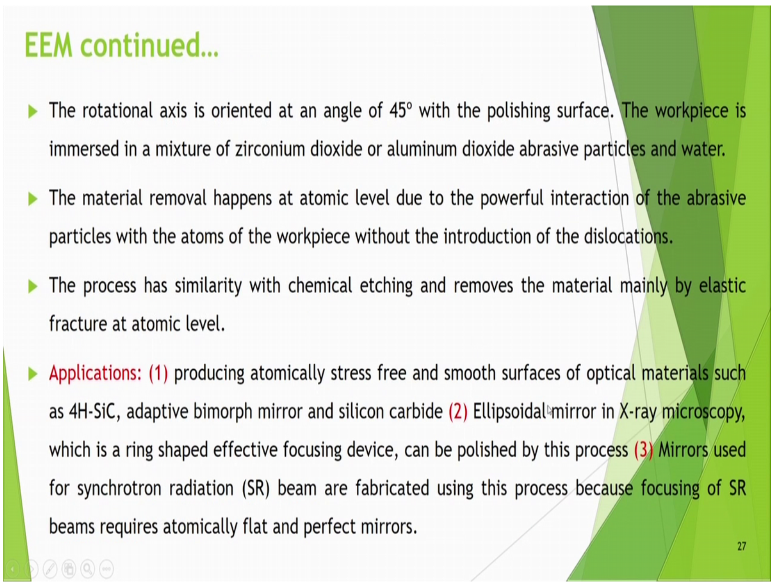

Rotational axis is usually inclined that an angle of 45 degree with the polishing surface the workpiece is immersed in a mixture of zirconium dioxide or aluminum dioxide abrasive particles and water. The material removal happens at atomic level due to the powerful interaction of the abrasive particles with the atoms of the workpiece without the introduction of the any dislocation or plastic deformation.

The process has similarity with chemical etching and removes the material mainly by elastic fracture at atomic level. Applications are producing the atomically stress free and smooth surfaces of optical materials such as 4H-SiC adaptive bimorph mirror and silicon carbide is ellipsoidal mirror in X-ray microscopy which is a ring shape effective focusing device can be polished by this process. Mirrors used for synchrotron radiation beam are fabricated using this process because focusing of synchrotron radiation beam requires atomically flat and perfect mirrors.

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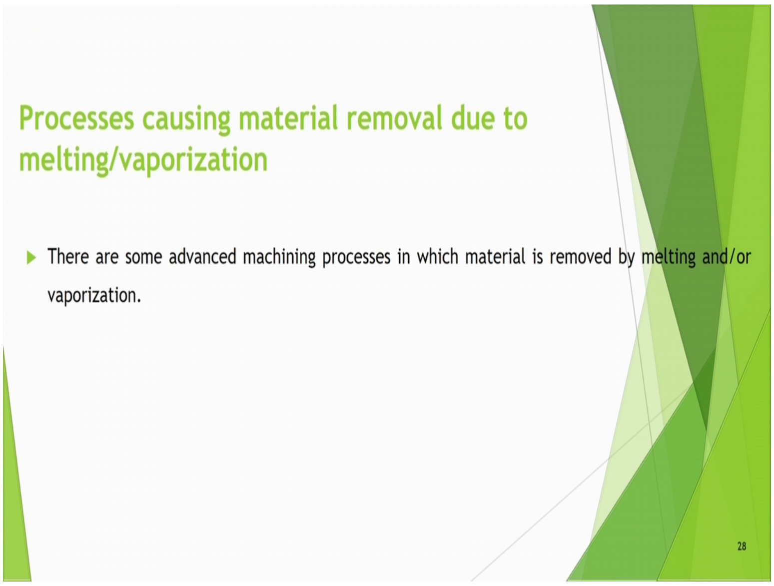

So, these are the applications. Now, I am switching were from this topic to another topic. Till now I discussed about the mechanical type of advanced manufacturing process in which by means of the forces material is removed, there are stresses generated on the surface of course, even if it is elastic emission machining there is a fracture occurring. But now I am going to discuss those processes in which material removal is taking place due to melting and vaporization. So, there are some advanced machining process in which material is removed by melting and or vaporization.

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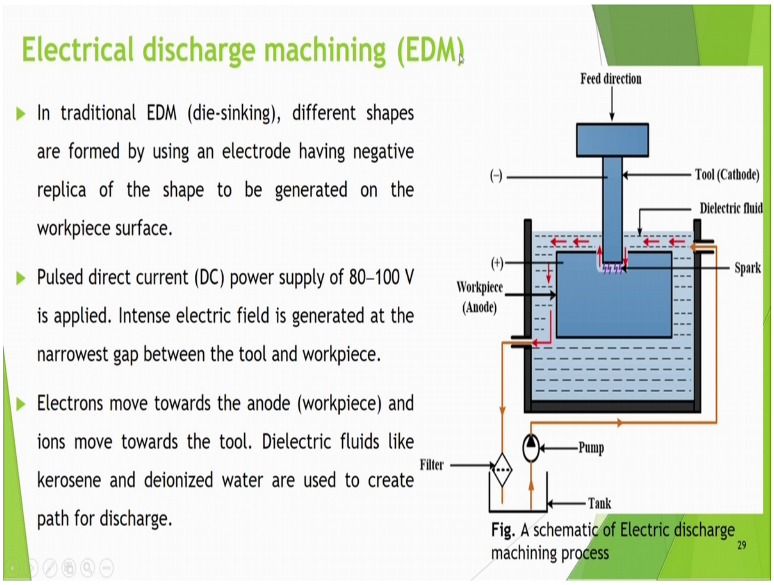

Example is electrical discharge machining in traditional EDM that is called die sinking because it makes a die type of thing different shapes are form by using an electrode having negative replica of the shape to be generated on the workpiece.

So, suppose it is I am generating this type of shape here. Now this is we have taken anode workpiece and that is tool is a cathode feed direction. So, tool is cathode workpiece is anode and we are generating this spark here and then there is a dielectric fluid, which may be even kerosene are any other such type of things that is being pump this is the symbol of pump it goes from here and it passes and again it passes through the filter.

So, pulse direct current power supply of 80 to 100 voltage applied, intense electric field is generated at the narrowest gap between the tool and workpiece. Electrons move towards the anode that is workpiece and ions move towards the tool dielectric fluids like kerosene and deionized water are used to create path for discharge.

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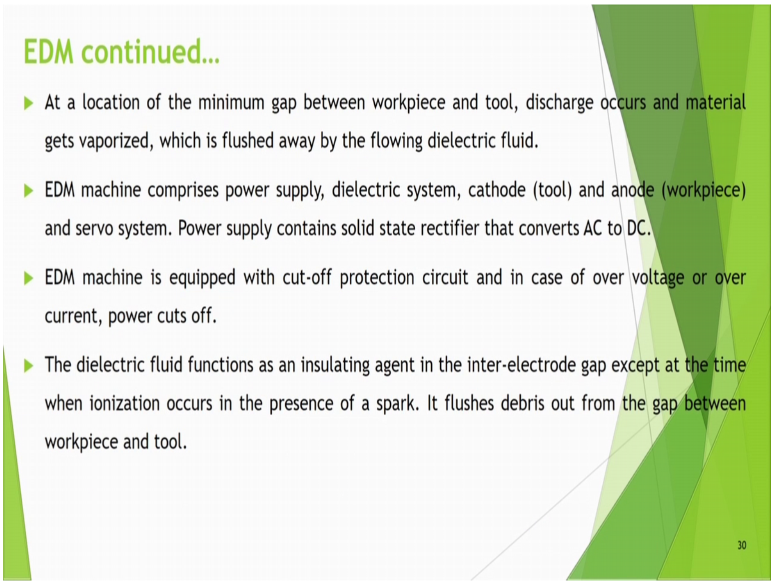

So, discharge occurs at a location of the minimum gap between the workpiece and tool discharge occurs and material gets vaporized which is flushed away by the flowing dielectric fluid.

EDM machine comprises power supply dielectric system cathode and anode and servo system. Servo system will maintain a constant amount of a guide means it is basically it will take a feedback and power supply contains solid state rectifier that converts AC to DC. EDM machine is equipped with cut off protection circuit and in case of any over voltage or over current power cuts off. Dielectric fluid functions as an insulating agent in the inner electrode gap except at the time when ionization occurs in the presence of a spark. It flushes debris out from the gap between workpiece and tool.

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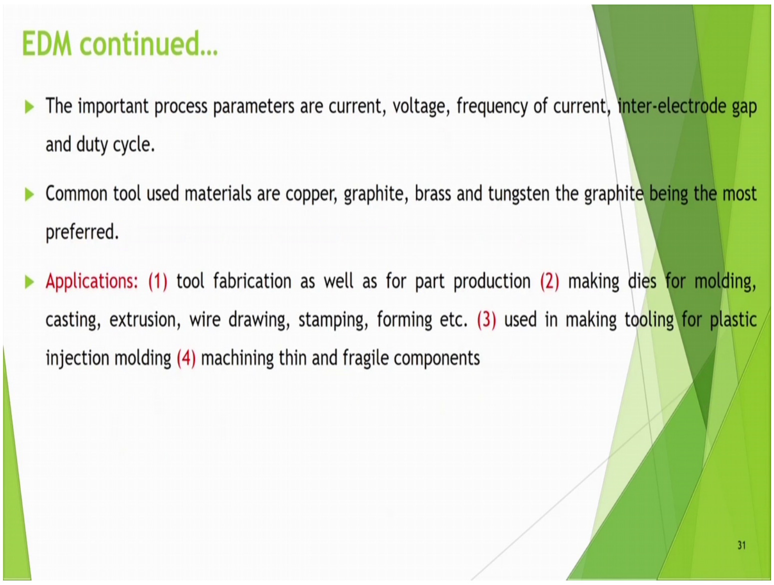

The important process parameters are current voltage frequency of current inter electrode gap and duty cycle. Common tool used material are copper, graphite, brass and tungsten; graphite being the most preferred, but we can may have the tool of copper etcetera. And applications are tool fabrication as well as for part production, they making dies for molding, casting, extrusion, wire drawing, stamping forming etcetera. It is used in making tooling for plastic injection molding and machining thin and fragile components.

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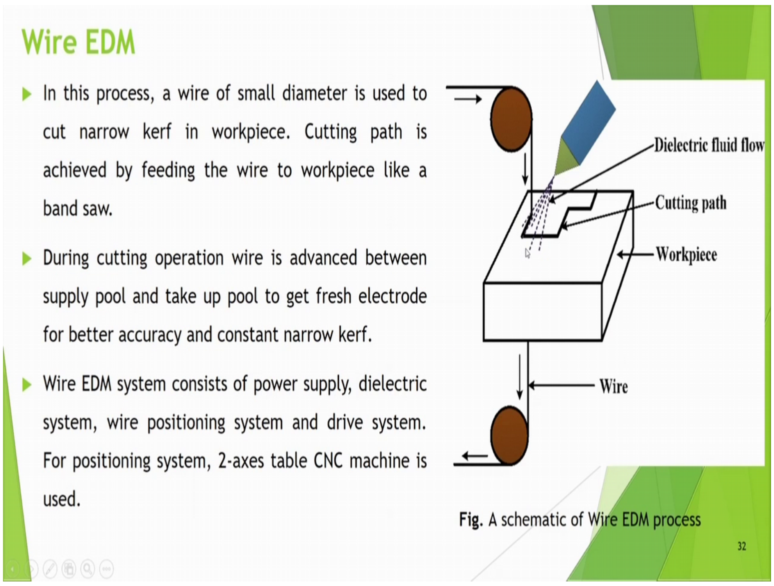

Now, variant of this electrical discharge machining is wire EDM, in which basically the tool is in the form of this is wire basically a spark is conducted between this. In this process wire of a small diameter is used to cut a narrow kerf is cutting workpiece, cutting path is achieved by feeding the wire to workpiece like a band saw. During cutting operation wire is advanced between supply pool and take up pool to get fresh electrode for better accuracy and constant narrow kerf. Wire EDM system consists of power supply, dielectric system, wire positioning system and drive system for positioning system 2-axes table CNC machine is used.

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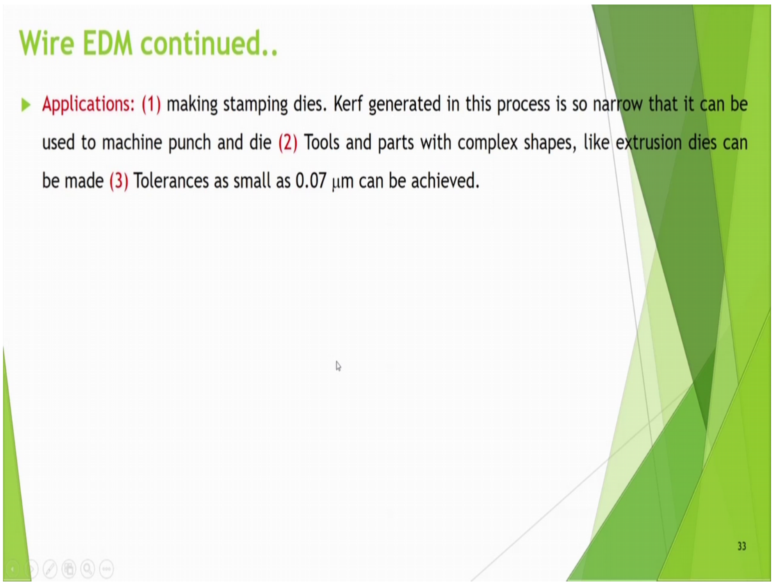

So, applications are making stamping dies. Kerf are cut generated in this process is narrow that it can be used to machine punch and die. Tools and parts with complex shapes, like extrusion die can be made. Tolerances as small as 0.07 micrometer can be achieved.

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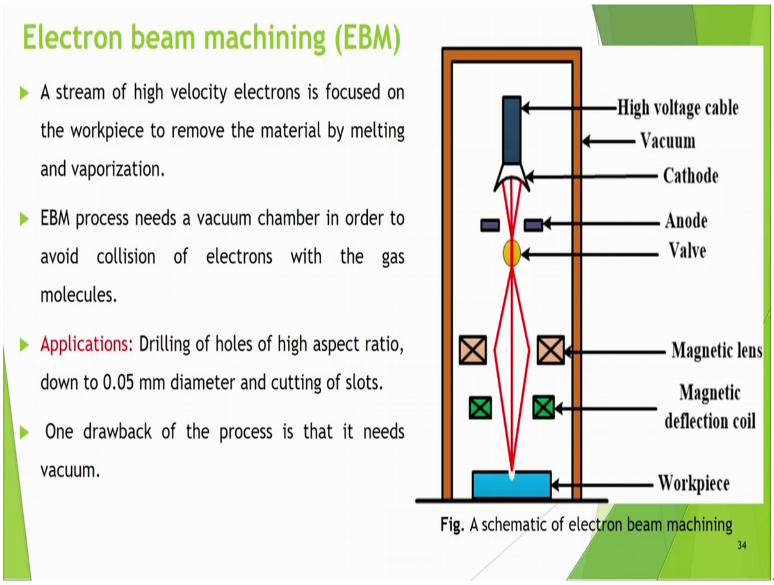

Fig. A schematic of electron beam machining

So, these are the process. So, this is a electrical discharge machining based on basically melting and vaporization of the material.

Electron beam machining is also such type of process, in which a stream of high velocity electrons is focused on the workpiece to remove the material by melting and vaporization. You can see it is a high volt voltage cable, but this process requires vacuum and then there is a cathode. Here the electrons are coming and they will be directed towards anode, then these are the valves which will actually focused. These are magnetic lens because you how to focus, but it is not a light these are electrons which have got the charges. So, by means of magnetic field, I can focus and then magnetic deflection coil is here and then workpiece. So, it can make some holes and it can do any other machining operation.

EBM process needs a vacuum chamber in order to avoid collision of electrons with the gas molecules. Application is drilling of holes of high aspect ratio down to 0.05 mm diameter and cutting of slots very small diameter hole like 0.05mm can be made. One drawback is of the process is that it needs vacuum. So, it is very expensive process as such usually you may get one machine of something like of the order of 10 [FL] or something, these are the rough estimates.

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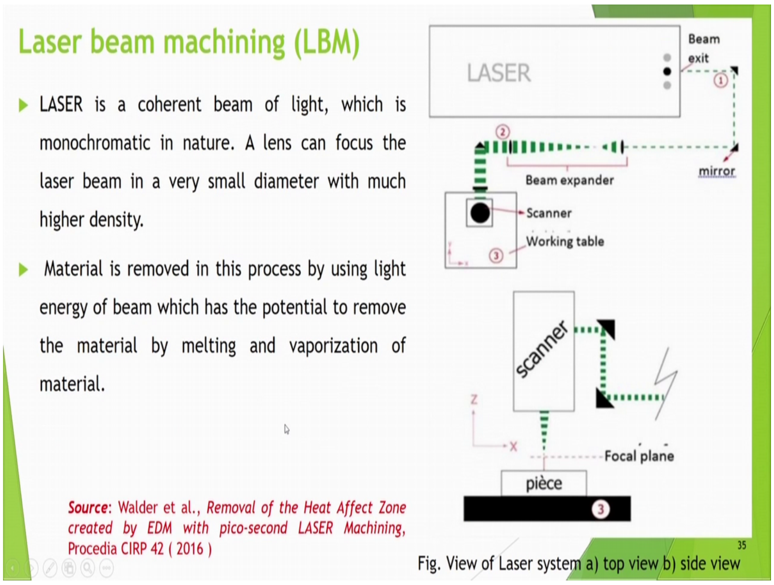

Then laser beam machining is you everybody is familiar with laser that is light amplification by stimulated emission of radiation. So, laser is a coherent beam of light which is monochromatic in nature. A lens can focus the laser beam in a very small diameter with much higher density. Material is removed in this process by using light energy of beam which has the potential to remove the material by melting and vaporization of the material. Now you see that here this is beam you may use some mirrors to focus if their working table may be like CNC type of this thing and then after that you have to say your machining and on the workpiece.

Now, what is there are impact femtosecond lasers which have got pulse duration is very very small in that.

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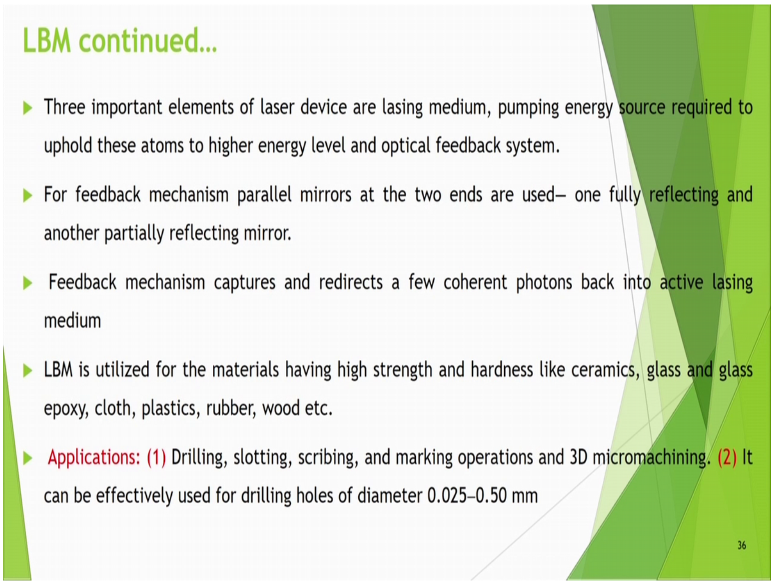

Now three important elements of laser device are lasing medium, pumping energy source required to uphold these atoms to high energy level and optical feedback system. For feedback mechanism parallel mirrors at the two ends are used- one fully reflective and another partially reflecting mirrors. Feedback mechanism captures and redirects a few coherent photons back into acting lasing medium. LBM is utilized for the materials having high strength and hardness like ceramics glass and glass, epoxy, cloth, plastics, rubber, wood etcetera.

Applications are drilling, slotting, scribing and the marking operations and 3D micromachining. It can be effectively used for drilling holes of diameter 0.025 to 0.5 mm. So, 0.025 mm also can be hole can be made which may be of point zero two five mm which means it is about 25 micron and 0.5 is of course, it is about 500 micrometer; so, 500 micrometer and 25.

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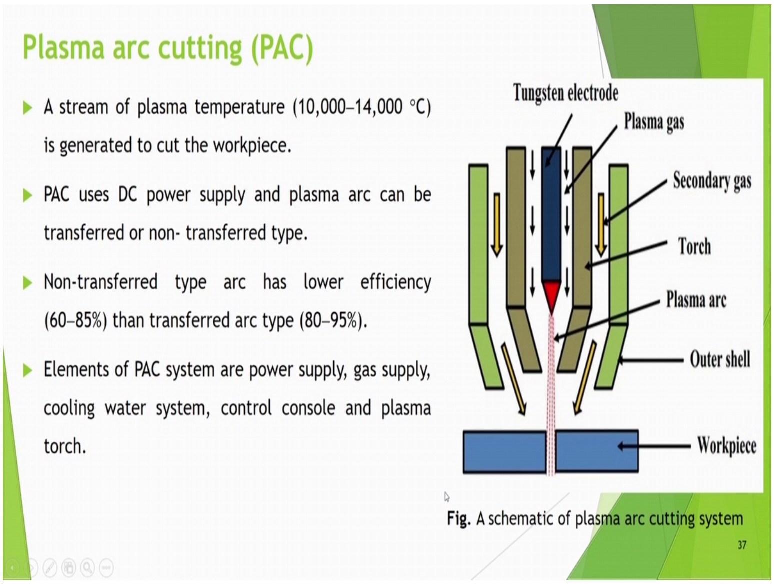

And plasma arc machining, it is also similar to laser beam machining, but here we are using a plasma. Suppose we have a tungsten electrode and which can be provided with the DC supply. A stream of plasma is basically ionized form of the gas in which there are ion. So, a stream of plasma temperature that is 10000 to 14000 degree generated to cut the workpiece. Plasma arc used DC power supply and plasma arc can be transferred or non transferred.

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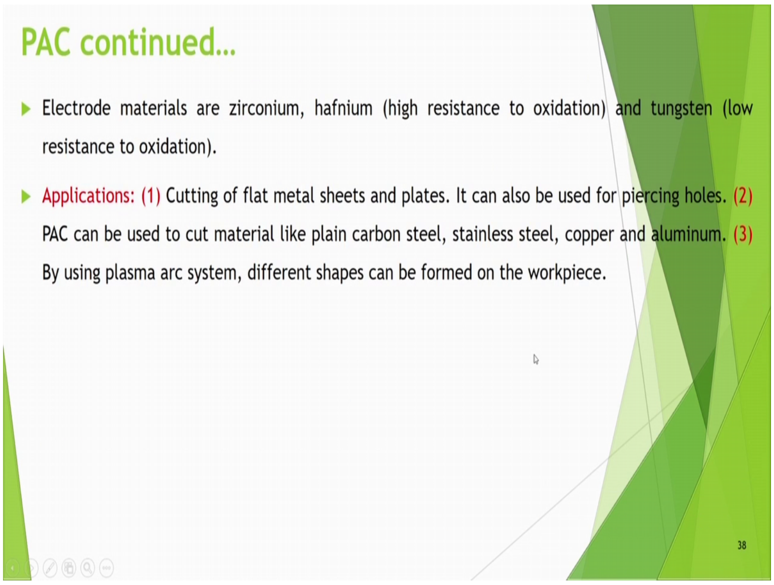

So, it is a two type of power supplies are there transferred and non transferred. Suppose in one workpiece itself is in the non transferred in the workpiece itself is acting as a one electrode and in another that suppose this is tungsten electrode, but other electrode is here. So, non transferred type of arc has lower efficiency 60 to 85 percent than transferred arc type and elements of PAC system are power supply, gas supply, cooling water system, control console and plasma torch electrode materials are zirconium, hafnium and tungsten. Applications can be cutting of flat metal sheets and plates. It can be use for piercing hole. PAC can be used to cut material like plain carbon steel stainless steel copper and aluminum and by using plasma arc system different shapes can be form on the workpiece.

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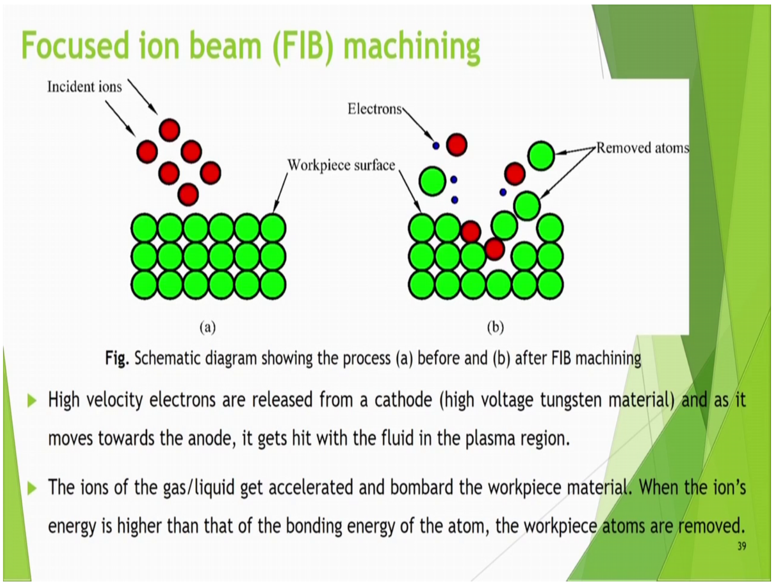

Now, I am going to tell like electron beam, we can have a focused ion beam, but here the material removal is not by thermal action. It is rather by steppering is spotoling action. So, it is spotoling takes place suppose incident ions are there. It is hitting the workpiece surface and it is removing the atoms. So, high velocity electrons are released from a cathode and as it moves towards anode, its gets hit with the fluid in the plasma region. The ions of the gas liquid get accelerated and bombard the workpiece material. When the ions energy is higher than that of the binding energy of the atom the workpiece atoms are removed.

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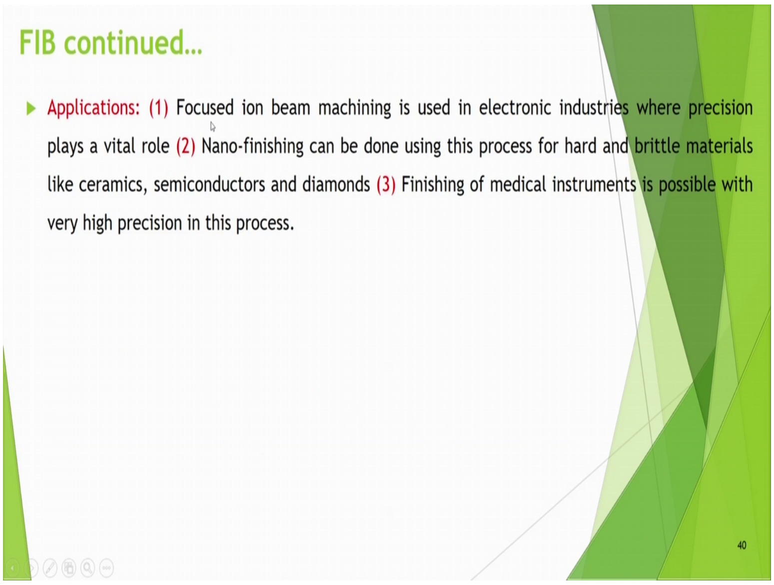

So, applications can be focused ion beam machining is used in electronic industries where precision plays vital role. Nano-finishing can be done using this process for hard and brittle materials like ceramics semiconductors and diamonds. Then finishing of medical instruments is possible with very high precision in this process.

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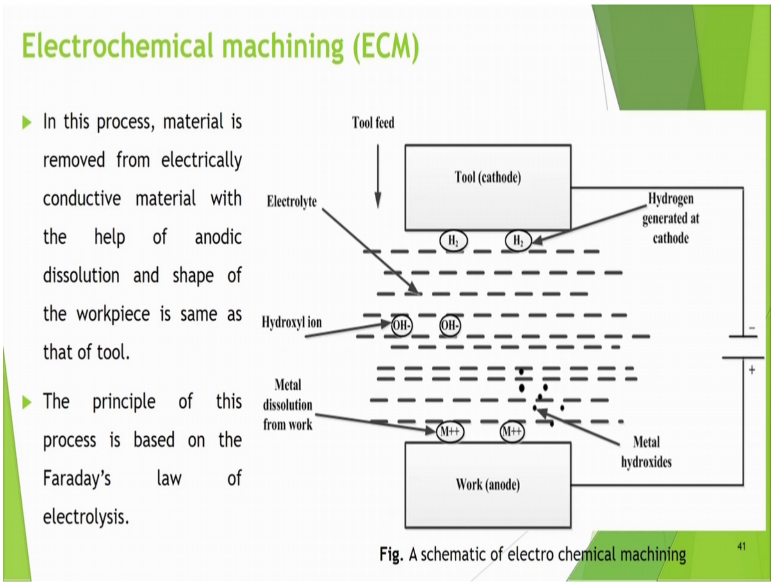

Now, I am going to discuss about electrochemical machining. So, this is quite different from the previous processes here it works on the Faraday's law of electrochemistry. Suppose workpiece is anode and tool is of cathode connected to negative one and this is positive one. And then this is electrolyte, then which may be like typically (Refer Time: 54:06). So, these are metal hydroxide so, this is ions are there and then what happens that these will be generated. So, what happens that if current is so, metal dissolution from the workpiece takes place it is here that m plus ions are removed and their these ions they actually can go that side and you can make hydrogen gas is evolved at H 2. So, this is the process and this will be shown here, in this material is removed from electrically conductive material with the help of anodic dissolution and shape of the workpiece is same as that of the tool.

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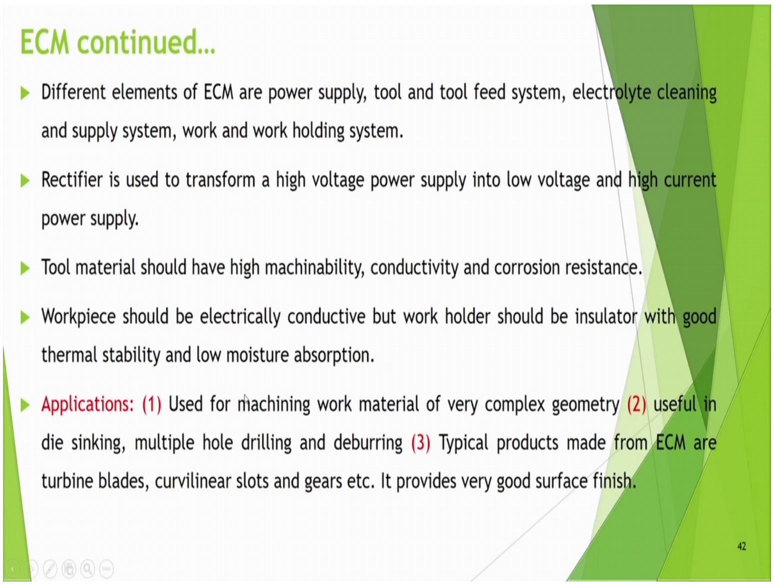

So, very high amount of the surface finish can be obtained in this. Principle of this process is based on the Faraday's law of electrolysis different elements of ECM are power supply tool and tool feed system, electrolyte, cleaning and supply system, work and work holding system, then rectifier is used to transform a high voltage power supply into low voltage and high current power supply. Then tool material should have high machinability conductivity and corrosion resistance Workpiece should be electrically conductivity, but work holder should be insulator with good thermal stability and low moisture absorption.

So, only electrically conductive materials can be machined. Application it is used for machining work material of very complex geometry. It is useful in die sinking, multiple hole drilling and deburring, then typical products made from ECM are turbine blades, curvilinear slots and gears etcetera it provides very good surface finish.

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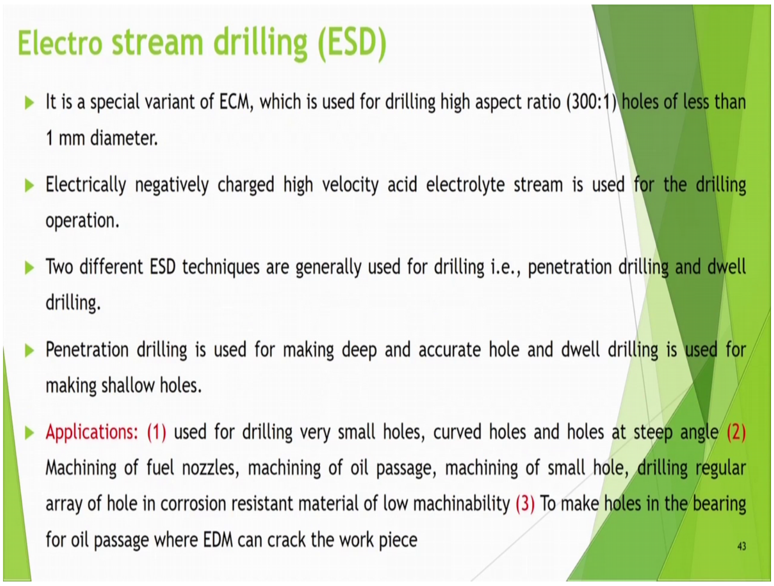

A variant of this process is electro stream drilling. It is a special type of ECM which is used for drilling of high aspect ratio 300 to 1 holes of less than 1 mm diameter. So, aspect ratio can be that much high; that means, length of the hole can be 300 time than its diameter.

Electrically negatively charged high velocity acid electrolyte stream is used for the drilling operation. Two different ESD techniques are generally used for drilling that is penetration drilling and dwell drilling. In penetration drilling is used for making deep and accurate hole and dwell drilling is used for making shallow holes. So, at the same location it rotates for some time and it makes this one shallow holes. Application can be it used for drilling very small holes, curved holes and holes at a steep angle machining of fuel nozzles, machining of oil passages, machining of small hole, drilling regular array of hole in corrosion resistant material of low machinability to make holes in the bearing for oil passage where EDM can crack the workpiece.

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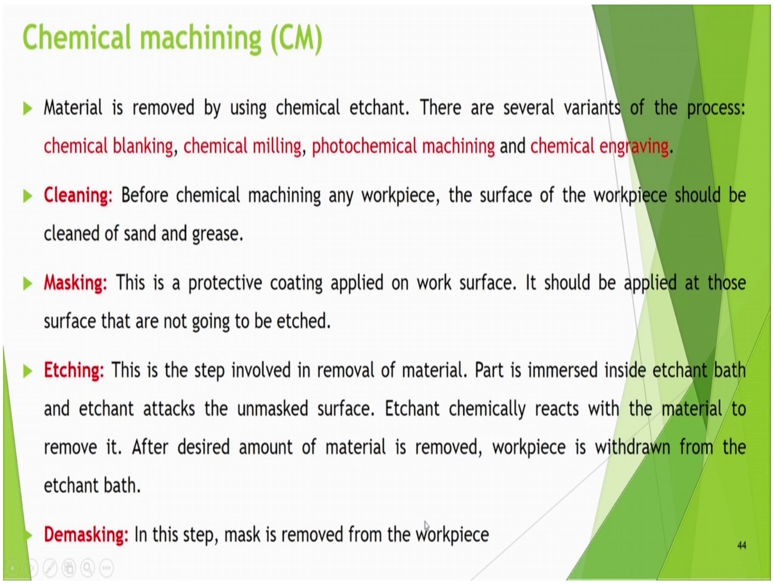

Then I discuss about chemical machining. Electro chemical machining uses electricity, but here it is for chemical action here material is removed by using chemical etchant. There are several variants of the processes; chemical blanking, chemical milling, photochemical machining and chemical engraving. If you have made any circuit in the PCB printed circuit board; probably you must have used chemical machining actually which removes that certain material selectively.

So, it is cleaning is first done before chemical machining any workpiece. The surface of the workpiece should be cleaned of sand and grease. Then masking is done to protective it is basically protective cooling applied on work surface. Earlier sometimes we used to work on the printed circuit board and we used to put some nail polishing, those areas where we did not want the material removal. Rest of the places the copper coating to used to get the dissolved.

So, like that masking should be there it should be apply to those surface that are not going to be etched and etching, this is the step involved in removal of material. Part is immersed inside etchant bath and etchant attacks the unmasked surface etchant chemically reacts with the material to remove it. After desired amount of material is removed, then workpiece is withdrawn from the etchant bath and then finally, we do demasking. That means, we remove the damask material like in the PCB, we used to remove the nail polish by slightly by using some blade to take it out. And in this step so, mask is removed from the workpiece. So, that is how chemical machining occurs.

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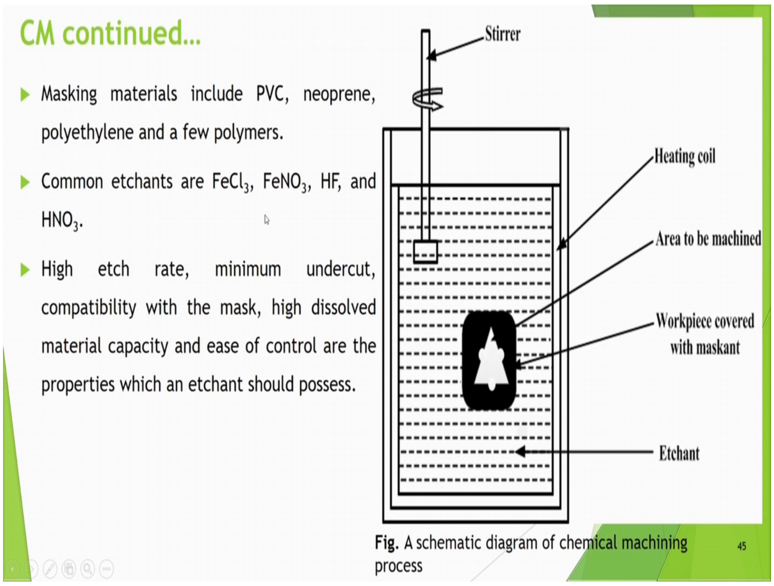

It is showing that schematic diagram that it is a heat contains that some bath in which etchant is there and workpiece is covered with a maskant, which may be of complicated shape and stirrer is there which will is still this one. So, that effectively the chemical will flow and area to be machined is mentioned here and then finally, it works.

Masking materials include PVC polyvinyl chloride, neoprene, polyethylene and few polymers and common etchants are FeCl 3, FeNO 3, HF and HNO 3. So, high etch rate minimum undercut compatibility with the mask high dissolved material capacity and ease of control are the properties which an etchant should possess.

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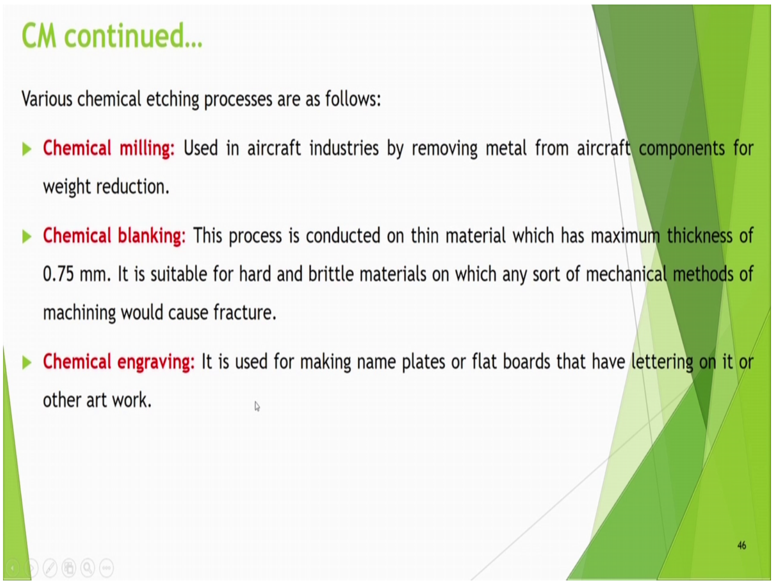

So, these are the properties and various chemical etching processes are as follows. Chemical milling; it is used in aircraft industries by removing material from aircraft components for weight reduction. Sometimes we use in aircraft industry, then we use chemical blanking. This process is conducted on thin material which has maximum thickness of 0.75 mm. It is suitable for hard and brittle materials on which any sort of mechanical methods of machining would cause fracture. And then chemical engraving it is used for making name plates or flat boards that have lettering on it or other art works.

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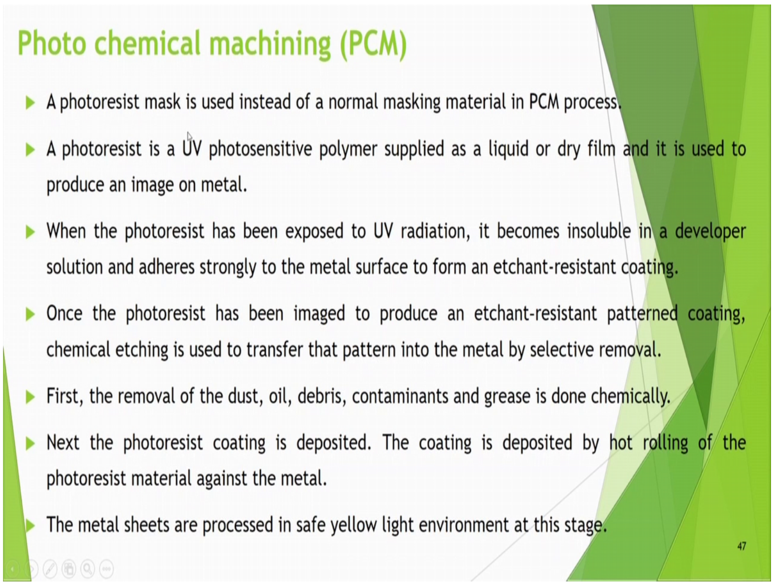

Then photo chemical machining is like a chemical machining only, but here a photoresist mask is used instead of a normal masking material in chemical machining process. A photoresist is a ultraviolet photosensitive polymer supplied as a liquid or dry film and it is used to produce on image on metal. When the photoresist has been exposed to ultraviolet radiation, it becomes insoluble in a developer solution and adheres strongly to the metal surface to form an etchant resistant coating.

Once the photoresistor has been imaged to produce an etchant resistant patterned coating, chemical etching is used to transfer that pattern into the metal by selective removal. First the removal of the dust oil debris contaminants and grease is done chemically. Next the photoresist coating is deposited; the coating is deposited by hot rolling of the photoresist material against the metal. Then the metal sheets are processed in safe yellow light environment at this stage.

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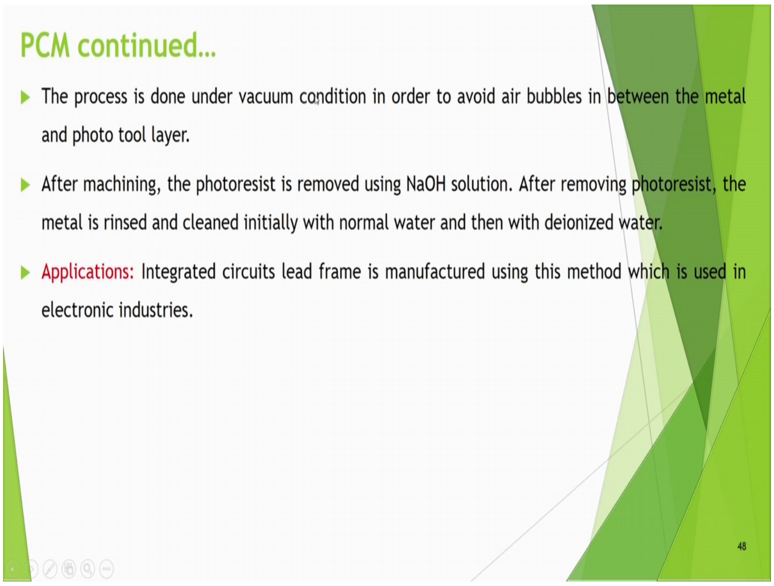

The process is done under vacuum condition in order to avoid air bubbles in between the metal and photo tool layer. After machining the photoresist is removed using NaOH solution. After removing photoresist the metal is rinsed and cleaned initially with normal water and then with deionized water. Applications include integrated circuits lead frame is manufactured using this method which is used in electronic industry.

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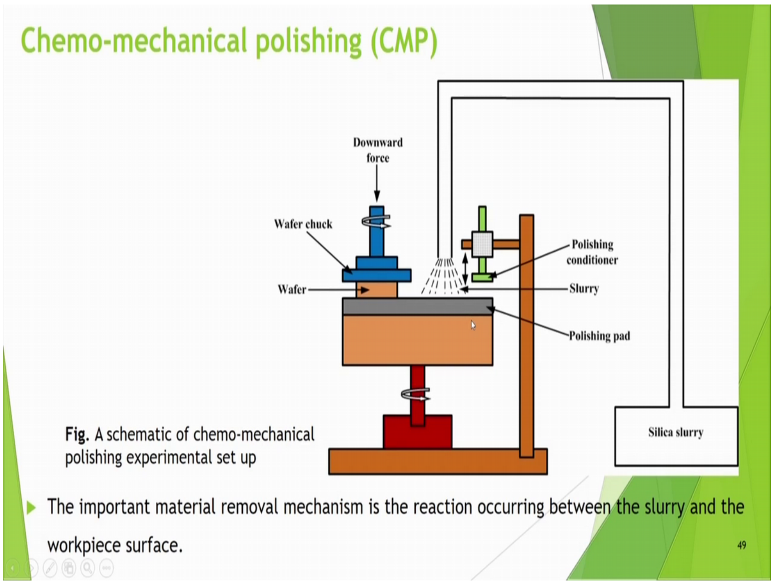

Then this is chemical mechanical polishing. This is basically chemical as well as mechanical action is there. This is shown that silica slurry is there, it is coming through this. This is a polishing conditioner and this is a polishing pad this is some wafer which you are going to machine.

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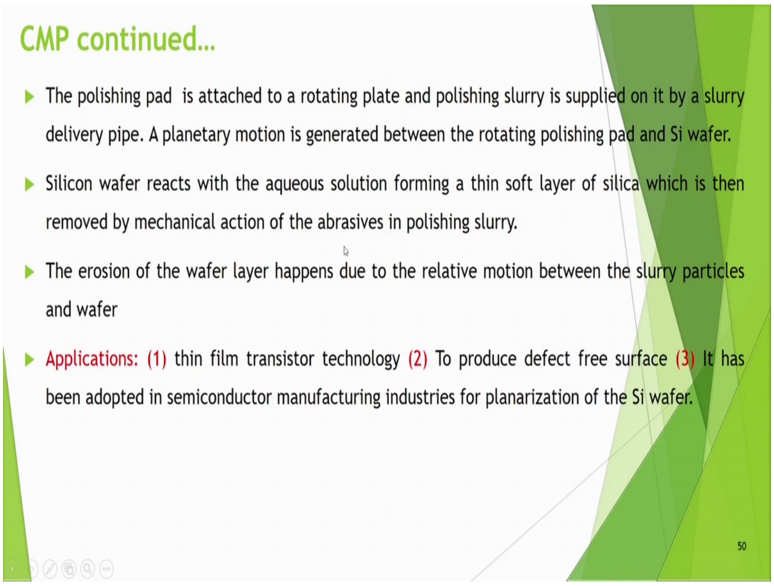

So, this is a wafer chuck and you are machining that wafer. So, in this important material, removal mechanism is the reaction occurring between this slurry and the workpiece surface. And the polishing pad is attached to a rotating plate like this, this is polishing pad and polishing slurry is supplied on it by a slurry delivery pipe like this it is coming from here.

A planetary motion is generated between the rotating polishing pad and Si wafer. Silicon wafer reacts with the aqueous solution forming a thin soft layer of silica which is then removed by mechanical action of the abrasive abrasives in polishing slurry. So, that is the erosion of the wafer layer happens due to the relative motion between the slurry particles and wafer. Applications are thin film transistor technology to produce defect free surface. It has been adopted in semiconductor manufacturing industries for planarization of the silicon wafer. So, this is I have discussed about various type of processes and I just have given type of exposure.

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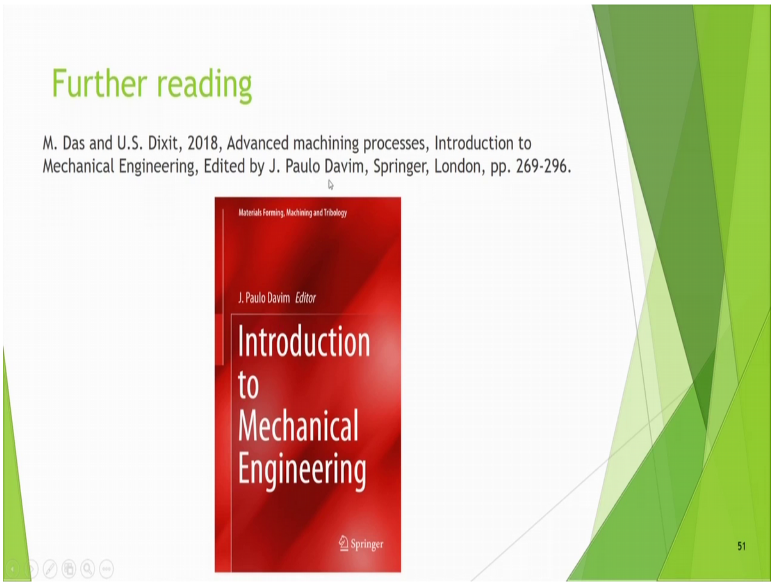

And for further reading you can refer this my chapter that is advanced machining processes by (Refer Time: 63:57) Das and us Dixit, Introduction to Mechanical Engineering. In this book it is contained, you can get that one. Otherwise you can read any book whatever the text books I have specified in the beginning like they will contain particularly GK Das book of machining will not contain this one. But it can it is contained in the book by Gosh and malik and other books are there is a book of VK Jain which is on Advanced Machining Processes in that you can get to know.

So, this is basically that it covers that complete course. It covers 20 lectures and I have discussed basic machining particularly how to find out the cutting forces, how to find out the surface finish, how to find out temperatures. Mostly I have discussed the analytical models. particularly we discussed three dimensional cutting mechanics also. But in this you how to understand many times because understanding it from a 2D screen. Those things are not so easy. So, unless you work it out many times you really not get understanding of the three dimensional force system. So, that type of thing.

But in spite of that I would say that these analytical models, they have their own limitations. I have discussed in the beginning that what are the basic governing equations basically you how to solve the stress equilibrium equations, constitutive equations and the strain displacement relations. Then you can do the things by FEM, but even by finite element also, there obtaining the proper solution is not so easy because, there are lot of uncertainties. Uncertainty about the material behavior at high strain rate and high temperature and so that behavior is also not very clear so, there is uncertainty in the material behavior. There is uncertainty in the friction. In fact, even there is uncertainty about the cutting mechanics; suppose you are doing that micro machining, then cutting mechanics is something different. In micro machining the cutting mechanics may be different. It may differ from material to material in some materials one misses yield criteria may be valid in some materials, it is not valid.

So, we have got so many limitations nevertheless many times these methods which we have discussed provide a good qualitative understanding and the results obtained can be fine tuned by means of the experiments. At least they provide that proper basis for designing or optimizing something, but the research in this machining area is still going. It is one that type of field in which I would say that the in a way that a particular type of research has got saturated not because we have known everything, but are the known methods have been tried and there may be a need of some break through.

That means, entirely new type of theory by which we can understand better. Nowadays other techniques are also there like molecular dynamic simulation in that we analyze the atom by atom and behavior is on understood at the molecular level; however, that such types of systems are still not very practical because first of are they require huge amount of computational time.

Similarly, you have that crystal plasticity models. They will capture the anisotropy behavior, but even then here the computational time and proper understanding of the various of physical variables is are issue. So, all these things are there, but I hope that this course has provided with you proper exposure and it has provided you with an ability to thing scientifically to understand the process, to understand what is going on this thing.

So, we started with a explaining you the concept of a wedge shape tool and then after that we have move to the various variants of the machining processes; conventional machining processes. And then finally, we have also given you exposure about advanced machining processes. So, this way this as a package of 20 lectures, this course has provided a sufficient exposure and an ability for you to continue your learning process because, learning is a lifelong process.

Thank you.