Introduction to Abrasive Machining and Finishing Processes
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Lecture - 16
Ultrasonic Machining (USM)

In today's class we are going to see another Abrasive Machining Process that is called Ultrasonic Machining Process. The ultrasonic machining process comes under one of the advanced machining processes are unconventional machining processes are nontraditional machining process, these are the synonyms for the advanced manufacturing processes. So, only we are going to look at the advanced machining processes that are involved with abrasive particles.

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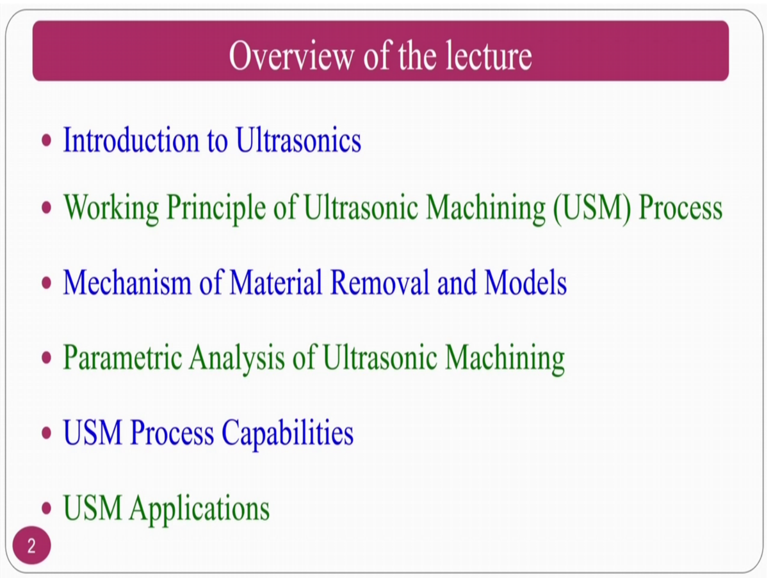

The overview of the lecture so, introduction to ultrasonics; what is ultrasonics? Because, you are going to study about ultrasonic machining so, you should know what is ultrasonics? The, working principle of ultrasonic machining, then the mechanism of material removal and what are the models like hitting model and other things. The, parametric analysis of ultrasonic machining then the capabilities of ultrasonic machining and applications; where you are going to use this particular process?

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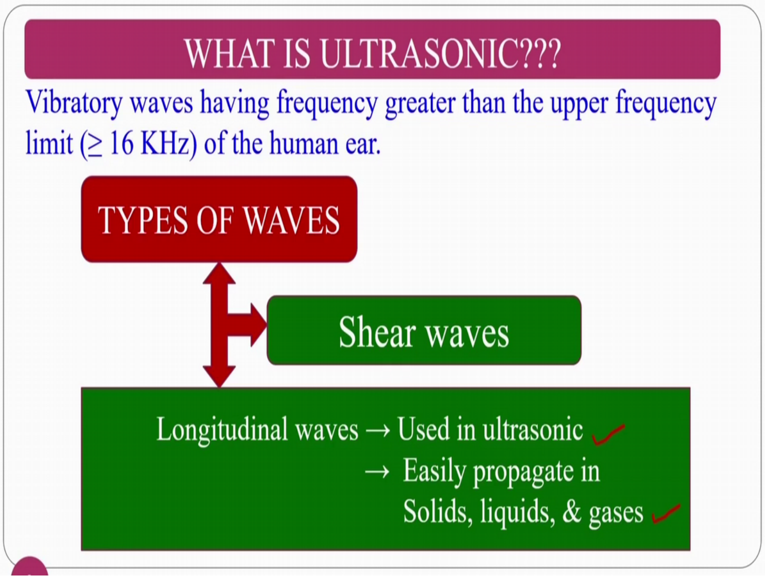

So, what is ultrasonics? Normally, these are the vibratory waves having frequency greater than the upper frequency of the human here; that means, that it should be higher the frequency of what we can here. So, normally the limitation is 16 kilohertz. And, the type of waves there are varieties of waves, but we are going to see about the two varieties one is a shear waves, another one is longitudinal waves that are used in ultrasonics.

At the same time easily propagate to the solids and liquids as well as gases. These are the longitudinal waves and what we are going to see in the particularly ultrasonic machining is longitudinal waves. Just we give the frequency and amplitude so, that it will reciprocate in a ultrasonic range.

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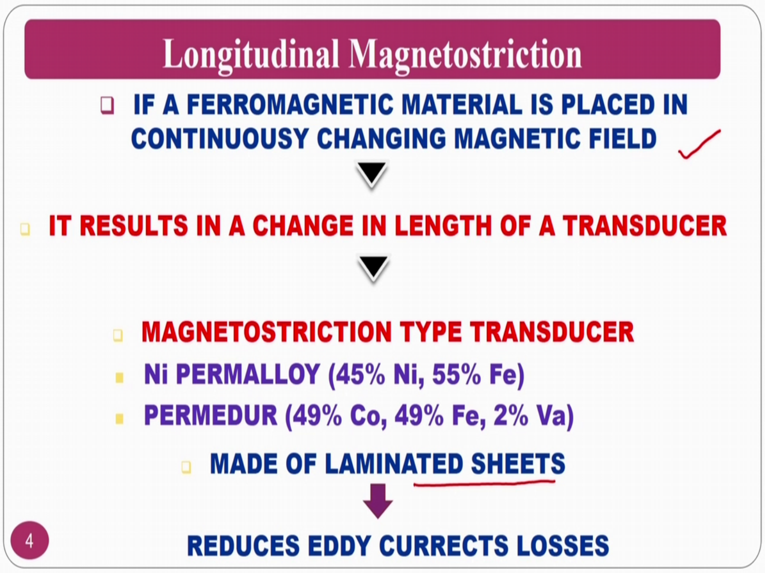

See as I said these are the longitudinal waves so, longitudinal waves how we are going to get? We are going to get by the longitudinal magnetostriction. So, if a ferromagnetic material is placed in a continuously changing magnetic field, then what will happen? It will result in a change in the length of the transducer; that means that it will change the length if there is a change the length; that means; that length is varying delta l is coming into picture.

So, the magnetostriction type transducer there are varieties, but N i permalloy is there permedur will be there. So, N nickel permalloy will consist of 45 percent of nickel, 55 percent of iron will be there, permedur will have 49 percent of cobalt, 49 percent of iron, and 2 percent of vanadium is there. And, in order to reduce the eddy current losses and other things, normally these transducers are made up of laminated sheets, that is one of the advancements in the ultrasonic machining process, in the transducer section is concern.

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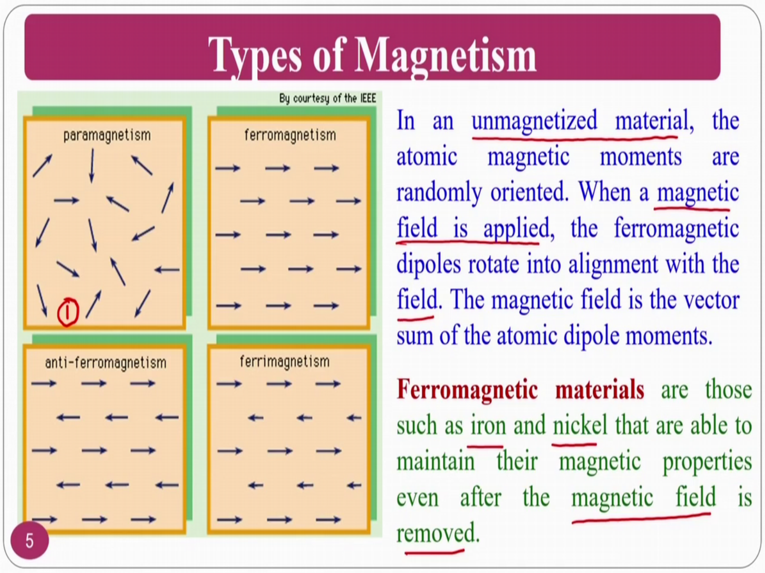

Type of magnetism as you are well aware of varieties of magnetism will be there that paramagnetism, ferromagnetism, anti-ferromagnetism, and ferrimagnetism and other things.

In the paramagnetism the basic thing is that in a un magnetized material. Basically, if you are not putting any if you are not if the material is not experience in any magnetism, the atomic movement are the atomic magnetic moments are randomly oriented. As, we can see here in the figure 1 this atomic magnetic moments are in randomly oriented. When the magnetic field is applied, what will happen these are all will align in one direction ok.

So, that is called the ferromagnetic dipole rotate into align along with the field. See this magnetic field is a vector sum of the atomic dipole moment ok, like this it will arrange. The ferromagnetic materials have those materials such as iron and nickel that are able to maintain that magnetic properties. Even after the magnetic field is removed that is what is there, whenever we are going to use you will use ferromagnetic materials.

Even though if you are not applying any magnetic field, it will have it is own alignment of dipoles ok. There is no requirement of you have to give some magnetic field are something this is not that. So, in a normal materials if at all in the normal state this dipole moments are randomly oriented, if you put into the magnetic field then it will align along the direction of the field and it will give some dipole moment and the vector sum will give you complete thing.

Then, enough if you are choosing instead of that particular material choosing it a ferromagnetic material there is no requirement of magnetic field are requirement of magnetic field will be there, but even though you remove it what will happen you will have the dipole moment. Even though you remove there will be the dipole moment.

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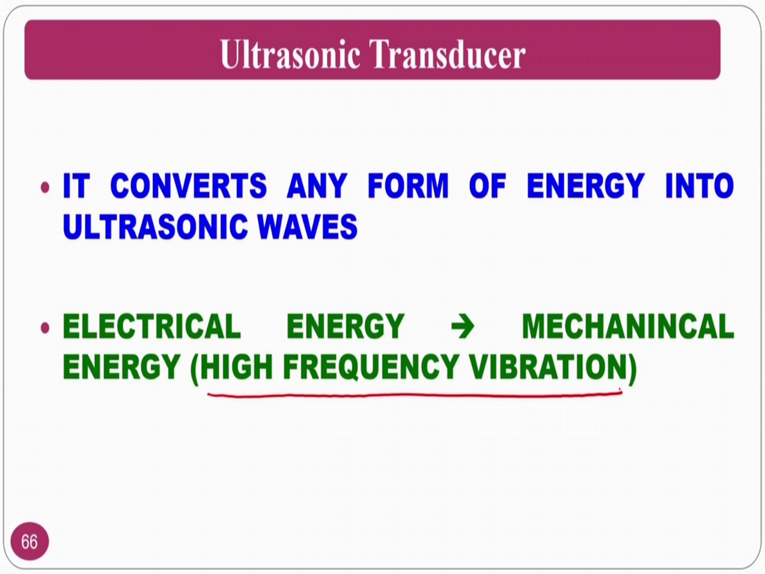

So, ultrasonic transducer normally, it converts any form of energy into ultrasonic waves, in the current work what we are going to see is electrical energy normally you supply the electrical energy. Then, it will convert into mechanical energy where high frequency vibrations are produced in particularly in the ultrasonic machining process.

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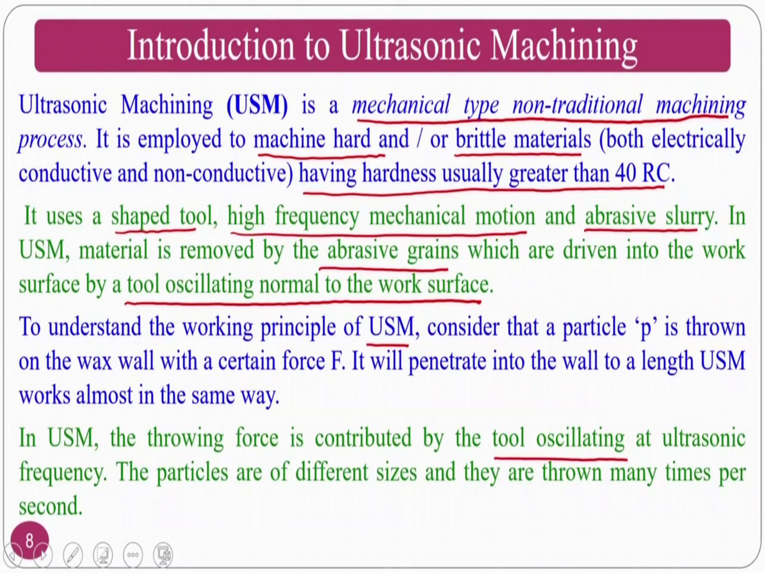

Coming to the working principle of ultrasonic machining process so, the introduction to ultrasonic machining, ultrasonic machining is a mechanical type of non-traditional machining processes as I said in the first slide. It is a one of the non-traditional or advanced machining processes normally; this is employed to machine hard and brittle materials.

So, both electrically conductive or non-conductive irrespective of electrically conductive or nonconductive having hardness values usually greater than 40 RC. It uses the shaped tool; basically depend on your shape that I assume that I want to get a hole circular hole.

So, you have to get a circular type of cylinder type of tool so, cylindrical type of shaped tool. So, high frequency mechanical motion is required to the tool and the abrasive slurry also should be there. If the abrasive slurry is there then what will happen it will reciprocate and there will be a mechanical action.

In the USM material is removed by the abrasive grains which are driven into the work piece surface by the tool oscillating normal to the work surface, because of which the material removal will takes place. To understand the working principle of ultrasonic machining considered a particle p thrown into the wax wall at a certain force F. It will penetrate into the wall to a length and USM almost work in the similar way ok.

So, the throwing force is contributed by a tool oscillating at. So, what did; that means, is there is a wax wall is there is just throw a stone are you just throw a particle with respect to p what will happen, it will go indent to the wall ok. Similarly, in ultrasonic tool will be there which is continuously increasing and decreasing it is length.

So, your slurry is going in between and this will going to hit the abrasive particles and abrasive particles go gain the kinetic energy and this kinetic energy will go and hit the work piece surface. So, that the material removal will takes place so, for the better explanation schematic diagrams and other things are there in the upcoming slides.

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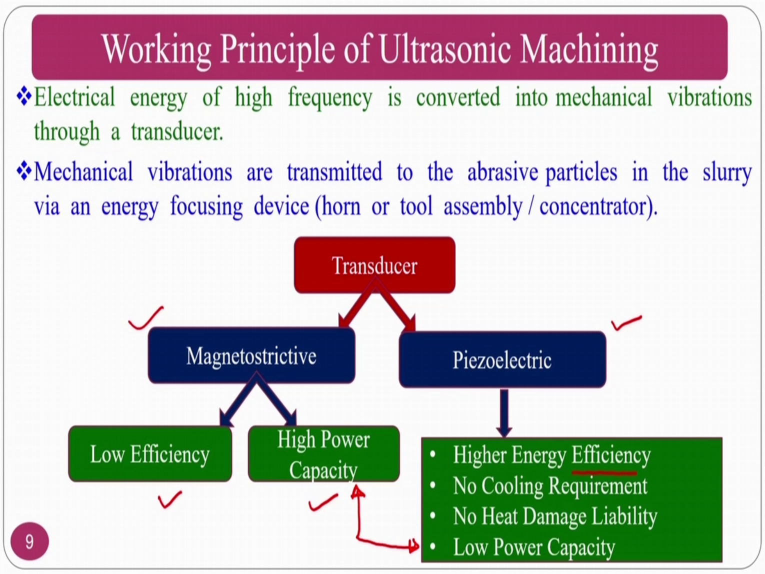

Electrical energy normally is converted into the high frequency into mechanical vibrations. And, these are the transducers, as I said magnetostrictive transducer and piezoelectric transducer, the basic problem with magnetostrictive transducers is it is low efficiency at the same time high power capacity will be there.

But, in the piezoelectric transducers will have higher energy efficiency; that means, that efficiency is good; that means, that your output also very good. No cooling is required in a magnetostrictive other things what will happen you have to put magnetic field to cool the magnetic coils; you need to have the cooling arrangement and other things.

So, there is no cooling requirement for piezoelectric type of thing, but you require cooling for the magnetostrictive type no heat damage to the liability and low power capacity. Here, capacity in magnetostrictive is very high and but if you see in case of piezoelectric transducers it is low; that means, that always if you see the piezoelectric type of transducers are preferred for the ultrasonic machining process.

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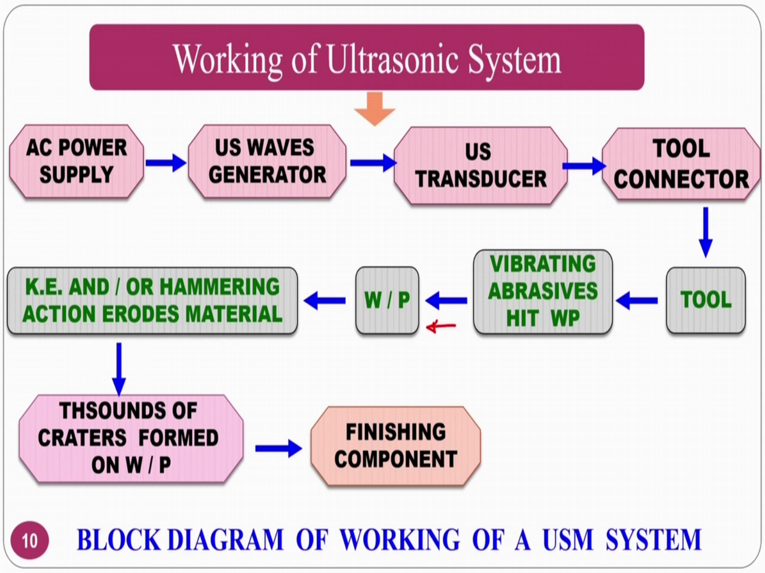

Working of ultrasonic system; so, how it works AC power supply just supply of a current, other power is supply the power, then it converts into the ultrasonic wave you just supply the AC power to the ultrasonic waves generator. Now, ultrasonic waves generator process is ultrasonic transducer, which is connected to the tool.

And, this ultrasonic transducer produces the ultrasonic vibrations and, these vibrations are fed are given to the tool these vibrating tool will hit the abrasive particles. And, these abrasive particles will hit the work piece and kinetic energy are hammering action of the abrasive particles on the work piece will remove the material. This is how the ultrasonic system complete system works? So, what we are interested is what is happening in the machining region of ultrasonic machining?

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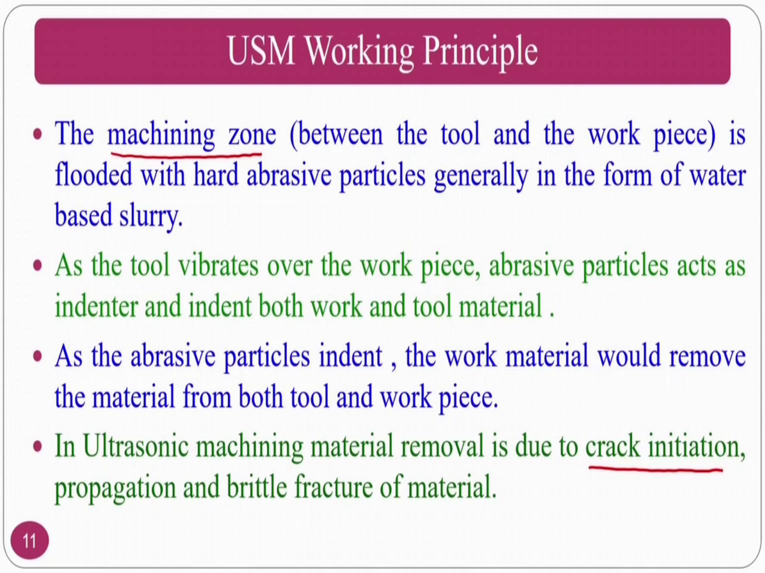

That we will see here in the principal when the machining zone that is between the tool and the work piece is flooded with the hard abrasive particles generally in the form of water and slurry. Normally, what will happen you have abrasive particles which are blended with water or any carrier medium?

The tool vibrates over the work piece, the abrasive particles act as the indenter and indent both on the work piece as well as tool; that means, that the slurry is comes in between the tool and work piece, but the work piece is stationary and your tool is vibrating assume that you are tool is like this straight and it is vibrating like this.

So, whatever the abrasive particles come here it will hit. So, that your work piece is at the bottom so, it goes and the abrasive particles goes and hit the work piece. If the work piece is brittle, the brittle fragments will comes out by brittle fracture. The ultrasonic machining material removal is due to crack initiation that is what I said if the work piece material is brittle, and propagation and brittle facture of the material ok.

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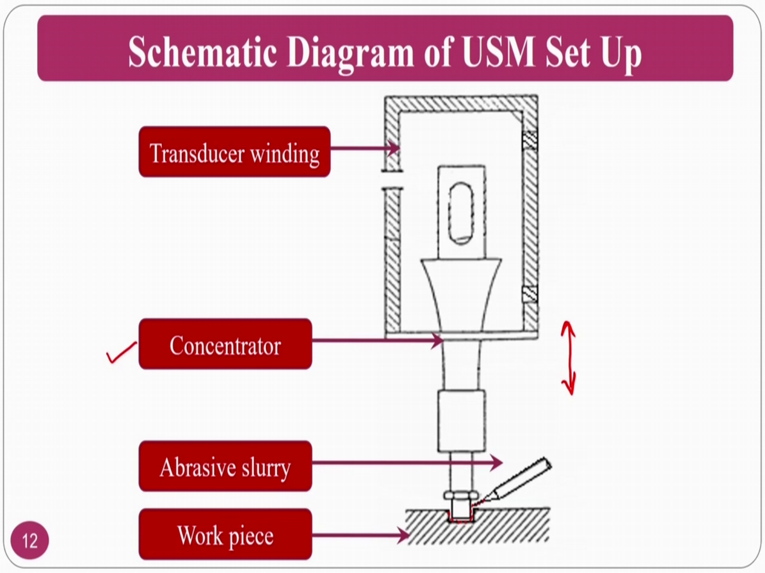

Schematic diagram if you see whatever I am saying in the previously this is a transducer winding, if you are going for magnetostrictive and other things this is a connector. And abrasive slurry so, abrasive slurry is fed between the work piece and tool and what will happen this magnetostrictive winding is supplied, then what will happen this transducer elongates and swings ok. Because of which what will happen you will see in the next slides. This is the how the originally the setup looks like original setup.

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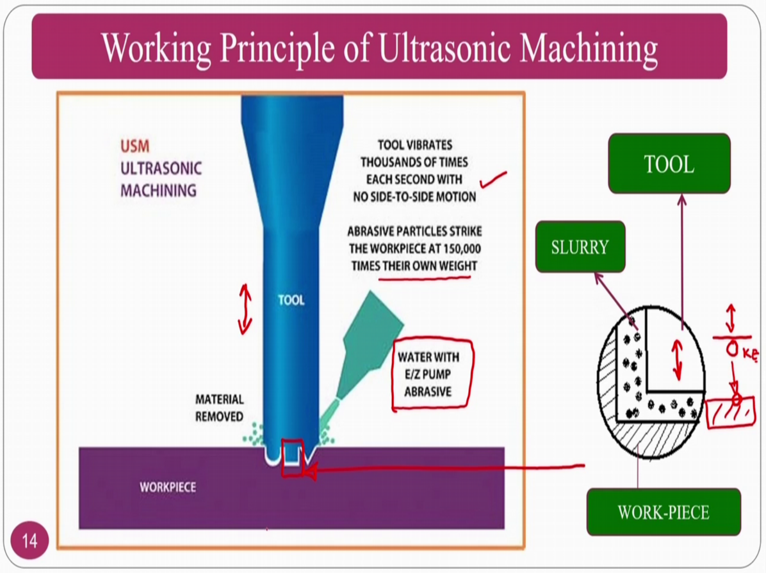

And, if you see here what is happening the this is the shape that I want to generate to explain you normally there are 3 types of geometries are given. So, if at all I want to generate what will happen this will reciprocate; that means that change in length. Because the tool vibrates 1000s of times each second with no side or side motion. There is no side motion only it moves in a vertical motion abrasive particles like the work piece at 1.5 lakhs times to their own weight.

That mean that the kinetic energy that it gains will have impact on the work piece and the work piece removes the material in the form of brittle fragments ok. Normally, the slurry if you see water with along with abrasive particles are fed here. So, if you enlarge this particular portion and if you see here so, just you enlarge this particular portion and if you see here what will happen? This abrasive particles are coming here this along with the water which is the thing, but a slurry and this is reciprocating my tool is reciprocating, what will happen?

If the tool is assume that this is my tool and abrasive particle is here, what it gains is whenever it is good reciprocating like this. The kinetic energy will carry to the abrasive particle and abrasive particle assume that my work piece is here. So, abrasive particle will move like this and creates the greater. So, kinetic energy of the particle will come and hit the work piece and the work piece will take the shape of whatever the shape that is given on the tool; that means that the tools converse shape will be taken in the work piece.

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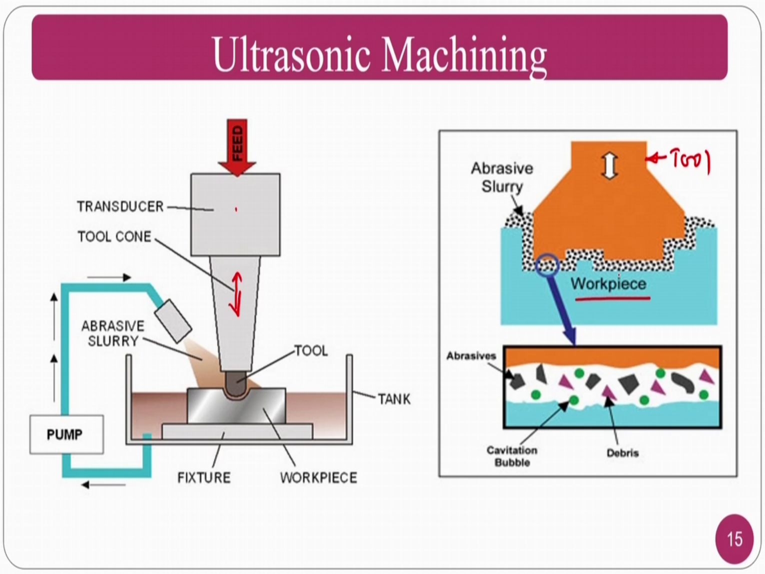

Ultrasonic machining if you want to see in the schematic way so, the abrasive slurry is fed like this and the tool is there. And transducer is there this transducer gives the vibrations and the tool vibrates like this and you will get the required or the conversion of the work piece. And, if you see the mechanism this is the tool it is unable to see this is a tool and this is a work piece you can see here.

So, the abrasive particles are hitting with the kinetic energy and whatever the shape is there, that shaped you can generate on the work piece material; that means, that the converse shape of the tool will be generated and the work piece surface. The mechanism and models of the material removal, normally the mechanism as well as the models there are the some of the models proposed by the famous people.

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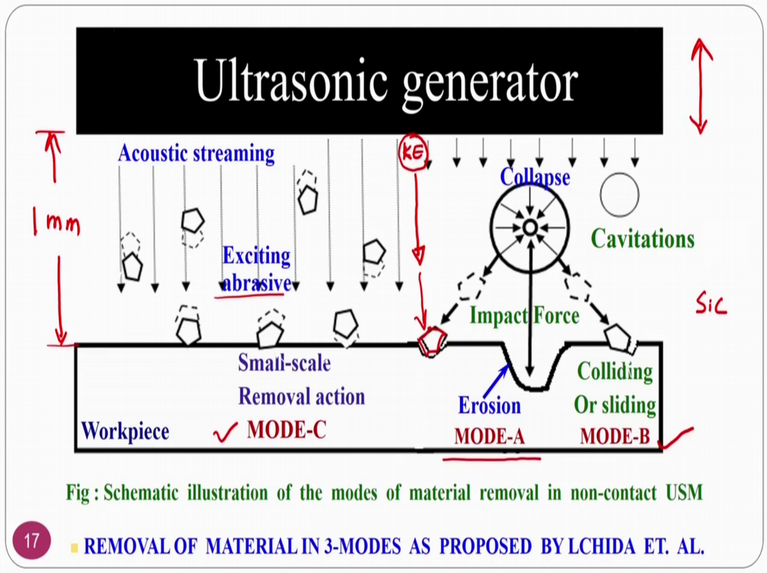

And, we are not going to study all the models; we are just going to see one of the models. See ultrasonic generator is there which is connected to the tool, whenever the ultrasonic generator produces the ultrasonic vibrations; that means, that this type of vibrations what will happen is abrasive particles gains the energy. Assume that my abrasive particle is here what is this going to do?

It, going to gain the kinetic energy and tries to move towards the work piece, do not think that this particular space is very large or something. It is in maximum few millimeters are normally it will be in the range of few microns or 1 m m or something ok. So, it will be within this distance the complete mechanism is taking place ok. If, you see the acoustic streaming, normally excited abrasive what will happen whenever the kinetic energy is given to the abrasive particle here. It gains the kinetic energy and excites and it will come and hit the work piece.

So, the material will be removed ok. The mode one the material removal is erosion; that means, that whenever the abrasive particle will hit. So, the erosion action takes place that mode 2 will be like colliding or sliding, whenever it comes in the sliding position or whenever it collides basically the work piece hardness is much lower compared to tool hard.

That means that the abrasive particle hardness. The common use the abrasives are silicon carbide alumina, boron carbide and other things the work piece material is like stainless steel or some other materials ok. The Mode-C will be small scale removal action; that means, that the whenever the surface hits with low kinetic energy.

And, it is not like that in the all the particles which are coming in get the same amount of energy, some of the abrasive particles will get the energy from the starting position. So, that they have very good kinetic energy to carry off, some of the abrasive particles will be touching the tool when it is moving back to it is original position so, it is not that all the particles will gain the same amount of energy. So, there are 3 modes and this regarding these modes we will see what is a penetration levels what is the shape and other things we will see.

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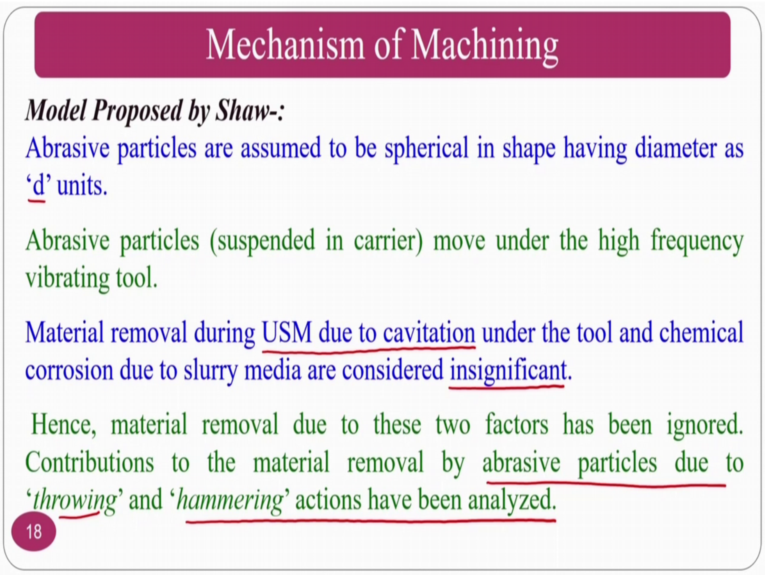

The material removal mechanism model is proposed by Professor Shaw. Abrasive particles are assumed to be spherical and shape having diameter of d. The abrasive particles suspended in a career move under the high frequency vibrating tool that, that mean that all the abrasive particles that you are feeding in the previous figures are moving under are we need the tool; that means, that we are assuming all the particles are going practically it is not so.

But, for modelling application normally we will see that for simplification of model we assume that all the particles are reaching to the beneath the tool, where the kinetic energies transformed from tool to the abrasive particle. Material removal during ultrasonic machining is due to cavitation under the tool and the chemical erosion due to the slurry are considered insignificant; that means, that these type of mechanism also is there right like cavitation as well as chemical erosion and other things.

Those are all considered insignificant; that means that the material removal action is taking care purely by the mechanical action of the abrasive particle. Hence, the material removal due to these two factors has been ignored contribution to the material removal of the abrasive particles is due to throwing and the hammering actions have been analyzed. That means that whenever you are considering the chemical corrosion as well as the cavitation is negligible then the only two options are mechanical options, that is throwing and hammering actions are analyzed.

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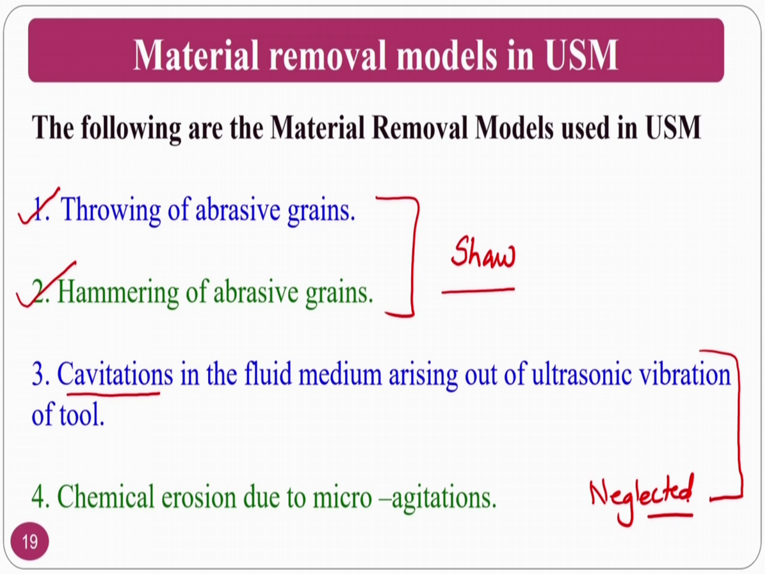

So, that means, that there are 4 mechanisms to be followed, that is throwing of abrasives, hammering of abrasives and this particular model consider these two only. So, other two things like a cavitation in the fluid medium arising out of the ultrasonic vibrations of the tool and chemical erosion due to micro agitations these two are neglected. So, what we are going to see is the throwing model as well as the hammering, these are the two actions how these are going to takes place in the material removal action.

Being a mechanical engineering or a manufacturing engineer we worry mostly about the mechanical action, that is why Shaw considered this particular throwing as well as hammering mechanisms only.

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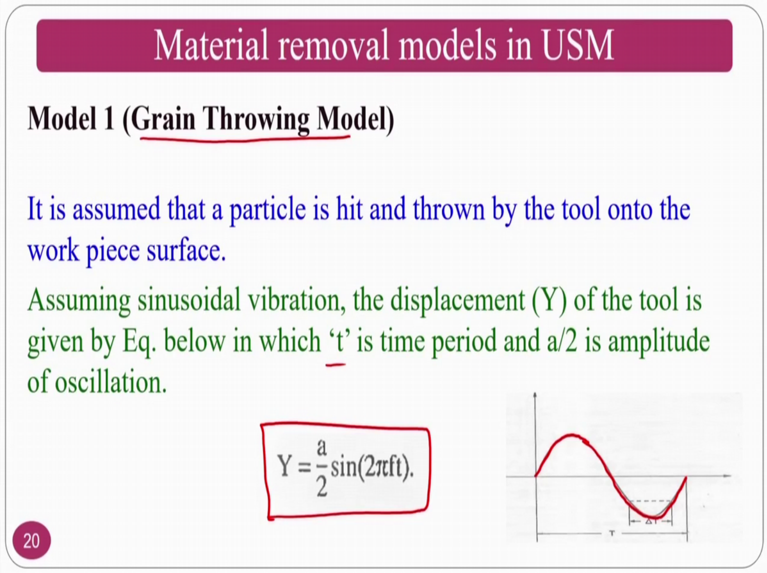

So, the model one that is a grain throwing model just I am not going in deeply of this models, because it has a big derivations and other things. So, just in a slide I just to give you a the glimpse. It is assumed that the particle hit and thrown by the tool into the work piece surface; that means, that the abrasive particles come in contact with respect to the tool and it gets the kinetic energy and this is thrown on to the work piece.

Whenever thrown what will happen the material removal takes place. Assuming the sinusoidal vibration and the displacement Y at the tool is given by the equation, where t is a time period and a by 2 is the amplitude of the oscillation. Normally, it is assumed that sinusoidal vibrations are given and where is the t in the equation, if you see this particular equation where t is the time period and a by 2 is nothing, but your amplitude of the oscillation.

So, from this model what is you are going to get is the this sinusoidal vibrations are throwing the abrasive particles, whenever the throw what will happen that it is goes you gains the kinetic energy from the tool and goes and hits the work piece, that is this model specifies.

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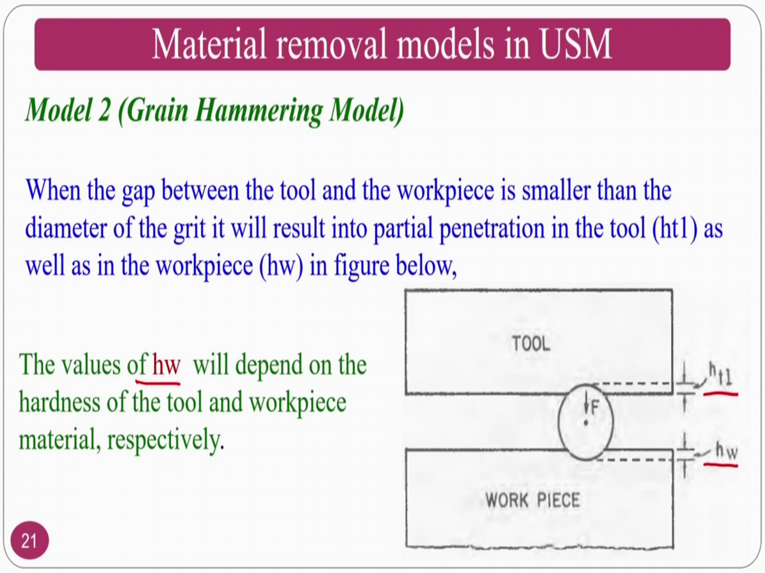

If you see the grain hammering model, when the gap between tool and the work piece is smaller than the diameter of the grit; that means, that abrasive particle it will result in partial penetration to the tool. As well as into the work piece ok; that means, that hammering will takes place.

Because, if the abrasive particle is much bigger than the gap what will happen continuous hammering will takes place. Because, your tool is changing it is length longitudinally even tool is changing your length and in one position are almost all the positions if the abrasive particle is big what will happen continuously it will it is compressed, but being a brittle material the abrasive particle will not compress what it will do it will indent into. The tool material as well as indent into the work piece material also that is called hammering.

Continuously hammering is taking place because of the vibrations effect of the tool. The value h w will depend on the hardness of the tool and the work piece material, respectively ok. So, h t 1 into the tool h w is into the work piece. What we want is not into the tool, what we want these h w that is, how much is penetrating inside the work piece material to make the required shape. This indentation of h w always will be function of the work piece material mostly and partially the tool material also.

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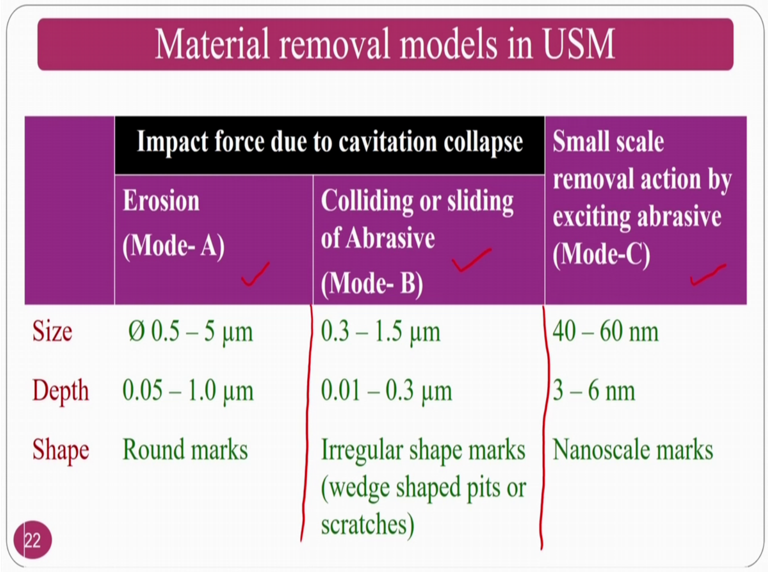

Material removal models in USM

	Impact force due to cavitation collapse		Small scale removal action by exciting abrasive (Mode-C)
	Erosion (Mode- A)	Colliding or sliding of Abrasive (Mode- B)	
Size	Ø 0.5 – 5 µm	0.3 – 1.5 µm	40 – 60 nm
Depth	0.05 – 1.0 µm	0.01 – 0.3 µm	3 – 6 nm
Shape	Round marks	Irregular shape marks (wedge shaped pits or scratches)	Nanoscale marks

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We have seen 3 modes of material removal that is erosion, colliding and sliding action of the abrasive particles and small scale removal by the exiting of this one. If you see the size 0.5 to 5 microns normally, if you see the collide distance it and it gives the depth 0.05 and the shape normally it gives the round marks basically, erosion will give the round marks. If, you see the colliding are the sliding action what will happen. The normally the size will be 0.3 to 1.5 microns, where the depth it can create is maximum is 0.3 microns and irregular shape marks wedge shaped pits or scratches are normally seen.

In a small scale removal of action by the exciting that is a Mode-C. Basically the size is 40 to 60 nanometers and 3 to 6 nanometers of this thing and nano scale box will be there. That we have seen as I was saying that the small scale removal will be because there it is not true that all abrasive particles will touch the tool in the forward motion only it may touch during the reverse motion also.

So, the kinetic energy gain by the abrasive particle, which is a part of the slurry will have less kinetic energy and since it is much harder compared to the work piece material. It has it is own impact, but the kinetic energy that gained the by that particular abrasive is less, because of which what will happen small scale removal will takes place ok.

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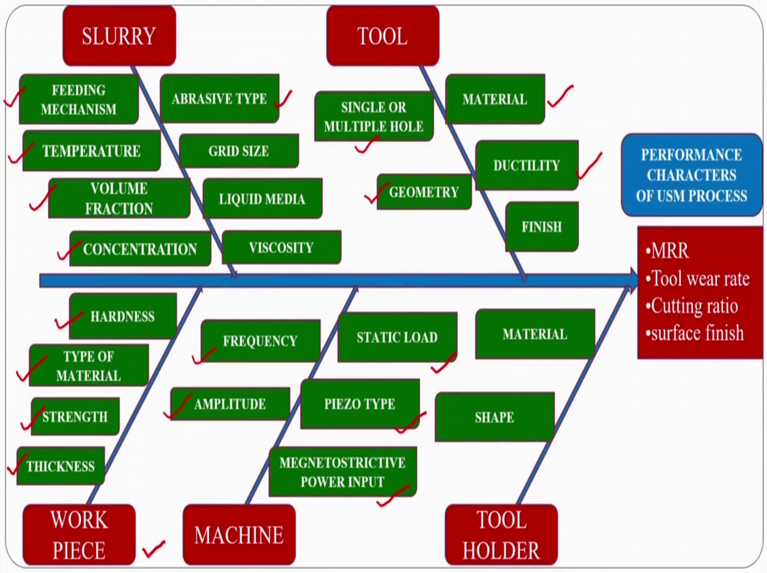

If, you see the input parameters and other thinks. The first one is work piece parameters, that is the just we will see the fishbone diagram of the ultrasonic machining process where in, how the output response is like material removal, tool wear rate, cutting ratio, surface finish all this will depend on various input parameters. The first input parameter that we are going to see is in the work piece properties.

That is nothing, but the hardness of the work piece type of the material like, whether it is a brittle material or a ductile material, strength of the material and thickness of the material, if the work piece thickness is too high what will happen if we take more time to remove the material. The slurry that is nothing, but the abrasive particles as well as the carrier medium like water are some other liquids.

So, the feeding system how you are feeding whether you are feeding with force, whether you are feeding by the gravitational action or something, temperature of the slurry, if the temperature of the slurry also play a major role and the volume fraction of abrasive particles to the career medium and the concentration how much concentration that we are sending.

And, on other side abrasive type that you are going to mix with the career medium grit size and the liquid media, what is the type of liquid media that you are going to be use in viscosity? Normally, viscosity should be low so, that what will happen it can reach to the complex surfaces of the tool so, that the same converse shape can be developed on the work piece surface.

So, coming to the machine parameters the normally the frequency of the tool and the amplitude how you are giving. These are the most important, if the amplitude is very high depth of indentation of the abrasive particle will be very high, because the kinetic energy it receives from the tool will be very high.

At the same time if the frequency is very high what will happen is number of abrasives touching the work piece will be very high. The static load how much load you will be and the piezo type, which type of piezo you are going to use on magnetostrictive to power input and other things will play the major role.

Among all these things frequency and amplitude are the major things that should be noted and the tool normally the tool material and the ductility of the material in the surface finish. If the tool itself is very rough what is you are going to get is the work piece also will get the very rough.

So, whether the tool you are going to have a single point or multipoint 2 holes that mean that at a same go, you can also generate the multiple holes also of different shapes. You have seen schematic diagrams at the same time you will see at the end also in the applications and the geometry, what type of geometric? If the geometry is very complicated then the time requirement also will be very high.

The tool holder normally tool holder material as well as the shape will play a major role in the input parameters ok. These are the main 5 input parameter that is slurring tool holder machine as well as work piece material. This parameters influence the output responses that are required.

If you are looking at the material removal rate; that means, that your main concern is about to remove the material, if you are looking at the surface finish that; that means, that you are looking at the ultrasonic surface finishing and other things.

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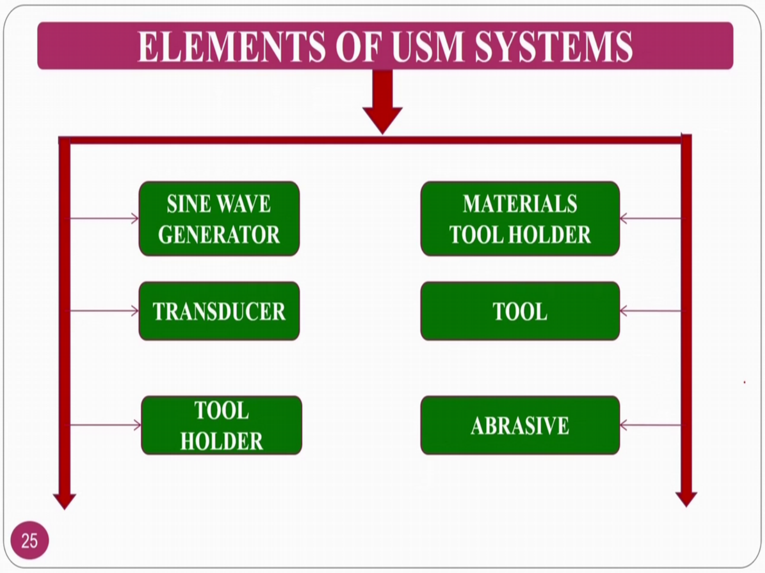

Elements we have seen mostly, but we will see individually what is this functions under sinks. Sine wave generator transducer, tool holder, materials for tool holder, tool as well as abrasive particles these are the elements of the ultrasonic machining system.

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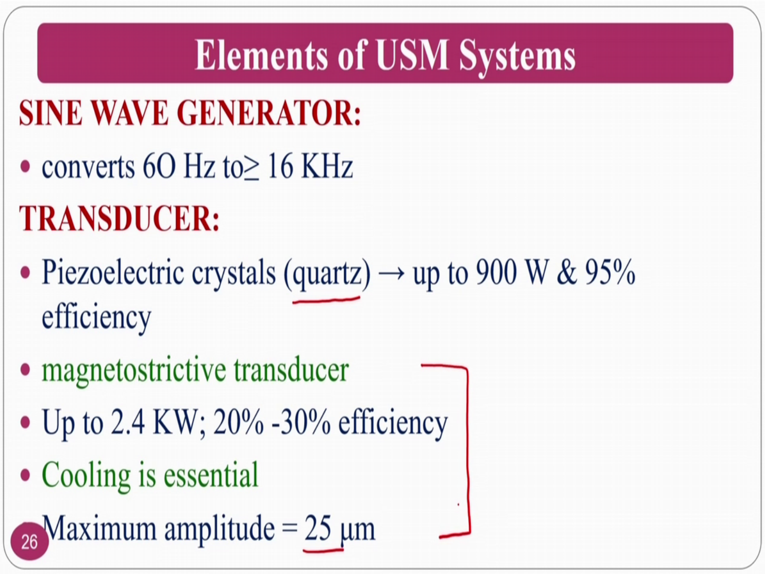

This element if you see the sine wave generator normally, converts is 60 hertz to less than 16 kilo hertz normally, the transducer basically piezoelectric crystals which are normally available is quartz. It will have the good efficiency about 95 percent magnetostrictive transducers normally up to 2.4 kilowatts where the efficiency is 20 to

30 only that is why. And, the cooling is essential and other things and the maximum amplitude is 25 microns, this is about the magnetostrictive transducers.

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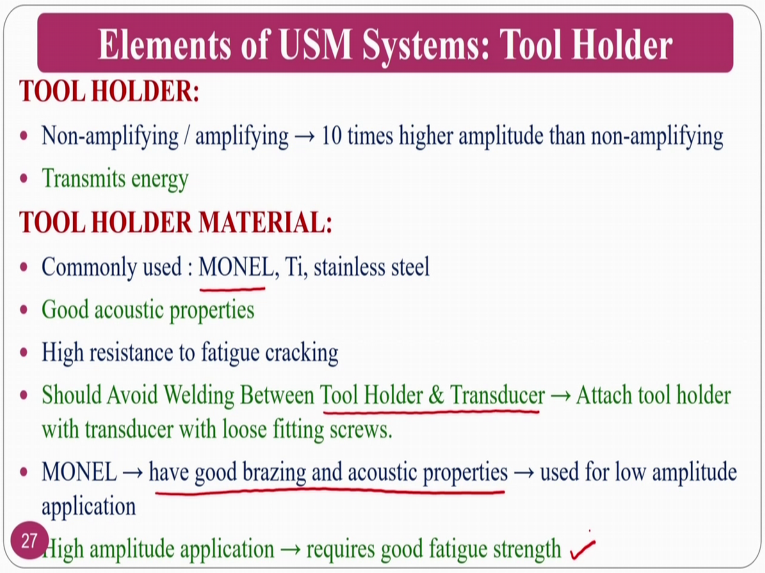

Tool holder normally non amplifying and amplifying varieties will be there and 10 times of higher amplitude than the non-amplifying will give the amplifying one. Transmit the energy; that means, that tool holders main function is 2 transmit the energy to the to the tool.

The tool holder materials normally will be used in Monel, which is other materials are normally used material is the Monel and you can also use that stainless steel and titanium. This have the good acoustic properties and high resistance to fatigue crack and should avoid welding between tool holder and transducer.

So, the tool holder and transducers are there transducer gives some vibrations and according to that tool holder will move. So, the Monel have good brazing and acoustic property that is why, it is mostly used in ultrasonic machining process. And, at the same time use for the low amplitude applications only high amplitude applications require good fatigue strength and other things.

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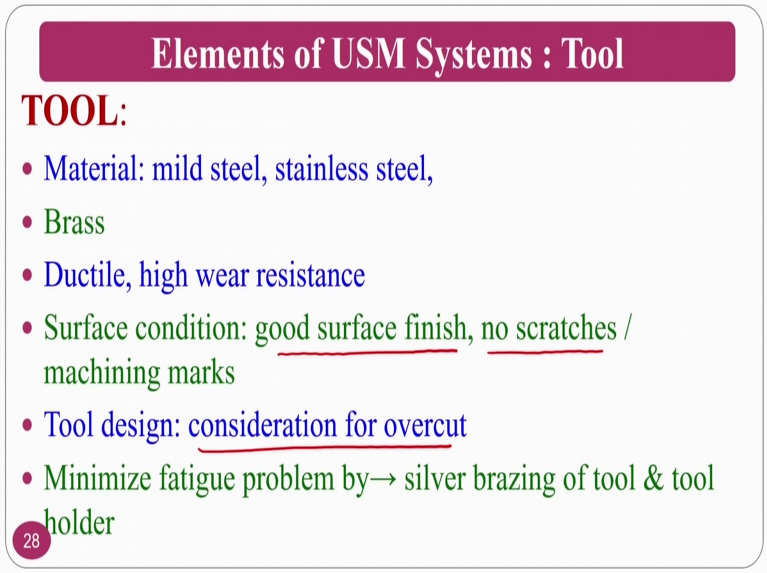

So, some of the others things or elements some of the other elements of this ultrasonic system is tool. The material is normally mild steel or stainless steel will be used, other materials are brass, ductile highway resistance. Surface condition normally you require good surface finish, no scratches, because the surface finish and scratches will replicate it is roughness and the machining marks ok.

The tool design consideration for the overcut normally, whenever you want to design a particular tool. You have to always careful about the over cut and other things. It should minimize the fatigue problems by silver brazing to the tool and tool holder normally, this welding and other things will be reduced basically. So, in order to reduce the fatigue problems, silver brazing of the tool and tool holder will be done in most of the cases.

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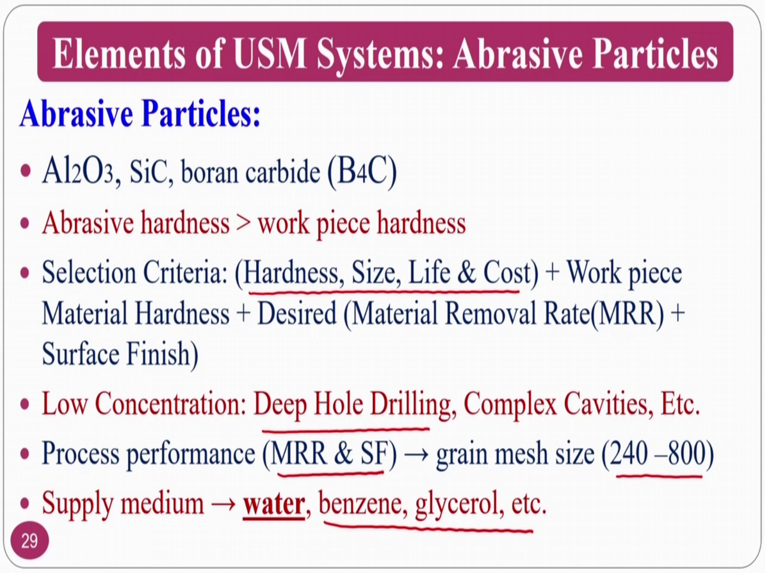

So, the abrasive particles that are used in ultrasonic machining process is boron carbide alumina as well as silicon carbide these are the common materials. As you know conventional machining and other things you might have come across that the your tool materials should be much harder than the work piece material.

So, same holds good for ultrasonic machining also because, ultrasonic machining is mechanical type of advanced machining processes. This ultrasonic machining is one of the mechanical type of advanced machining processes. That is why you should always get the tool material harder than the work piece material. The selection criteria normally the abrasive particle hardness, size, life, cost, because normally as I said in India we can get 1 k g of silicon carbide of mesh size 220 below 500 rupees now a days.

So, it is not a costly process only thing is that you need to make your transducer tool holder and other things ok. You can develop your own set up, but your laboratory with the minimum price also ok. So, but I strongly suggest that you take the help of the other departments, where they have expertized transducers, electrical systems and other things. And you can come up with a good master's thesis or BTP project and other things.

Work piece material hardness desired for material removal rate and surface finish. Lower concentration normally the abrasive see if you are we using low concentration deep hole drilling, complex cavities and other things. The process performance MRR and surface finish gain mesh size you have to go for fine mesh size.

So, if at all your mesh size is high that mean that number of holes are number of meshes for unit area will be very less. So, the abrasive particle size will go down that mean that you are going to get a super fine or ultra-fine abrasive particles to be used for super finishing or finishing applications.

Supply medium normally are the career medium will be used is water, benzene, glycerol, and other things. Normally, glycerol will be added in some of the magnetorheological fluids also for to avoid the sedimentation of the abrasive particles and other things.

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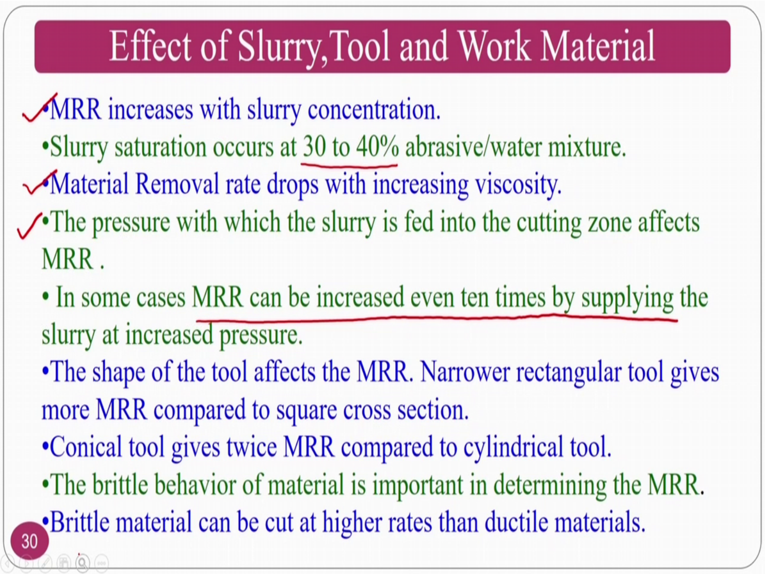

So, effect of slurry tool and work piece material normally MRR, that is material removal rate increases with respect to a slurry concentration, that we will see some of the graphs in terms of performances.

So, if you are abrasive particles are more what will happen material removal will be obviously; more because you are abrasive particles number of abrasive particles for unit time going and hitting the work piece will be very high. So, slurry saturation occurs at 30 to 40 percent of abrasives and water mixture; that means, that you are advised to not use more than 30 to 40 percent of abrasives in the slurring.

If, you are using more and more abrasive particle then what will happen the viscosity of the fluid will goes up and the viscosity, if the viscosity goes up what will happen the this slurries may not penetrate or this may slurries cannot pass in between to the tool and the work piece material. Material removal rate drops with increasing the viscosity that is what I was saying.

If, the viscosity increases that the flow ability of the slurry will decrease. If the it is decrease then the number of abrasive particles in between the tool and work piece will be very less. The presence the pressure with which the slurry fed into the cutting zone affect them are; that means, that if the pressure is very high, what will happen the flow rate of the slurry will be very high. With the flow rate of the slurry is very high what will happen the number of abrasives in the machining region will be very high.

In some cases MRR can be increased even 10 times by supplying the slurry at increased pressure; that means, that if the pressure is very high; that means that material removal also increases. So, the shape of the tool affects the MRR normally, narrower rectangle tool gives more MRR compared to square tool of the same cross section.

Conical tool gives twice MRR compared to the cylindrical tool and the brittle behavior of the material is important in determining the MRR; that means that if the material is brittle. Then, the material removal will be in terms of fragments, if the metal is ductile what will happen, it is yield strength and other things will play a major role. Brittle material can cut into higher rates than the ductile material that is what because, the brittle fracture will takes place and the fragments can seal along with the carrier fluid out from the machining region ok.

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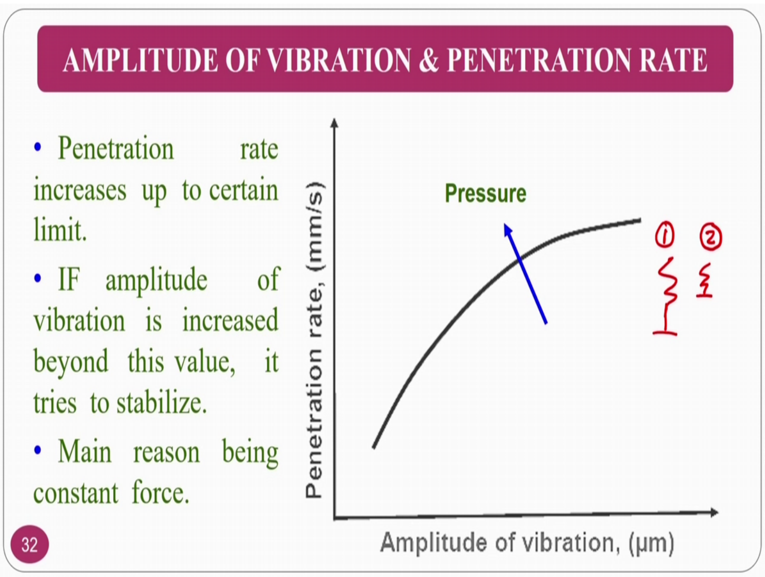

The parametric analysis this is a glimpse what you have seen, but you see in terms of the graphs and other things. If, you see the amplitude of vibration and penetration rate what will happen if the amplitude of vibration. Assume that my vibration is this much what will happen?

So, it will be high, if my amplitude is this much what will happen. So, the penetration of the abrasive particle will decrease. In case 1 penetration will be more in case 2 the penetration will be less that is what is the penetration rate is always proportional to the amplitude of the vibration.

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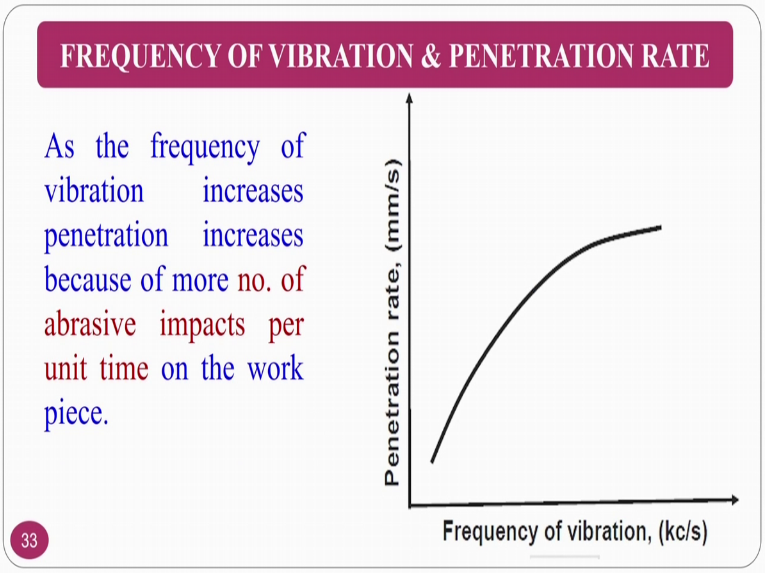

If, you see the frequency of vibration with respect to penetration rate, if the frequency high what will happen number of abrasive particles impact per unit time will be high. If the number of abrasives coming in contact with the work piece is high; obviously, the material removal will be very high, if the material removal is very high the penetration; obviously, will increase.

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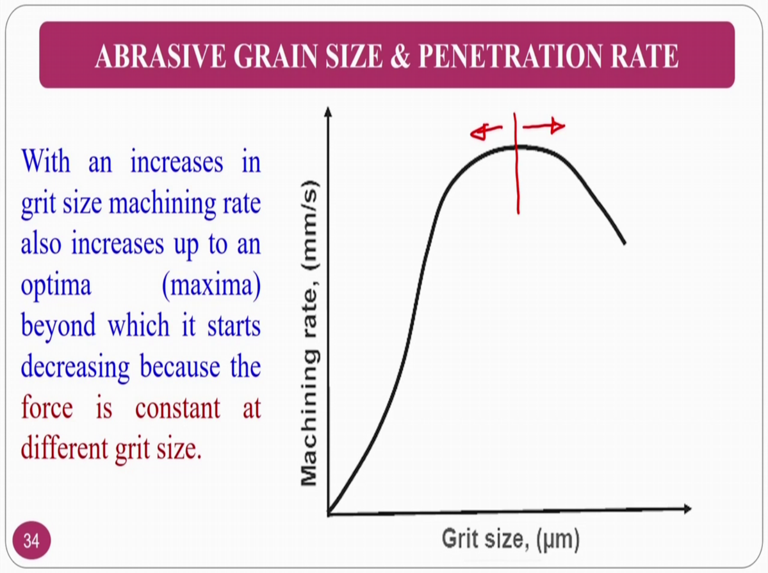

And, the grit size if the grit size is increasing what will happen you have 2 spectrums here. In the region one as you increase the abrasive grit size that; that means, that you are going to increase the particle size what will happen, the material removal increases and increases and increases.

But, everything has it is own saturation, if you are going to increase more and more what will happen. Your force is constant, because you are amplitude is constant at the same time if you are going to use bigger size particles hammering action will takes place. And at the same time because of the hammering what will happen your abrasive particles may also break because, abrasive particles are brittle in nature, that is why you will get the decrement of material removal also in the second region.

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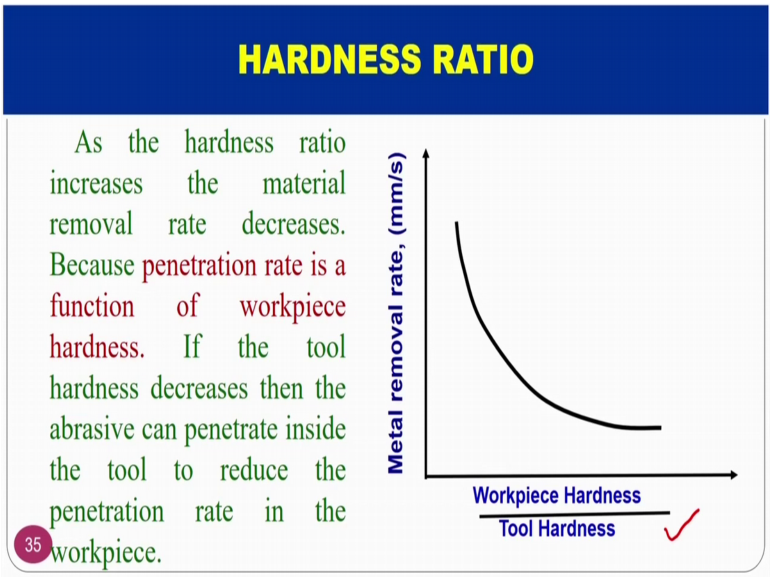

Hardness ratio; normally hardness ratio is the ratio of work piece hardness to the tool hardness. If the hardness ratio is increasing; that means, that my work piece hardness is increasing. If the work piece hardness increases what will happen, the material removal normally depend on penetration ok. Resistance to penetration is nothing, but the hardness if, the hardness increases the penetration ability of the abrasive particle will decrease; obviously, if the penetration rate depth is decreasing the material removal also will decrease.

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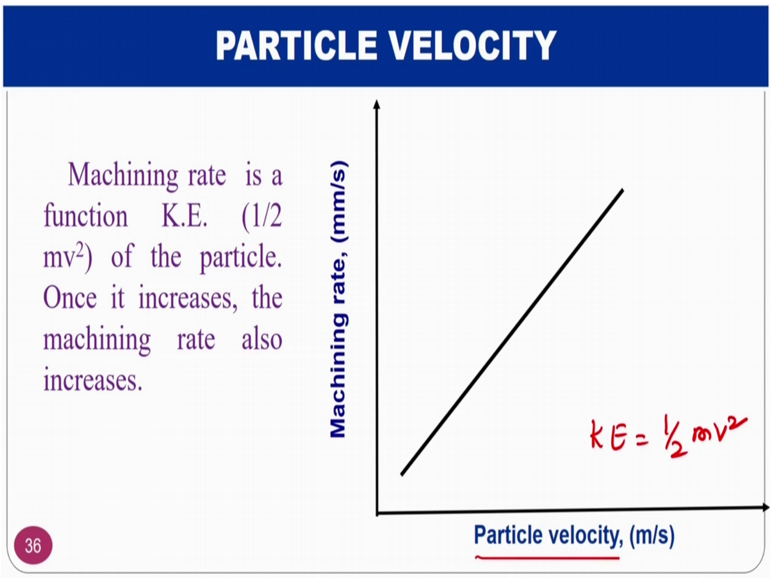

So, if you see the particle velocity, how far the particle velocity is if the amplitude is very high what will happen the particle will gain more and more velocity. Along with that you are sending the abrasive particle along with the nozzle with some pressure also. So, these are all will play a major role in increasing the particle velocity.

If, the particle velocity increases the kinetic energy of the particle will be more if the particle velocity will be more, the kinetic energy of the particle will be more and it will come and hit the work piece with the greater velocity, the particle will come and hit the work piece with the greater velocity. So, the material removal or machining rate will be continuously increasing and the particle velocity is proportional to machining rate.

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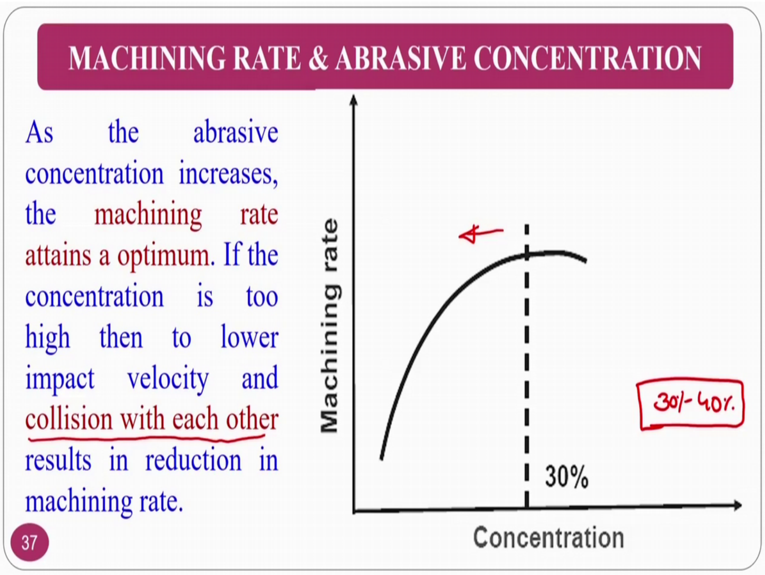

The, if you see the concentration as I said normally 30 to 40 is the optimum, in the abrasive slurry ok. So, what will happen if you are increasing the concentration? What will happen number of abrasive particles per unit time in the machining region will increase, beyond which if you are increasing what will happen the area that you are having in the tool is a constant, but if you have number of particles the particle will also collide each other.

So, the velocity may go down ok, that is what the collision with each other will take place if the particles are too high what will happen the collision among the particles will very high. If, the collision among the particles is very high what will happen the velocity at which it has to go and hit the work piece will go down. If it is go down what will happen, if it is goes down what will happen is that the material removal will reduce are the machining rate will reduce.

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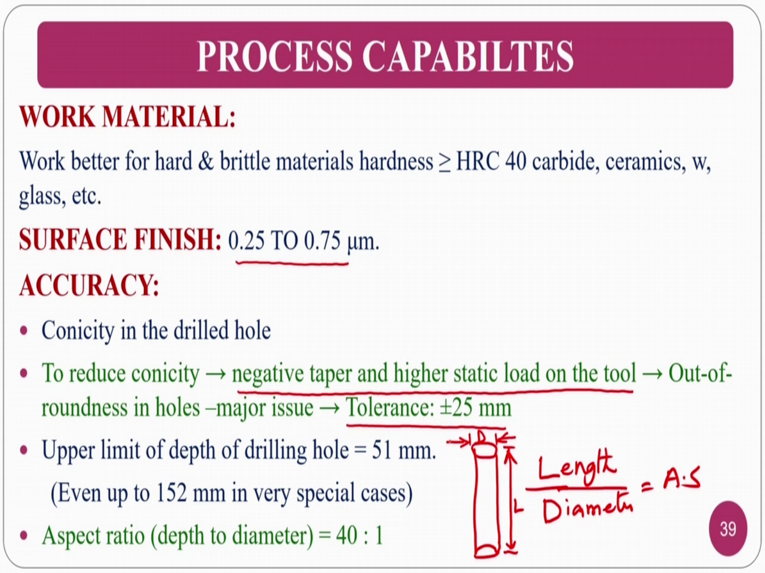

Process capabilities and applications of this particular ultrasonic machining process; process capabilities if the work piece material is better for hard and brittle materials that is nothing, but HRC 40. Normally, carbide and ceramics will be used for machining. Surface finish that you are can achieve is 0.25 to 0.75 microns and, accuracy consistently in drilled holes normally you can achieve. And to reduce the conicity normally what you have to provide is negative taper and high static load to the tool can be given.

And, out of roundness in the holes and major issues and the good tolerances you can achieve, upper limit of the depth of the drill hole is 51 m m we can achieve even up to 150 m m also in special cases you can achieve. So, that means, that the best thing that one can achieve using the ultrasonic machining is aspect ratio is 40 is to 1; that means, that aspect ratio means L by D ratio. Assume that I want to make a hole is nothing, but aspect ratio ok. The, length of the hole divide by the diameter of the hole ok. This is the length L and this is the diameter so, this is nothing, but the aspect ratio.

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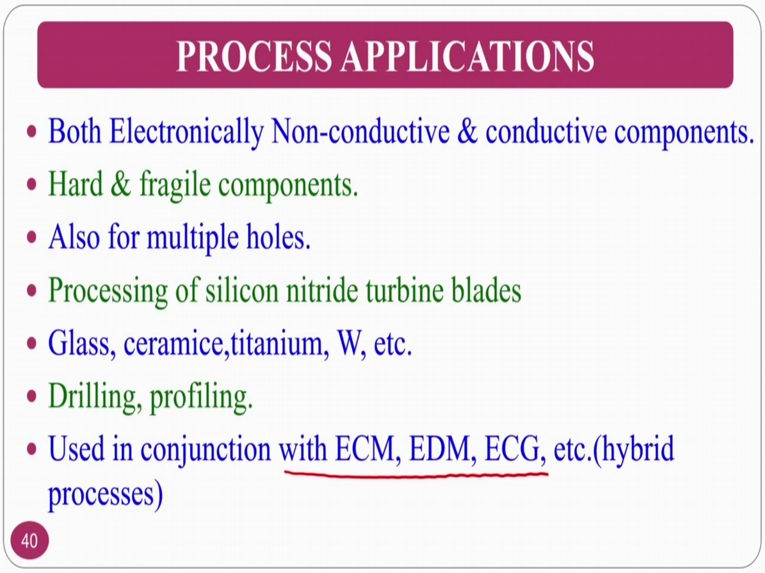

So, some of the other process; process applications if you see both electrically conductive and non-conductive components can be done using this particle process. If, you see electrical discharge machining and other process basically what you are going to do is only electrically conductive materials only will do ok, but this is a mechanical action where the mechanical abrasive particles are going to hit the work piece material ok.

So, there is no discrimination between electrically conductive nonconductive, you can use for the both materials, you can generate the cavities are required shapes on this work piece material. Hard and fragile component can achieve hard and fragile components can be machined using the ultrasonic machining. Also for multiple holes, example you will see in the upcoming slides, processing of silicon nitride turbine blades can be done by the this particular process.

Glass and ceramics and titanium tungsten work pieces can be done, drilling and profiling is possible used for conjunction, you can use for hybridization of electrochemical machining EDM, ECG and other things. Normally, ultrasonic assisted electric discharge machining, ultrasonic assisted electrochemical grinding. These are some of the hybrid processes are there some of the people who are you may be from the Btech student. So, hybrid there is some difference between hybrid and advancement.

If you are mixing 2 processes like, grinding plus EDM, that is electric discharge grinding. Where you are mixing electric discharge machining as well as grinding so, electric discharge machining and grinding if you are mixing and you are taking it as a electric discharge grinding, that is called hybrid process.

Where you are mixing 2 technologies; so, advancement normally what is the advancement is that EDM is there if, you find another advancement like, Y REDM or another process, that is called advancement. There is no addition of some other process like grinding or milling or something ok so, that is called advancement like.

Now, for example, advancement means you have a small CRT monitor TV in olden days. Now, you have a L C D L E D, this is called advancement. There is no of blending of some other process or something ok. If, you are blending 2 process or 3 process then it is called hybrid process.

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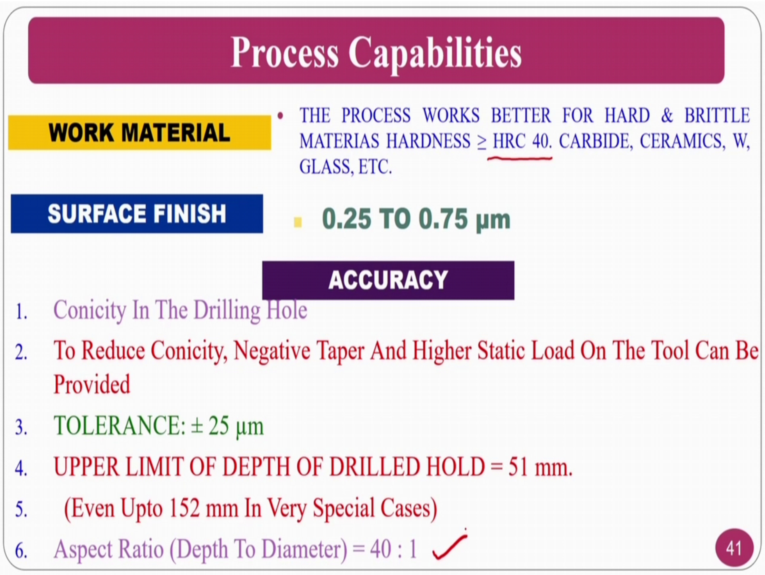

The process capabilities normally work piece material now you can go up to 40 HRC carbide ceramic surface finish also you can achieve. Conicity and other things tolerances says these are all we have seen in the upcoming slide as the aspect ratio approximately 40 is to1 you can see.

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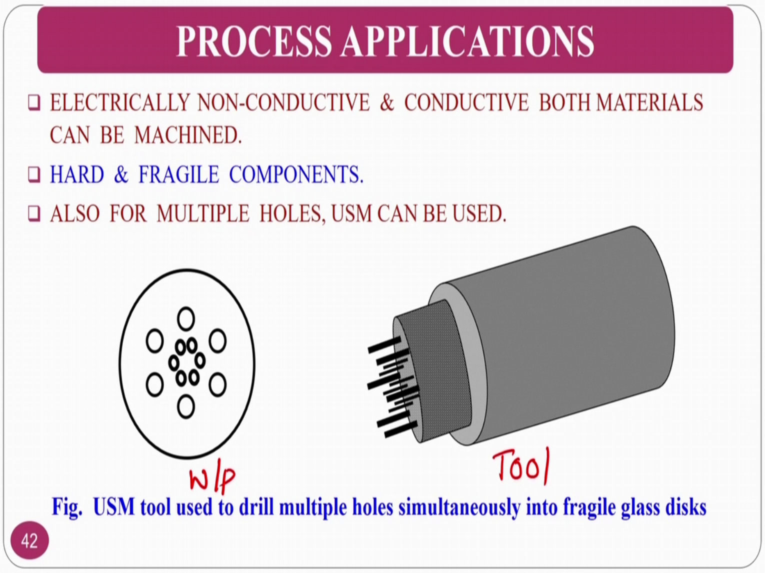

And, this what I was saying that you can make multiple holes by using a multiple tool, multiple features of a tool ok. Electrically conductive nonconductive and other things we have seen, if at all I want to generate this type of holes, you can choose a tool according to that ok. And, you can do the multiple holes that mean that this particular process can give you a multiple holes or multiple features on the work piece material simultaneously.

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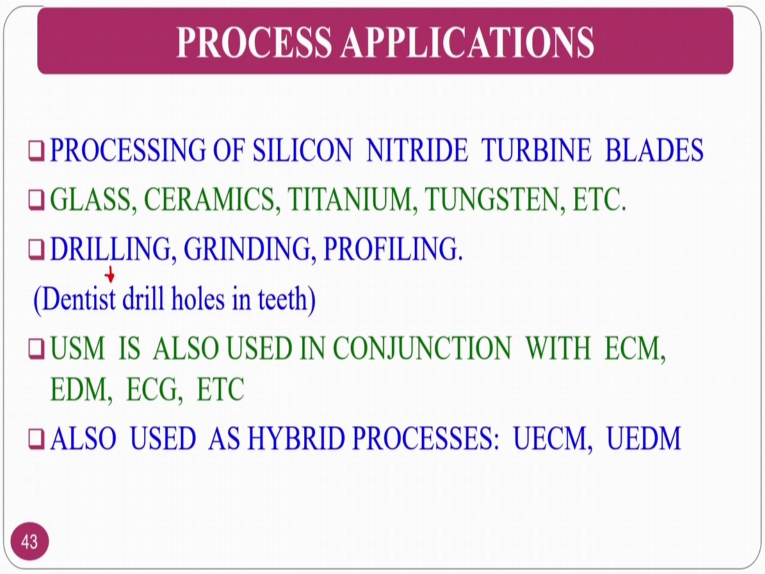

So, you can use for the dentist holes in the teeth like a drilling whatever you are see is a dentist normally uses the ultrasonic assisted drill bit, also is it used with a some other process.

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These are the applications, if you see the applications on the glasses or the many other applications you can see using ultrasonic machining.

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These are the some of the features developed by ultrasonic machining. Normally ,this particular process is very good for the brittle materials ok.

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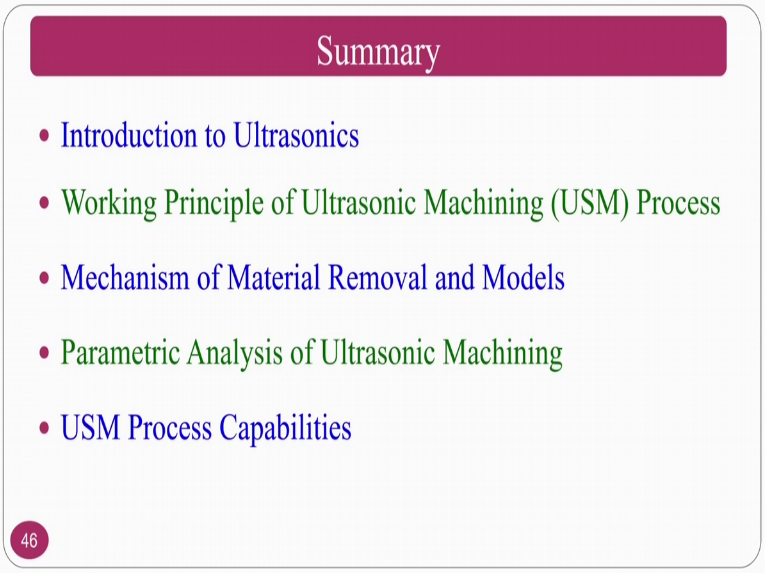

The summary of this particular class we have seen in introduction to ultrasonics, how the ultrasonics are generated, how these ultrasonic waves or the amplitude of ultrasonic and frequency helps the ultrasonic machining process? And, the working principle of ultrasonic machining we have seen and the mechanism of material removal and model which we have seen the throwing model as hammering model, whenever the abrasive particle size is much bigger than the gap between the tool and work piece normally hammering will be taking place continuously ok.

So, these models are proposed by the Shaw. At the parametric analysis of the ultrasonic machining we have seen 5 input parameters, how it will influence the material removal rate tool wear as well as the surface finish of the final component and other things we have seen. And, the process capabilities we have seen it can be used for conductive nonconductive, it can generate the good surface finish; it can remove the material very good in brittle materials rather than the ductile materials and other things and applications.

It can be mostly used for the glasses lenses and other things if at all I want to generate a particular cavity or I can generate the multiple holes are multiple features simultaneously by having a similar or converse type of tools ok. If, at all I have one to one hole I can have one feature on my tool if I have multiple features on my tool, I can generate converse features on the work piece. So, thank you professor Jain, because some of the slides I have borrowed from him thank you for your kind attention for this particular class.

Thank you.