Non-traditional abrasive machining process: Ultrasonic, Abrasive jet and abrasive water jet machining

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Lecture – 01
Non- traditional abrasive machining: Ultrasonic Abrasive jet and abrasive water jet machining

Welcome to the first lecture of the online course Non-traditional Abrasive Machining Processes Ultrasonic, Abrasive Jet and Abrasive Water Jet Machining. My name is a Roy Choudhury and I am a professor in the Mechanical Engineering Department of IIT Kharagpur.

So, basically we are going to discuss about the non-traditional abrasive processes machining processes which have gain popularity over the last few decades. And we find the raise of I mean the development of ultrasonic machining, abrasive jet machining and abrasive water jet machining. In these cases instead of the conventional machining practice, we find the use of non-conventional or non-traditional methods of removing material.

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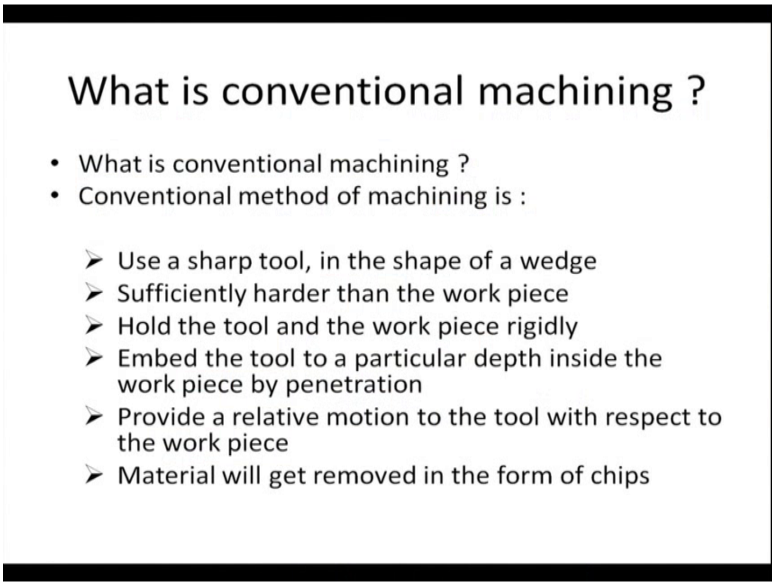

So, first let us have a quick look what is exactly non-traditional sorry what is exactly conventional machining practice. Machining essentially means that we are obtaining a particular shape from a blank by the way removal of material in the form of chips, so it is a subtractive process. And what are the essential features of conventional machining, we have basically a sharp tool in the form of a wedge a triangular element, so that it has a sharp point, it can apply sufficient pressure through that particular point. And the work piece which it is going to shape that work piece that having the tool is sufficiently harder than the work piece, so that it can be indent, penetrate the work piece.

The tool and the work piece are held rigidly because typically the forces which arise in their interaction can be in hundreds of newtons. So, the tool is embedded into the work piece up to a particular depth by penetration, it has the sharp point. So, it penetrates in to the work piece and after that a relative motion might be provided to the tool with respect to a work piece so that material will get removed in the form of chips.

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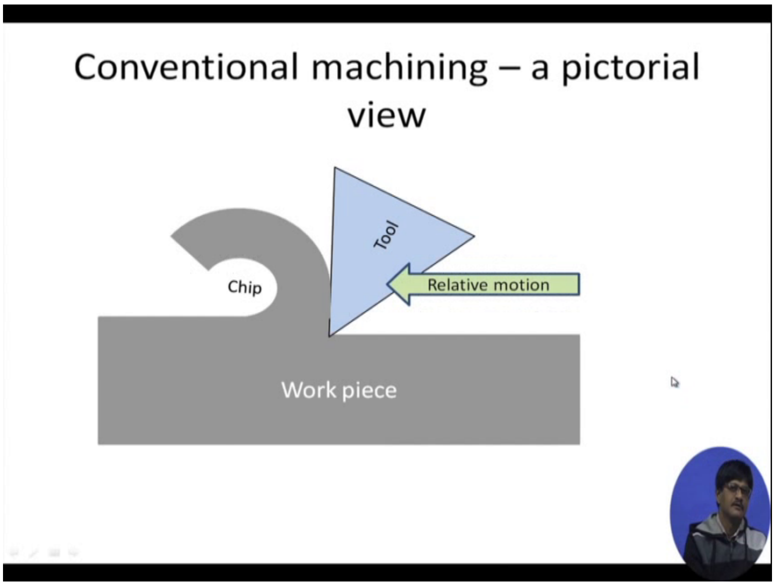

So, let us have a pictorial view of this particular phenomenon. The triangular portion as it is written; it is a tool; it is embedded into the work piece. And after that a relative motion has been provided, so that you can see that from the work piece some material is getting removed and that particular material which is getting removed it is called a chip. Generally, material gets material fails by shear, so that it is finely it is removed. This relative motion is sometimes refer to as cutting speed; the depth up to which the tool is embedded that might be the depth of cut or the uncut chip thickness.

And after this material has been removed from one side to the other the tool might be shifting sideways which is called the feed motion. So, this is conventional way of removing material the tool has to be harder than the work piece it has to a have a sharp edge it has to have a well-defined geometry and all these things might become very difficult to maintain in very you know stringent situations.

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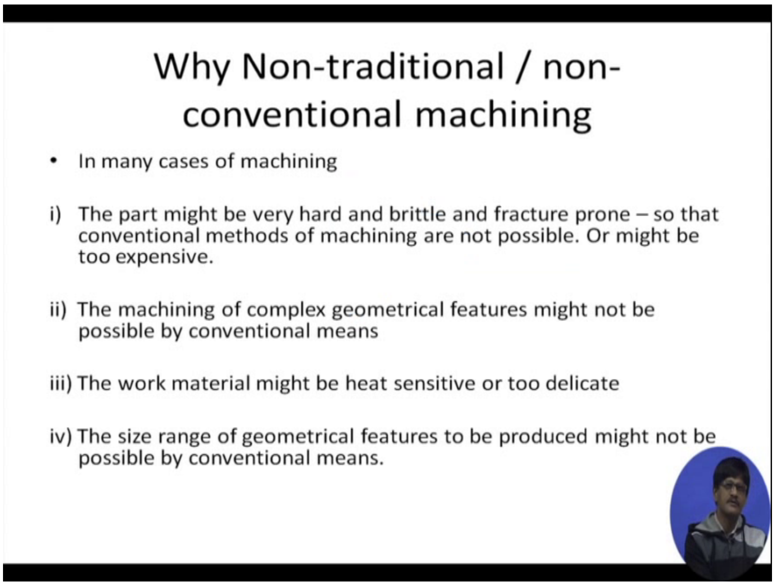

So, compare to conventional machining, why would be at all go for non-traditional or non-conventional machining. So, for that matter in many cases of conventional machining we find that the part might be very hard the work piece material might be very hard and brittle; and if we try to machine, it will be fracturing. So, if it fractures we will find that the blank is spoiled and the work piece cannot ultimately we made from that. Secondly, apart from this the machining of complex geometrical features might not be possible by conventional means. So, the particular feature which has been produced, it so complex, it cannot be made or if it can be made it becomes very expensive and it very specific tools part specific tools have to be made and this will be costing money. So, it will become physically you know not very the process will not be or conventional process will not be very competitive in the market.

Apart from that, work piece material might be heat sensitive or too delicate that means, it cannot with stand much force etcetera. So, in these cases also conventional machining might not be the most popular or you know that the best or the most appropriate process.

Further, we might be working in a size range where conventional machining might not be possible. For example, you might have a drill of diameter I mean basically a twist drill of say high speed steel of the diameter say 0.4 millimeters, but if I say that no I want still lower than that with high l by d ratio, there we have a problem. Then we perhaps cannot go for conventional means of drilling a hole and we have to find out some non-conventional method. So, there are. So, many cases in which we will find that- no conventional method of machining is definitely not the most appropriate or it is in fact in impossible or it is too expensive something like that.

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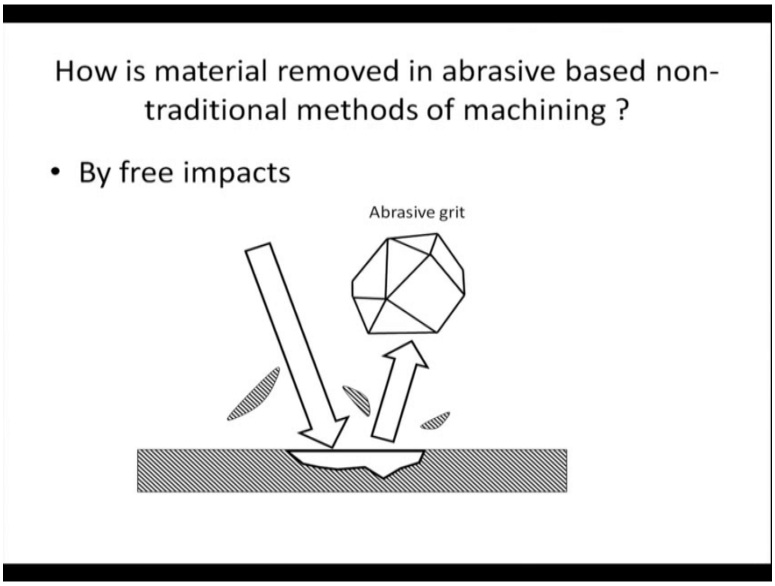

So, if we are talking of abrasive based non-traditional methods of machining how is machining going to take place that means, how is material removed in those cases. Here what we have shown is an abrasive grit or sometimes it is known as an abrasive particle; that means, we are seeing it in magnified view. When if this abrasive particle is you know accelerated to a very high speed and made to impact against a brittle work material, it might be able to remove material in the form of chips, I mean not in the form of chips in the form of debris, which comes out of this impact. It is frequently known as impact erosion. So, simply in plain and simple words it means that you have a hard object, you throw it basically to impact against a brittle hard brittle object, the second one might be you know taking up some damage that is all, so damaging hard brittle material by impacts.

So, why does the abrasive itself have to be hard, it has to be hard because first of all if it is not hard, it will itself deform and take away part of the energy which is contained in it as kinetic energy in this case. Secondly, if it is you know it has to be very rigid and hard and if it takes up fracture itself, we cannot fully avoid that. But if it fractures very easily the problem is then also it will be taking a part of the energy with which it has been you know projected towards the work piece. So, hard you know objects I mean hard material particles are generally chosen as abrasive particles.

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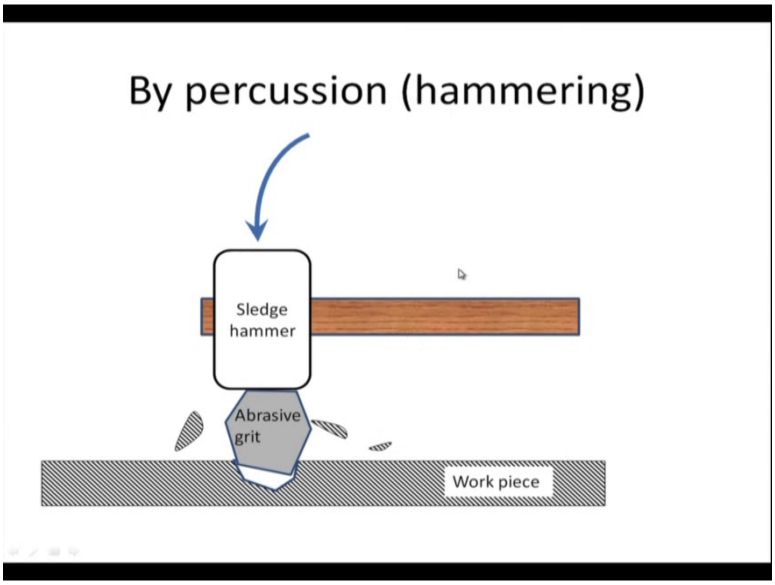

Another way in which the abrasive particles might be utilized to remove material from the work piece is by percussion are basically in simple words by hammering. We have shown here pictorially, a sledgehammer being you know used to create impacts on the work piece not directly. See the sledgehammer is made of some steel you know the hammering head. So, the hammerhead is made of steel, but it does not impact the work piece directly, a very hard abrasive grit is placed in between, so that the impacts of the hammer are on the abrasive and this abrasive intern impacts the body, so that material gets removed from that.

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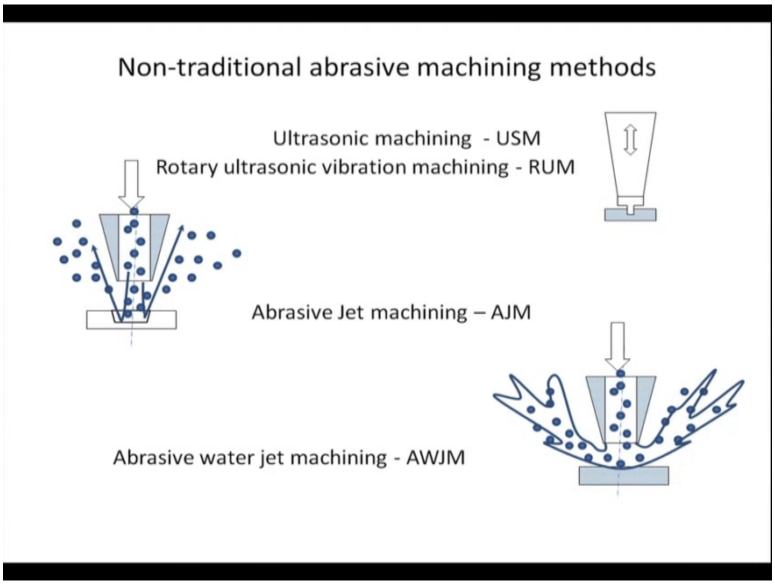

So, let us have a quick look at the non-traditional abrasive machining methods which are existing and which are in use today in laboratories, in commercially available etcetera. Ultrasonic machining as the name implies there is some vibration involved. How is this vibration made use of, this body which is called the horn this elongated or tapered body this you know vibrates in this direction at ultrasonic frequencies that means, say around 19 to maybe 25 kilohertz. And by virtue of this particular vibration, it hammers against this particular work piece with abrasive particles in between, so that that percussion method of material removal takes place and the conjugate profile of the tool this last portion is the tool.

So, horn tool work piece with abrasives in between. So, the abrasives in between they give rise to material removal by impact erosion, so percussion. The abrasives are generally contained in water, so that they can be transferred from one place to another way easily and that is called an abrasive slurry for depth of space we have not shown that in detail. Ultrasonic method of machining can also be you know applied to a rotary tool which might be having diamond particles impregnated on its end, so that rotating tool can remove material just like milling and it becomes very versatile.

So, in another way instead of making use of percussion method of material removal, we can also have this free impact. Free impact means that the abrasives are accelerated to a particular speed; and with this speed they hit the work piece and come out causing some damage to the work piece. Here we have shown that this part is called damage that means, material has got removed here due to those impacts. So, abrasive jet machining makes use of a career median as a gas, it might be plain and simple air, it can be argon, all sorts of materials can be used. And generally the speed range here is around 150 to 300 meters per second; 150 to 300 meters per second. What is the speed range for ultrasonic machining is around 10 meters per second. So, there is a definite speed difference between the particles of ultrasonic machining and the particles of abrasive jet machining.

So, if gas can carry these particles we might have might make use of some liquids which can carry these particles and accelerate them to an even higher speed, so that is abrasive water jet machining where water can be accelerated to a speed. I mean it can be confined in a pressurized chamber, so that on release from that confinement water can be accelerated to speeds of say 1000 meters per second, so 1 kilometer in 1 second. This water when mixed with abrasives, its speed will come down slightly say 800 meters per second. So, 800, 900 meters per second of speed is attained by these abrasives, and they can be made to impact against a work piece surface, so that practically any material can be removed by that high speed abrasive jet carried in a water medium.

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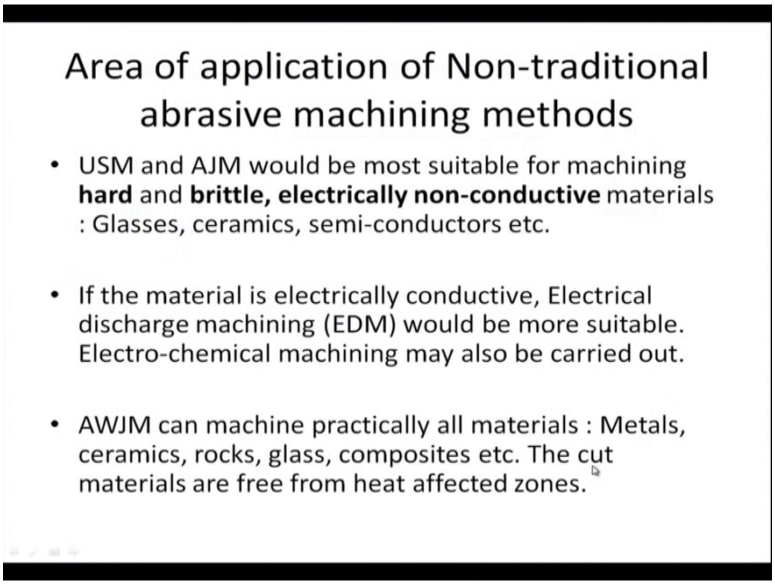

While, USM and AJM are most suitable for machining hard and brittle electrically non-conductive materials; abrasive water jet machining can practically, machine all materials any material. The speed to which the abrasive particles are accelerated 1000 meters per second or near value that makes it possible to machine any material. But why is ultrasonic machining and abrasive jet machining you know confined to the machining of hard and brittle materials which are electrically non-conductive that is because if they are electrically conductive there are better you know options for example, electrical discharge machining or electrochemical machining might be employed instead of USM and AJM.

Why so, because USM and AJM ultimately they are relying upon the hardness of the abrasives being be higher than the hardness of the work material, but in EDM and ECM there is no such restriction; the material removal rate can also be higher because ultrasonic and ultrasonic machining and abrasive jet machining the machining rate is lower. So, they have their own area of application. If it is a ceramic or a glass material, you will find that we cannot carry out EDM on it; we cannot carry out ECM on it why because they are electrically not conductive. So, in that case you will find USM and AJM perhaps will be the most appropriate options.

So, they have a well defined area of application not so far abrasive water jet machining as mentioned before they can machine practically all materials. And the added advantage of abrasive water jet machining over conventional methods of machining is that the cut materials are free from heat affected zones. Since, we are using a medium of water; it has a high cooling capacity. So, it keeps the temperature range within you know limits. So, that there is no burning effect, there is no you know high temperature damage, there is no phase change, there is no burning if oxygen is present like that.

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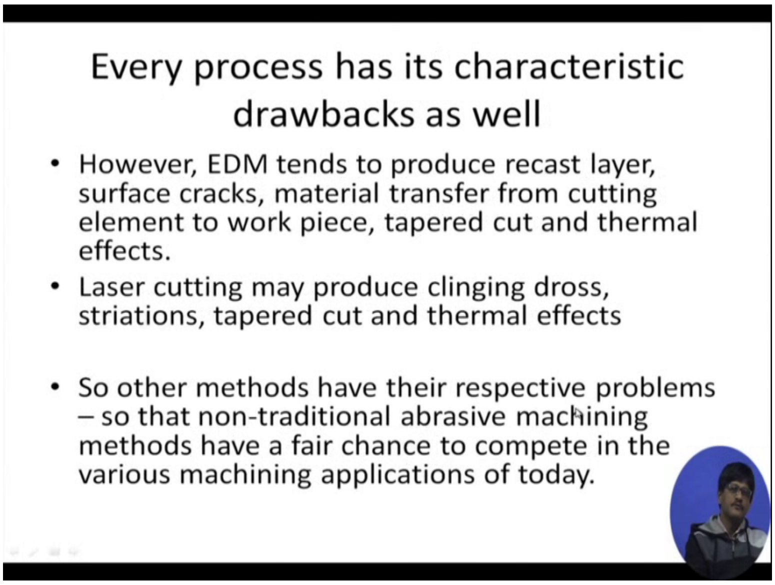

So, we might think of this that if EDM is there and if the work piece is may electrically conductive, I do not have to bother about USM and AJM. VCM is there so same thing, but actually it is not so why because every process has its characteristic drawback also. For example, suppose we are going for EDM, what are the possible problems that we are going to meet, EDM will definitely produce a recast layer which means you will find some material which has been melted and remove from the work piece surface that will come and get solid re solidified that means, it will get deposited on the finished surface. So, just imagine you have a finished surface on top of that in drop droplets of recast material will be covering the finished surface. And if you look at it under the microscope you will find a lot of cracks, and deposited material totally you know covering the finished surface. And this way material transfer can also take from this cutting element to the work piece.

What is this mean suppose you are using a copper tool or a brass wire to cut material from the work piece in case of electrical discharge machining or wire cut electrical discharge machining. If you look at it under the microscope the surface will reveal that lot of material from the tool has got deposited on the work piece, so that means, that EDM also have its disadvantages. So, it is not you know absolute the supreme method to be used if material is conductive. If you have you know problems with recast material, if you have problems with surface cracks, heat affected zones, material transfer from the tool, then in those cases if the work piece material is you know hard and brittle AJM and USM might be providing you with better alternatives.

What about lasers, lasers seem to be you know the ultimate solution to all engineering problems that are connected with manufacturing. However, if laser cuts are you know examined critically then many materials will be producing clinging dross. Clinging dross, what does it mean, it means that on the underside of the cut material, which is re-solidified from the cut material will be clinging or hanging onto the cut and producing totally unusable piece of final product. It cannot be used either some secondary processes has to be carried out to remove that clinging dross or you know some precautions have to be taken, so that clinging dross does not occur in the first place, for example, like tandem cutting.

So, lasers also suffer from laser cut surface is also suffer from striations that means, you know parallel marks creating a rough texture on the surface, cut surface of you know laser cut materials. The cut might be tapered and of course, there are thermal effects. So, that means, that non-traditional abrasive machining methods are also competitive in this world of you know production of machined surfaces; it is not that they are absolutely unusable in the material is conductive or if other methods are available.

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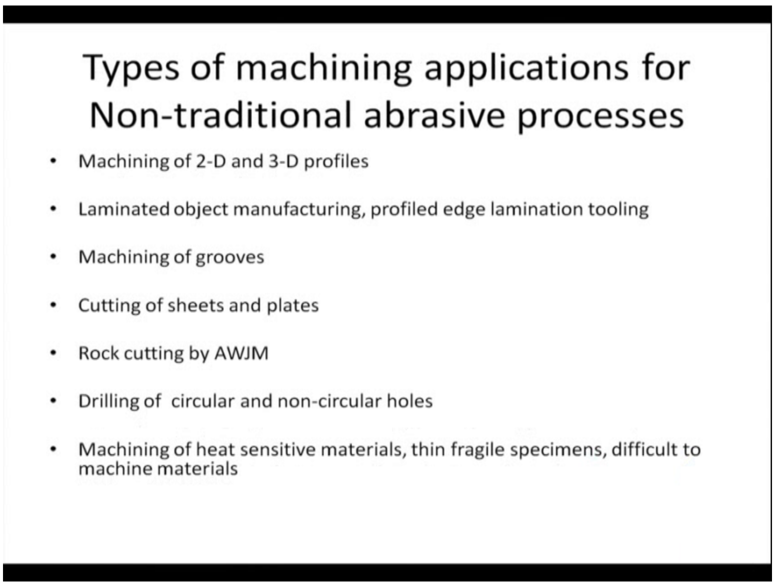

So, where do we apply these non-traditional abrasive processes? As a generalization, we can say that machining of two-dimensional and three-dimensional profiles. If you want to make some you know die surface and if it is very brittle material or very hard material in that case if you want to employ say contour milling using cutters, you might be incurring so much cost of tooling that it might prove to be un-economy. So, in that case USM might be providing you with a better alternative. However, we should note that u s m also results in high tool wear tool varies high since abrasives are used and the tool is getting constant impacts just like the work piece is getting them. So, in that case we have high tool wear in USM also.

Abrasive processes like abrasive water jet machining etcetera can be employed in laminated object manufacturing, profile edge lamination tooling etcetera that means, wherever you have to cut out a material from a plate like structure or a sheet etcetera with the help of a cutter. And five axes water jet machines are now available which can cut you know bevel edges to a particular material. Machining of groups can be done by say abrasive jet machining abrasive water jet machining and also by ultrasonic machine. Cutting of sheets in place plates, rocks cutting of rocks can be done by abrasive water jet machining drilling of circular and non-circular holes machining of heat sensitive materials thin fragile. So, these thing we have already discussed and I think you have got a fair idea of what are the materials what are the applications that are you can be done by these processes.

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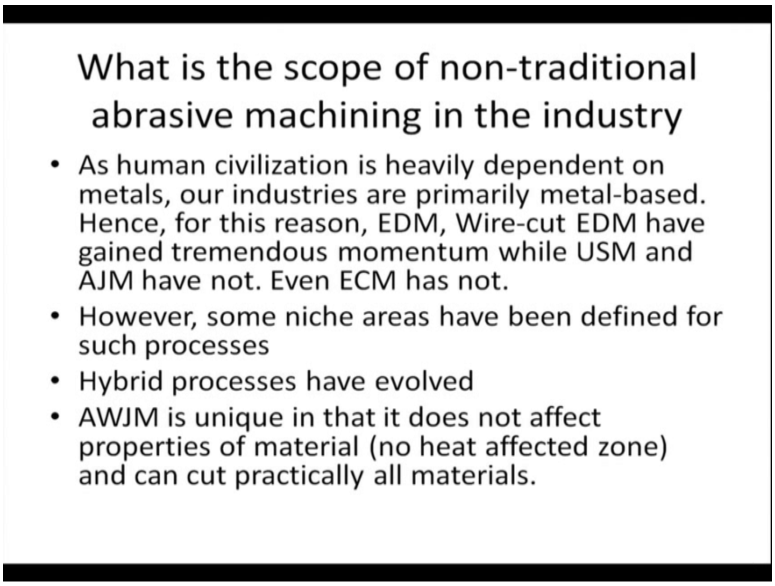

So, let us see the scope as we have discussed since our civilization is still heavily dependent upon metals that is why ultrasonic machining and abrasive jet machining have not gain the amount of popularity that has been gained by electrical discharge machining and wire cut electrical discharge machining not even ECM that means, electrochemical machining. Why is this so this is because while electrical discharge machining can only take place for you know definite gap between the tool and the work piece; beyond this gap that means, if you increase this gap then electrical discharge machining is not going to take place. So, this is a sort of you know safety catch.

In electrochemical machining, however, whatever be the distance some amount of material removal will definitely take place why electrolyte in dissolution, so that means, electrical discharge machining ensures that wherever you do not want the material to be removed in case of you know larger gaps existing, but we will not get removed in those places. And you will be sure that yes I have not removed any material from those places. In electrochemical machining, if you provide a pathway to you know passage of charges from one side to the other, material will get removed in those cases that is why electrochemical machining is not as popular as electrical discharge machining.

And for the same reason that you know mainly we have metals in our industry to be processed to be manufactured metal based jobs that is why EDM and wire cut EDM they are much more popular than USM and EJM, but there are some areas in which you know material machining is still done by our abrasive based processes. Hybrid processes have been involved and abrasive water jet machining that way is unique that it does not affect the material properties and can practically machine all materials.

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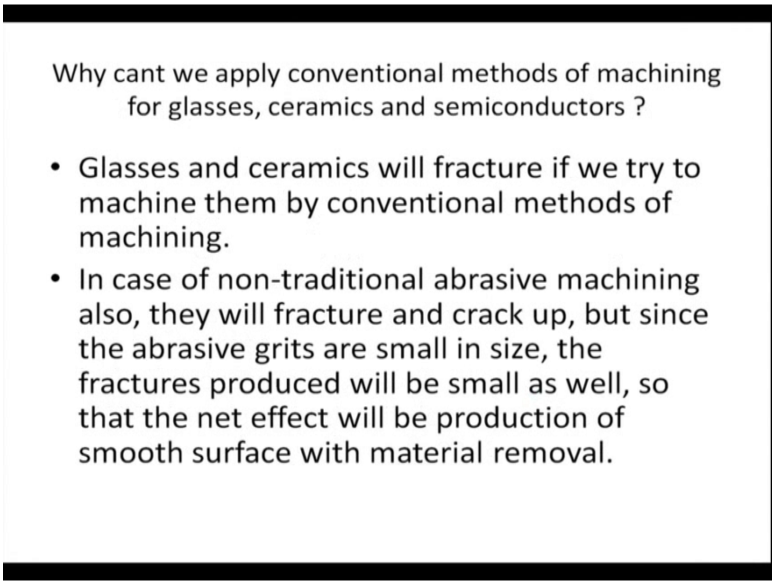

So, why cannot we apply conventional methods of machining for glasses, ceramics and semiconductors that we are claiming is to be (Refer Time: 26:41) area of abrasive processes, this is because glasses and ceramics will fracture if you try to machine them by conventional means. But if we used non-traditional abrasive machining then also there will fracturing crack, but the catch is that we use abrasive powder or particles of very small size, how much small size say 25 to 50 microns even less than that.

What is the advantage the cracks and the fractures will which occur due to you know due to the use of such powders they will also be restricted to that size range, so that ultimately the surface which is produced it will be a smooth surface and material removal take place and their surface geometry will be acceptable. The fractures which are taking place they will all you know cumulatively they will disappear as a whole, the surface to the for all practical purposes will be usable.

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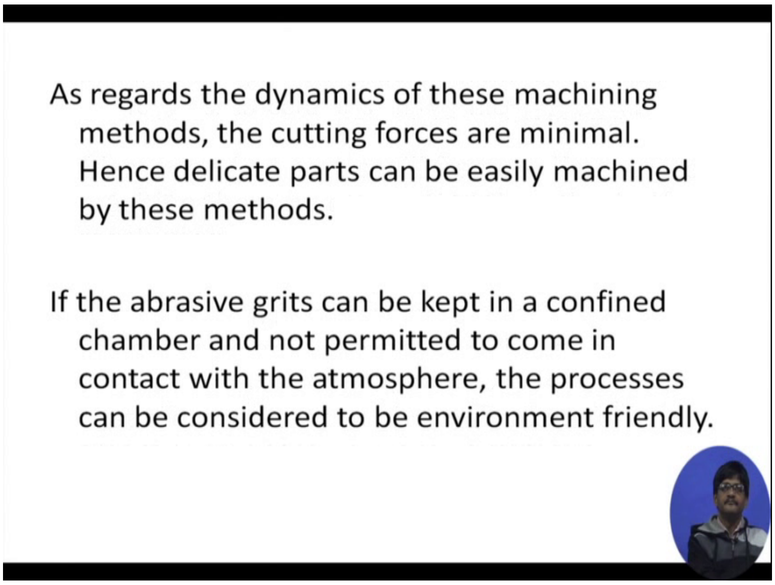

And as regards the dynamics of such machining methods, the cutting forces are minimal. So, delicate parts can be easily machine by these methods. And also if the abrasive bridge can be confined in a chamber and they are not permitted to come in contact with the atmosphere, this can be considered to be an environment friendly process.

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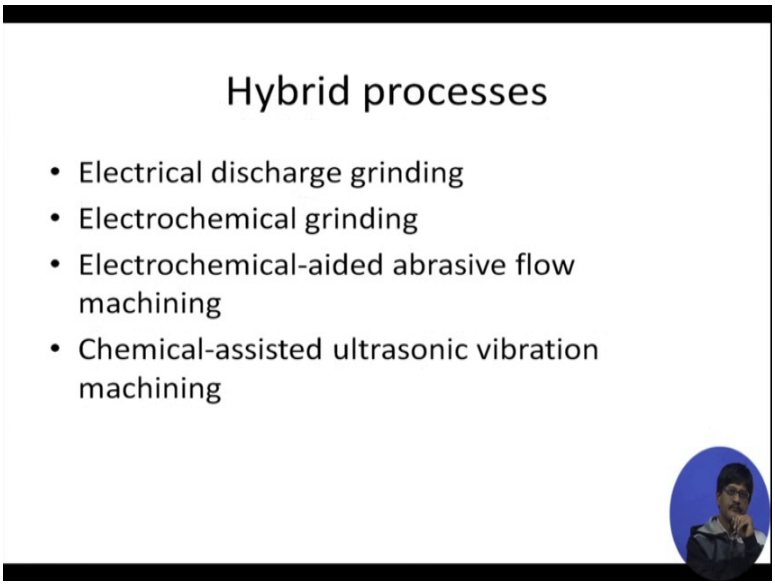

Some of the hybrid processes which are used, the electrical discharge grinding though the use of abrasives is in a conventional way that is by grinding which is conventional. Electrochemical grinding, this also is you know hybrid between electrochemical machining and conventional grinding. We can also have electrochemical-aided abrasive flow machining in which you know inside geometries like whole geometry and other inside hollow geometries machining can be done for finishing purpose. So, by electrochemical means with abrasives put inside. In the same be chemically assisted ultrasonic vibration that can also be employed to remove material these are all hybrid processes.

For example, say hydrofluoric acid might be used which chemically can remove material from ceramics, glasses etcetera and that will enhance the performance or the material removal rate capability of ultrasonic vibration.

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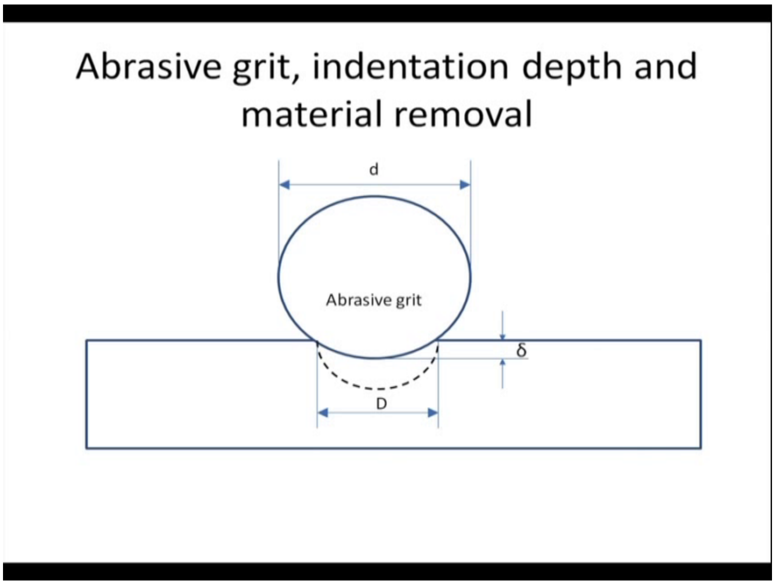

So, I will end the lecture with you know look forward towards the analysis that we are going to perform for abrasive machining. So, here I have shown an abrasive grit of a perfectly spherical shape which is having a diameter small d and which is indenting into a work piece with the depth of indentation to be delta. Due to the indentation there will definitely be forces arising between abrasive grit and the work piece, but we are assuming that the abrasive does not you know lose its shape; it retains its perfectly spherical shape, but the work piece being plastically deformable, it suffers this indentation delta, and due to this indentation if the work piece is brittle or it will undergo material removal equal to the volume of the hemisphere having diameter big D.

So, by dotted line we have shown the material which is getting removed from the you know work piece surface in the form of a hemispherical chunk. So, the basic assumption is if the material be brittle, this hemispherical volume is our material removal per impact.

So, next time that we meet again, we are going to discuss about you know analysis of the material removal mechanism, and we will try to derive an expression for material removal in case of ultrasonic machining.

Thank you very much.