Advanced Manufacturing Processes
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Module - 3
Advanced Machining Processes
Lecture - 4
Water Jet and Abrasive Water Jet Machining

Welcome to this session on water jet machining under the course advanced manufacturing processes. In the last session, we have discussed about the abrasive jet machining process. We have seen its principle, advantages, disadvantages, applications, etcetera. Extending the same theory and principles to another similar process, in this lecture, we will take up a new process as follows.

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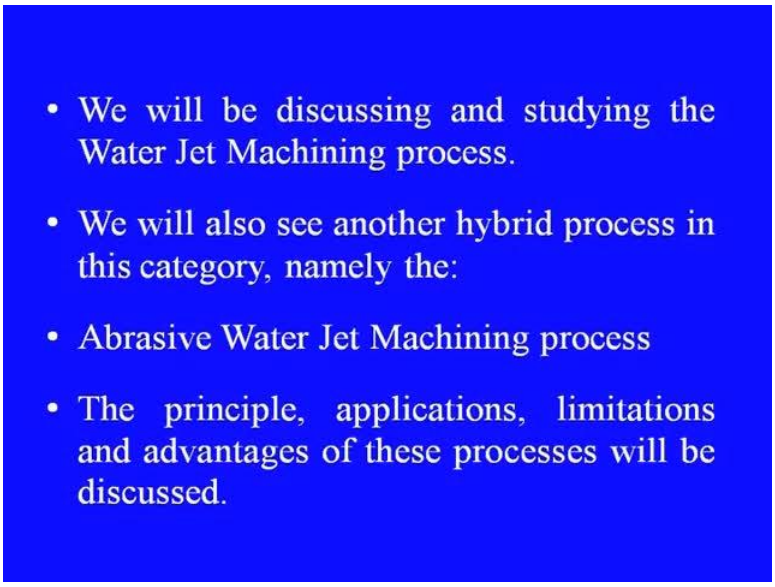

We will be discussing and studying the water jet machining process. We will also see another hybrid process in this category, namely water abrasive water jet machining process. The principles, applications, limitations and advantages of these process will be discussed. Now, let us move to the water jet machining, also in short popularly known as WJM. In this process, a water jet is used, which act as a tool in the form of a water saw. This water jet at a high velocity and pressure is able to slice materials and some metals using some abrasive particles mixed in it. This works something like this.

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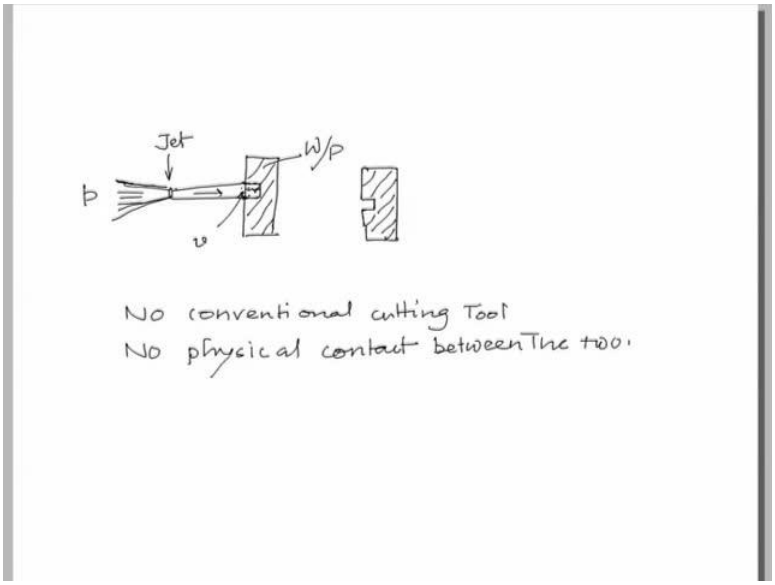

Let us consider this is the target material to be machined and we have a water jet at very high velocity coming through this. Then this will strike, this work material, this work material at a very high velocity v, very high v and because of this kinetic energy of this particles, this will cause some crack into this work material, which will ultimately cause failure of this material. This will cause removal of the material along the dimension of this jet. So, if this is the profile of the jet, then this will cut or form a cut on this material something like this, after repeated application of this jet for a particular period of time.

So, therefore what we conclude is, there is no conventional, no conventional tool, cutting tool, what we call in conventional technology, therefore no physical contact between the two. The, the contact is only through the water water jet, which obtains very high velocity through this jet by the process of conversion of high pressure into high velocity, while passing through this jet. So, in brief this is the working principle of this particular process. Let us see in details about the process and then different components its advantages disadvantages and so on.

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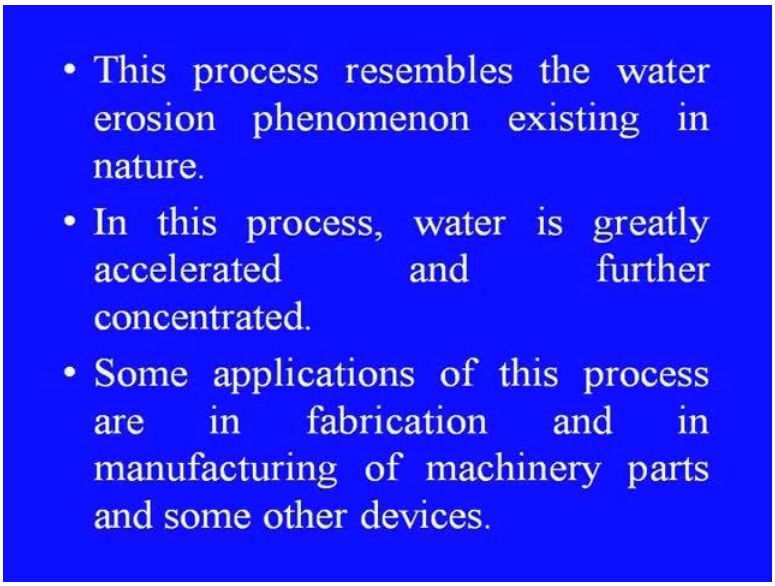

This process resembles the water erosion phenomenon existing in the nature. In this process water is greatly accelerated, as I have already shown and further concentrated on the target work piece. Some applications of this process are in fabrication and in manufacturing of machinery parts and some other devices. Basically the brittle and hard materials are more suitable for this particular process, although all sorts of materials including rubber and metals can be machined or cut.

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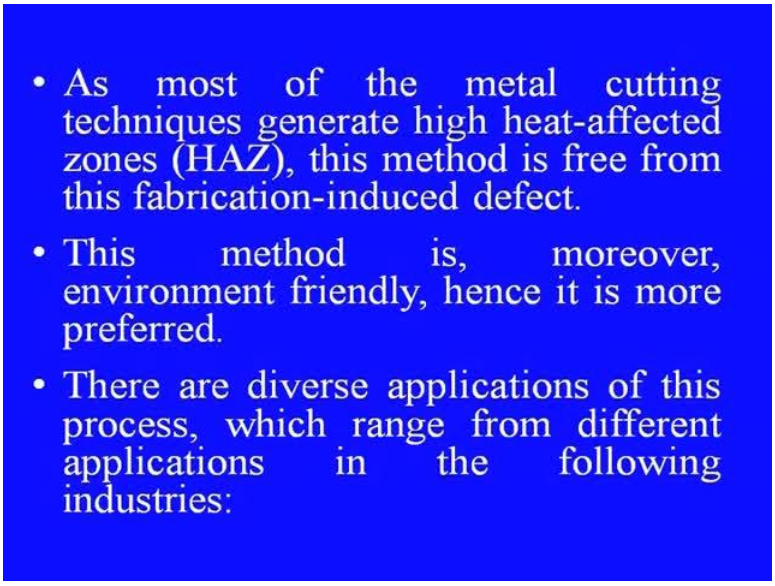

As most of the metal cutting techniques generate high heat affected zones, also called as HAZ, this method is free from fabrication induced defect. This is a big problem, almost all thermal based problems, manufacturing techniques where very nearby to the cutting zone, there will be a defective zone also called heat affected zone. But in this process being a mechanical process, there is no as such heat affected zone related to, what are z cutting or machining process.

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This method is moreover environmental friendly, hence it is more preferred. There are diverse applications of this process, which range from different applications in the following industries. Like in mining industries, were rocks and hard materials can be easily cut, without causing any chemical disturbance to the mild materials or without creating any possibility of fire hazards. As there is no temperature increase in this process and the working fluid used is water.

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Then in aerospace industries, wherein primarily it is used for cutting, carving, shaping applications. Then water jet machining and abrasive water jet machining have potential for cost reduction and speeding up the process, through considerable reduction in secondary processes of machining. The cut edges are clean with fewer bunds as there is no heat.

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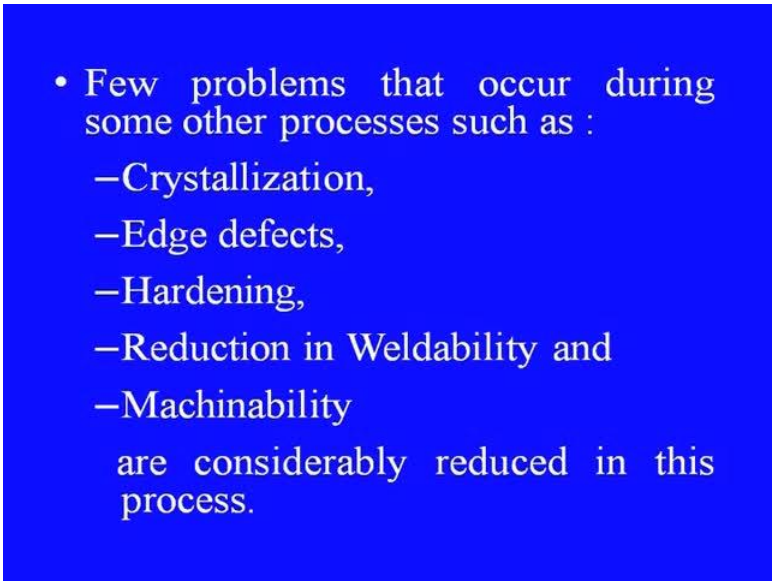

Applications few problems that occur during some other processes like include crystallization, edge defects, hardening, reduction in weld ability and machinability,

these are some of the problems associated with some other popular manufacturing techniques. But these types of problems are considerably reduced in water jet machining process. The term water jet is made used for describing the equipment, which uses a high pressure water stream for cleaning and cutting applications. In some applications no abrasives are used, wherein the process is termed as pure water jet machining process. The semantic of this process is shown in this figure.

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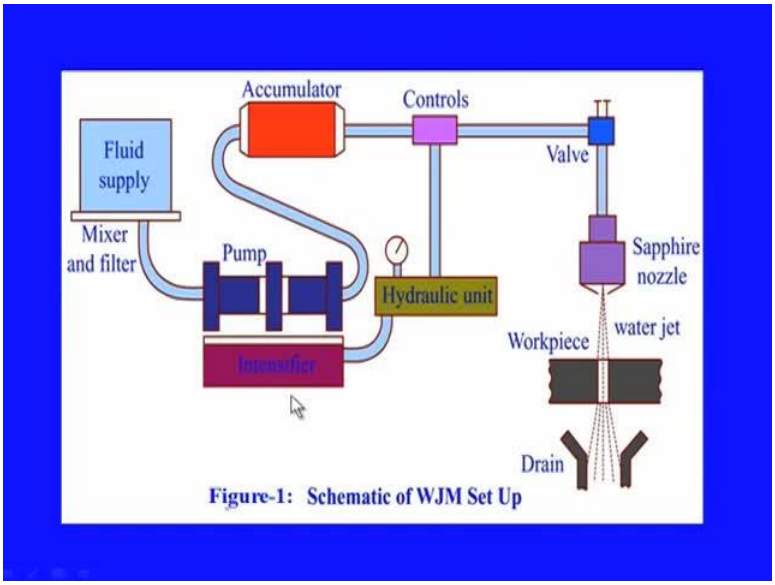

So, here this is the fluid supply unit, which will supply fluid means essentially water and as we know water is the most friendly fluid, that occurs in nature, abounded also and not harmful to the operator neither to the environment. And this fluid is drawn up by this pump system and intensifier, which pumps this to an accumulator, where very high pressure of this water will be created and this pressurized water will be allowed to flow in to the nozzle through some control device. Some control valves will be there in between and this will help the operator, to maintain its quantity of water been flown and to maintain the pressure of the water being flown into the nozzle system.

This is where the pressure energy will get converted into the mechanical energy and the water at high pressure will flow through this nozzle and will obtain very high velocity. High pressure will be converted into high velocity, as it comes out from this nozzle and with that high velocity that means with very high kinetic energy, this will strike on this work part. Thereby this will cause some fractures here, some initiates some cracks on

this work piece surface and as you continue the water jet to apply for a longer period, the initiated cracks will get depend or further propagate inside the water this job or the target material, thereby causing a cut or the removal of the material. The material being removed will be taken away by the water along with it. Of course, there should be some water maintenance systems or management system, which will come out from this after working on this job. This will contain some pieces or some materials of the chips of this job as well. So, this is additional requirement in this set up, wherein this water after doing the work here will be collected and will be sent for further purification and other or may be re circulated through this.

One problem, little problem associated may be associated with this, some water mist may be created in this environment nearby to this area. That may cause some sensitive instruments or equipment, some harm otherwise the process is environment friendly, water friendly and so on. Let us see some more details, how the actual cutting will take place in subsequent phases? Major components in this water jet machining or abrasive water jet machining… Why we are calling abrasive water jet machining is like, we can just we can see in this figure only pure water is coming out through this nozzle. So, this what we talk about the pure water jet cutting set up.

However, in addition to this water to enhance the efficiency or an performance of this this process, we can introduce some abrasives as well into this highly pressurized water stream. At this stage and this water plus abrasives abrasive, this mixture can be directed towards this target work piece, which will act as abrasive water jet cutting set up. So, this enhances, this basically enhances the performance of this cutting process or the efficiency of the entire set up will get enhanced. So, in this entire system, the following components are major components are required.

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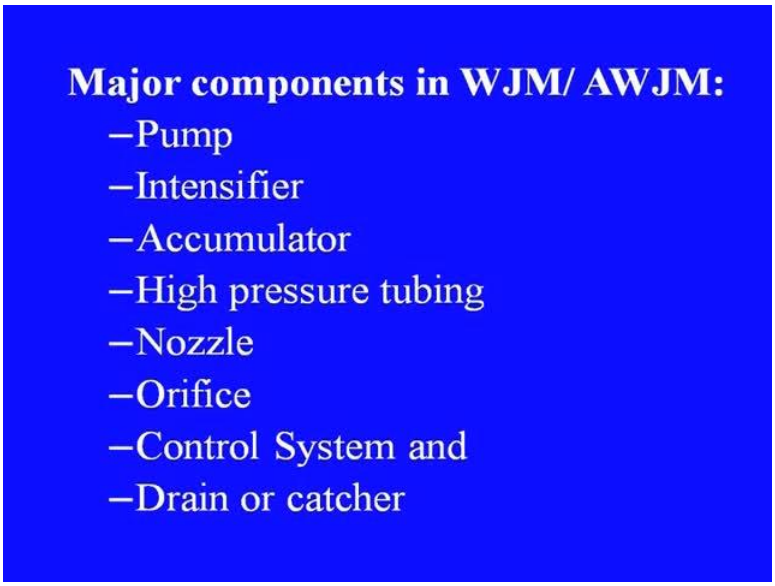

Number one is pump. For pumping the water, then the intensifier and accumulator, which will accommodate the high pressure water. Then high pressure tubing through which the pressurized water will be flown in, then nozzle through which the pressurized water will be directed to the target work piece. Then the orifice through which the water will actually come out, then the control system for controlling the flow of water pressure or the flow of the abrasives and mixture appropriate mixture, then the drain or catcher for this water coming out of this work piece.

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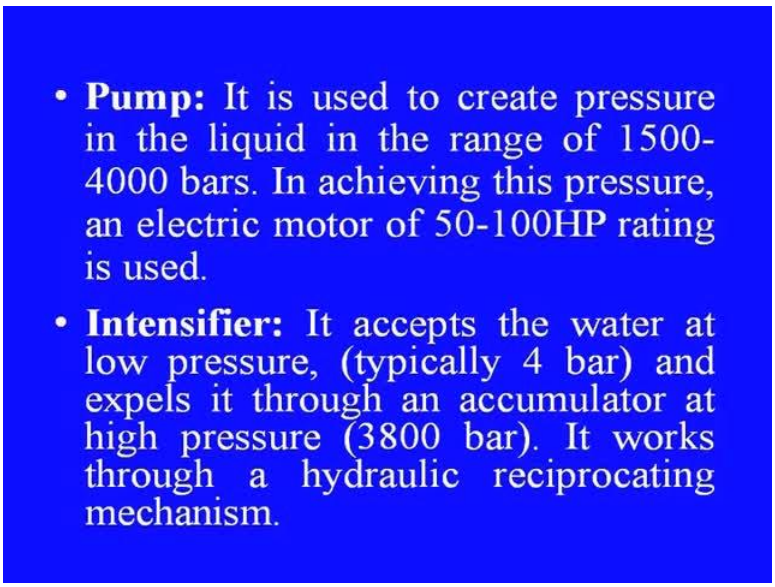

The pump is used to create pressure in the liquid, in the range of 1500 hundred to 4000 bars. Thus we can see this is a very high pressure, that will be created in water. In achieving this pressure, an electric motor of 50 to 100 horse power rating is used. Now, let us see what is an intensifier? It accepts the water at low pressure, typically at 4 bar and expels it through an accumulator at high pressure, that is approximately 4000 bar. It works through a hydraulic reciprocating mechanism, which is responsible for intensifying or enhancing the pressure of the fluid. Then what happens in the accumulator is, it maintains the continuous flow of the high pressure water and eliminates pressure fluctuations. During the working of the system continuous pressure is maintained through this unit, that is also known as accumulator.

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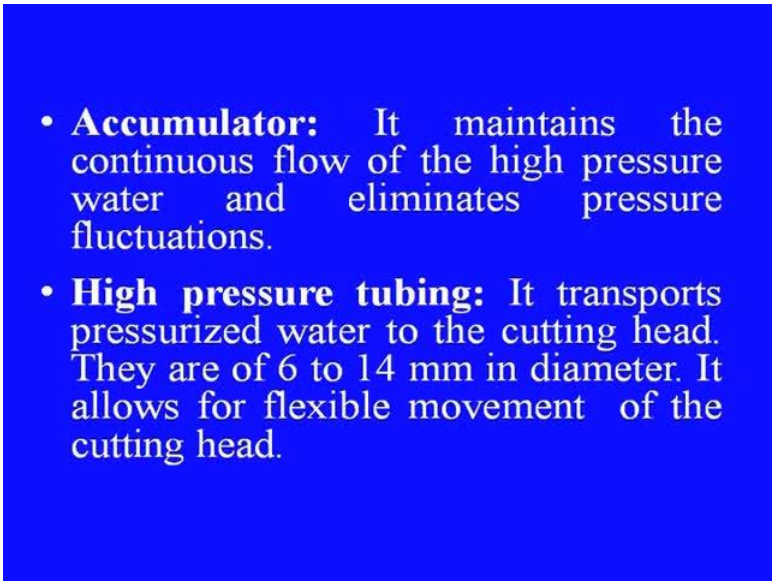

Then high pressure tubin, so the function of this is to transport pressurized water to the cutting head. There are of 6 to 14 mile meter in diameter depending on the application in which we are using it. It allows for flexible movement of the cutting head jet cutting nozzle. These nozzles are used to convert the high pressure liquid into high velocity jet, as I have already indicated this is the unit where, this pressure high pressure will be converted into high velocity.

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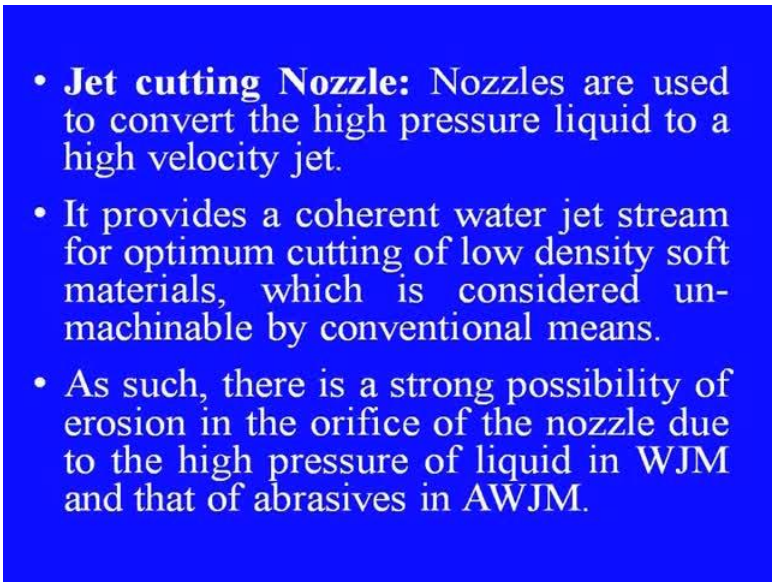

It provides a coherent water jet stream for optimum cutting of low density soft materials, which is considered unmachinable by conventional means. As such there is a strong possibility of erosion in the orifice of the nozzle due to high pressure of liquid in water jet machining and that of abrasives in abrasive water jet machining.

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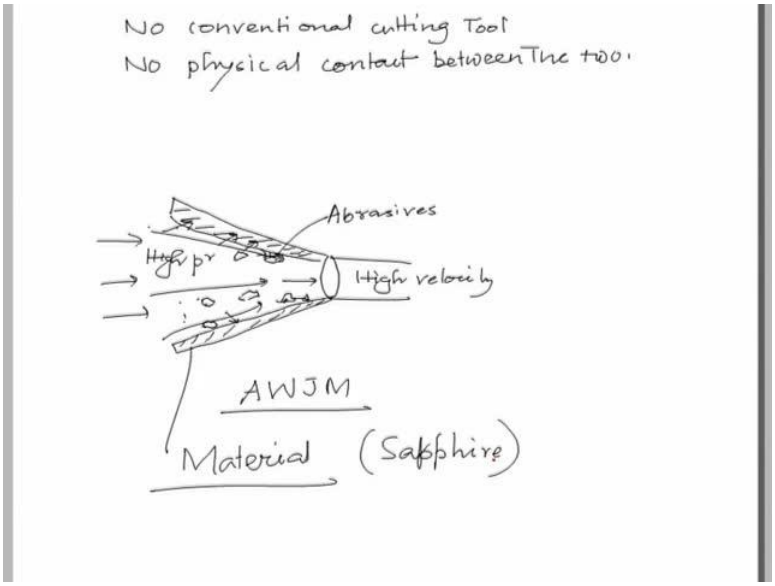

As I told earlier this jet is the very crucial component in this entire set up. Since, the water will be coming through this at very, very high pressure, at this stage it will be of high pressure. At this stage while discharging it will be of very high velocity, therefore

every possibility that, this jet wall, jet wall may get eroded or some deturdiations on this jet wall will take place, because of this high velocity fluid passing through this. Also if this is AWJM abrasive water jet machining, then in addition to this water, there will be abrasive particles mixed in this and this jet walls, this jet walls are the materials which will have to withstand this pressure of this fluid, as well as the impact of this abrasive particles.

So, these are abrasive particles, abrasives. Now, because of this continuous impact of this abrasives and this flowing fluid flowing fluid, this jet walls may get eroded very frequently and this is one of the major problems being encountered in this system. Therefore, the choosing the material the right material for this jet or this nozzle is a very big question, generally sapphires are used, which are considered to be a very good material as for these nozzles are concerned. Therefore, a high wear resistant materials such as synthetic sapphire is used, as nozzles as I have already told and mixture is there in the screen also.

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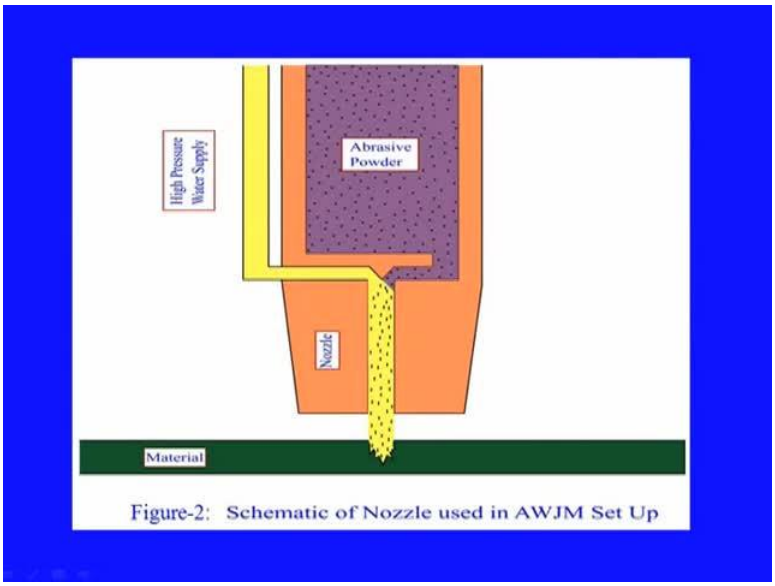

This is, this is how it works. This is the abrasive powder or abrasives and this is the, high power sorry, high velocity water coming out and this were it gets mixed. This jet or this nozzle walls will have to bare this pressure as well as the abrasive action of this abrasive materials, while enabling this jet or this mixture of high pressure water as well as the abrasives through this. Let us see the functions of the grain or the catcher. It acts as a

reserve foil for collecting the machining debris and drain in the water. It also helps to reduce the noise level associated with the reduction in velocity of water jet. Now, let us look into the factors that effects water jet machining performance. These factors are generally grouped into three major categories.

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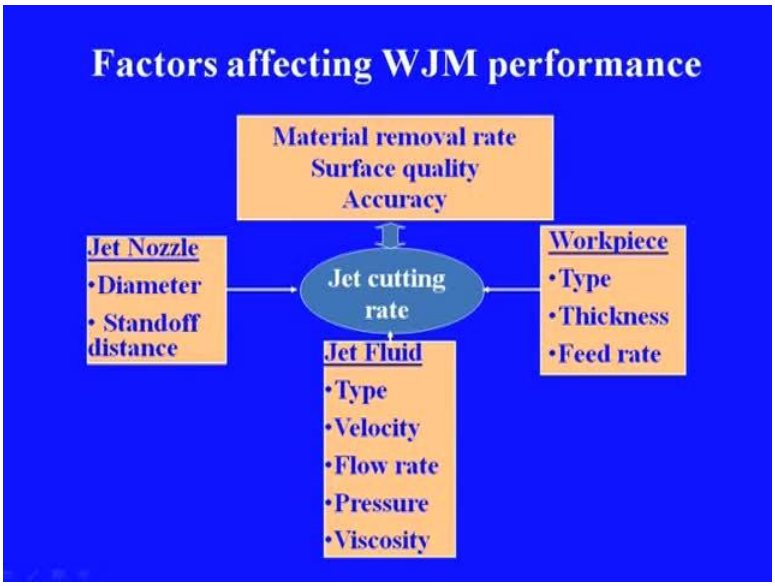

These are jet or nozzle based parameters or factors. Here the jet diameter or the nozzle diameter is one of the major factors. So, higher the diameter of this nozzle, so there will be possibility that the nozzle, the water stream coming out through this nozzle will get diversified more or there will be more diversion in this case. And then the stand of distance, as we have seen in in case of abrasive jet machining, the stand of distance which is the distance between the jet opening and the target material. So, this is a very, very critical parameter.

So, depending on this the energy with which the particles the energized water particle and abrasive particles will hit the target, will depend upon. Therefore, accordingly the performance of the process will also vary. There has to be an optimized distance for this stand of between this nozzle and the target. Then the next category is the jet fluid. Here the type of the fluid which fluid we are using, it may be water or it may be other liquid also. However water is always preferred low cost and it is afford or an environmental friendly and of course, available also.

Then the velocity of the fluid which is very, very critical, this velocity will give the energy to the particle or the working energy. Then the flow rate at which it is flowing, then the pressure of this fluid, then the viscosity of the fluid. If the fluid type changes, then the viscosity will also change, but if it changes appreciably then one has to have some mechanism to maintain the viscosity, so that with temperature or with factors it does not get changed during the working hours.

Then the third category is the work piece related parameters. So, here what is the type of the work piece, then the thickness of the work piece and then the feed rate of the work piece. So, it is to be mentioned here that the thickness, if it is a very high thickness, the work piece then the process may not be very, very efficient in this case. So, all these three categories of parameters, will affect the final outcome of this process, which is either cutting or the finishing or the cleaning of the target surface.

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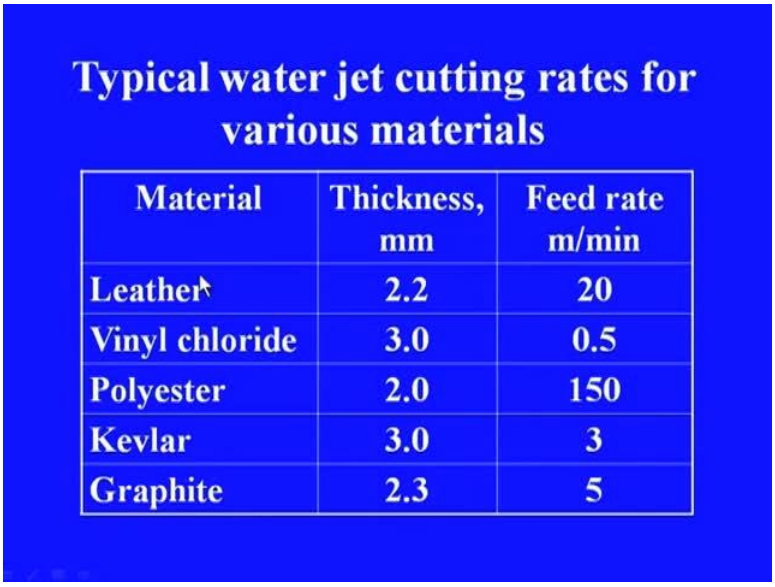

Let us see few parameters like water jet cutting rates for various materials like leather. For leather of thickness say 2.2 millimeter feed rate used is 20 meter per minute/ Similarly, if the material is vinyl chloride and a thickness of 3 millimeter the feed rate suggested is only 0.5 meter per minute. Similarly, for polyester of 2 millimeter thickness, the feed rate is 1 point, 150, 150 meter per minute for kevlar of three millimeter thickness only 3 meter per minute. Then for graphite of 2.3 mile meter thickness 5 meter per minute is recommended.

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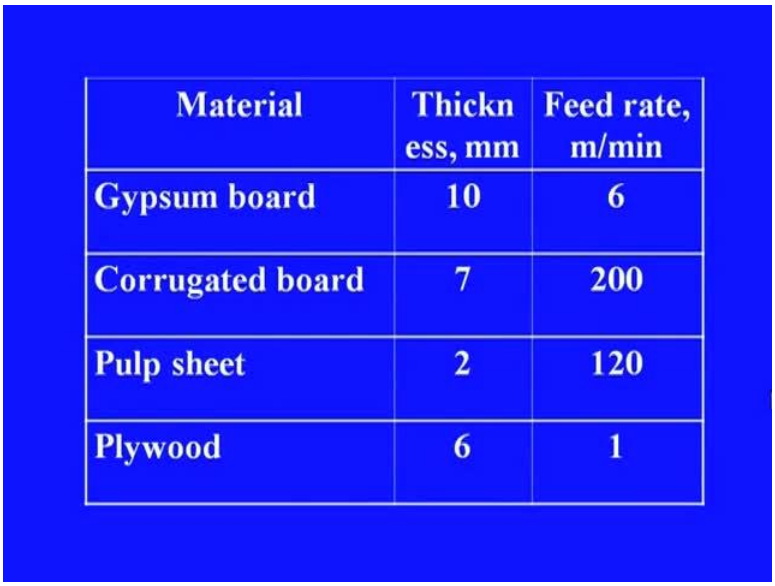

For gypsum board of 10 millimeter thickness feed rate is 6 meter per minute, corrugated board of 7 mile meter feed rate is as high as 200 meter per minute. Pulp sheet for 2 milllimeter thickness feed rate suggested is 120 meter per minute. Then for plywood of 6 mile meter thickness 1 meter per minute feed rate is suggested. Abrasive water jet machining is a sub category of water jet machining in which an abrasive is introduced in the water to accelerate the process. As I have already discussed with the help of diagrams, hence this abrasive water jet machining process is dually considered as an extension of this water jet cutting machining process also. It is called a hybrid process of basic WJM in which hybridization in the form of abrasives and there by the enhancement in the cutting performance or the cutting rate.

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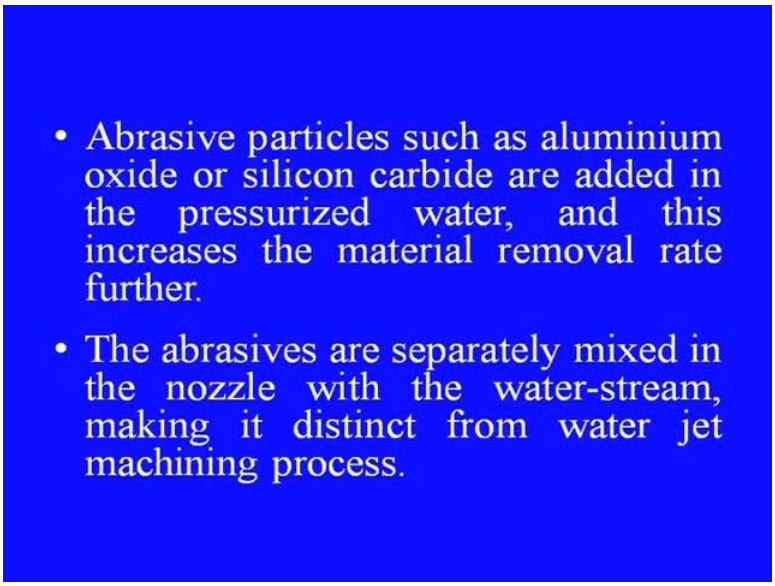

Abrasive particles such as aluminium oxide or silicon carbide are added in the pressurized water and this increases the material removal rate further. The abrasives are separately mixed in the nozzle with the water stream making it distinct from the water jet machining process, in which only pure water is used as the cutting medium. The abrasive water jet cutting process is suitable for machining different types of materials, ranging from hard brittle ceramics and glass to soft metals like materials like rubber and form. In fact water jet machining process is considered to be very, very effective machining process for cutting very soft material like rubber and form, which are otherwise difficult to cut by some conventional machining processes.

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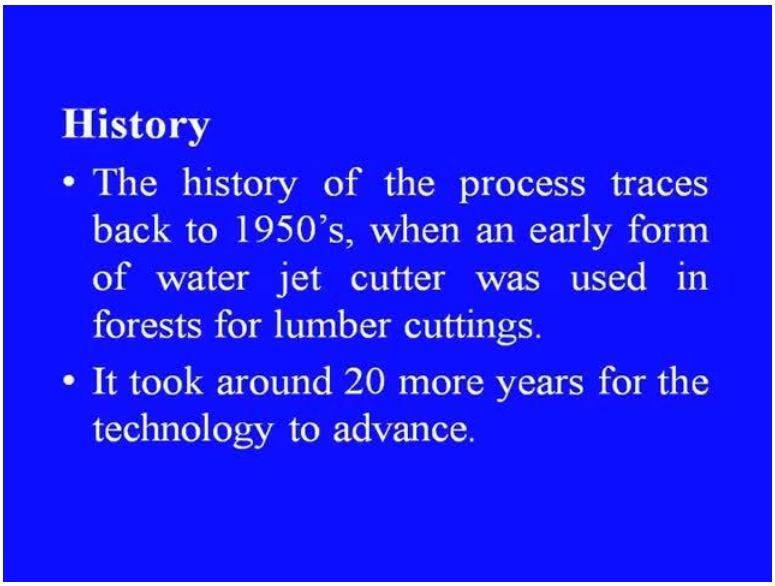

Let us look into little bit of historical development about this process as well. The history of this process traces back to 1950's, when an early form of water jet cutter was used in forests for lumber cuttings. It took around 20 more years for the technology to advance further. Later in the year 1970 or in that decade, industrial abrasive water jet machining was introduced. Nowadays, this process is measured and has changed the manufacturing methods of many products. A brief chronological evolution of this water jet machining process is something like this.

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In the 1930's this was used in mining industries although not in the present form of water jet machining, what we use today. This was at that time used for removing stone and coals by the shear pressure of this water, then during 1960's necessity arose in aerospace industries, for cutting the advanced materials, which are also otherwise difficult to cut through a conventional machining process.

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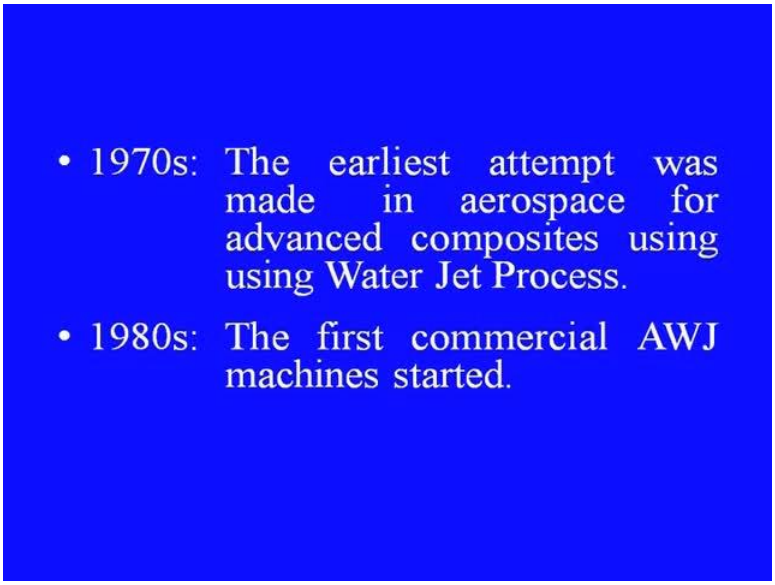

Coming to 1970's the earliest attempt was made in aerospace again for advanced composites using water jet process. Then in during 1980's the first commercial abrasive water jet machines were introduced.

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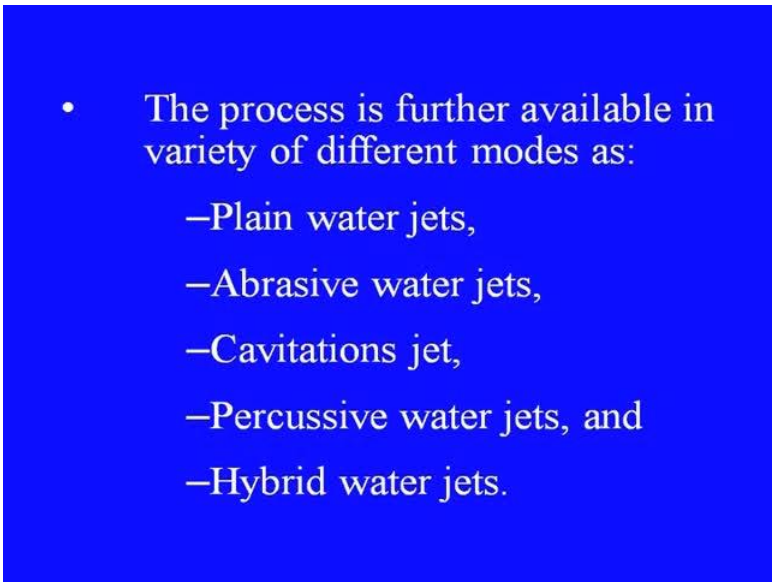

The process water jet machining is further available in variety of different modules, they are also known as plain water jets, abrasive water jets, cavitations jet, percussive water jets and hybrid water jets. Now, let us look into little theory of the water jet and abrasive water jet machining.

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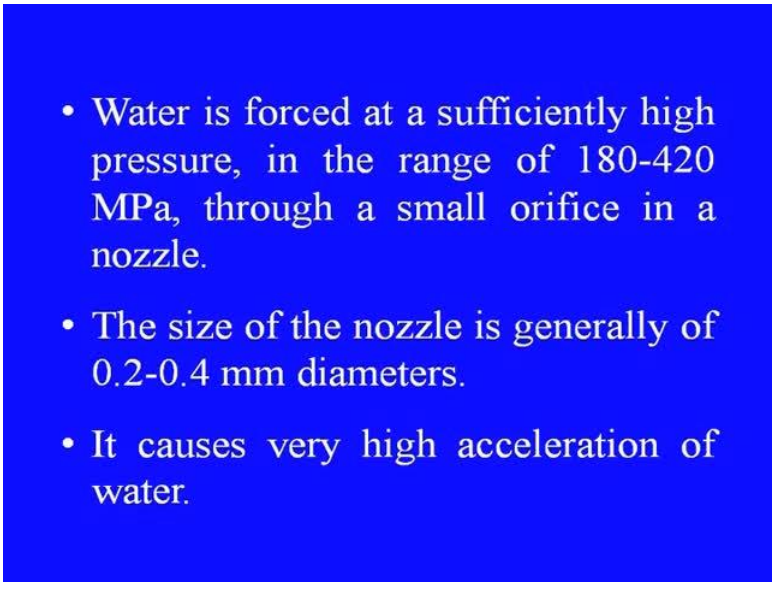

In this process water is forced at a sufficiently high pressure, in the range of 180 to 420mega pascal, through a small orifice in a nozzle. This is what I have already discussed in the early part of this session. The size of this nozzle is generally of 0.2 to 0.4

mile meter diameters and it causes very high acceleration of the water, which is already under pressure.

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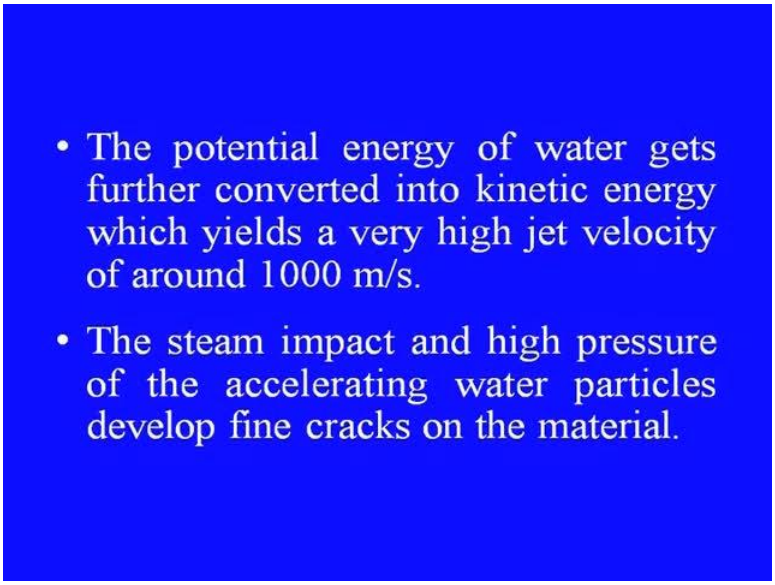

The potential energy of water gets further converted into kinetic energy, which yields a very high jet velocity of around 1000 meter per second, which is in fact a very high velocity. The stream impact and high pressure of the accelerating water, develop fine cracks on the material. This fine cracks propagate further, under the impact of high pressure and abrasives. With the crack propagation taking place to a considerable extent, it is considered to be the basic phenomenon of material removal, which helps in cutting the material finally.

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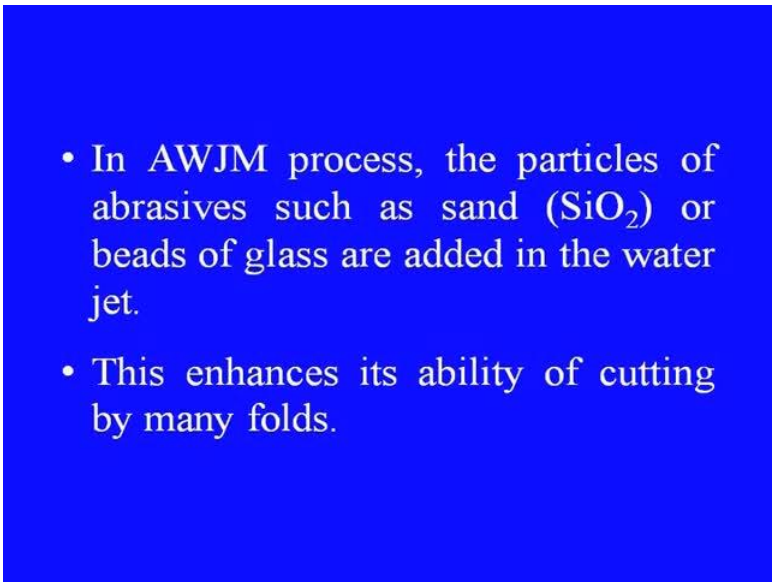

In abrasive water jet machining process, the particles of abrasives such as sand, which is nothing but silicon oxide Si O 2 or beads of glass are added in the water jet. This enhances the ability of cutting by many folds. The abrasive water jet machining are mainly of two basic types.

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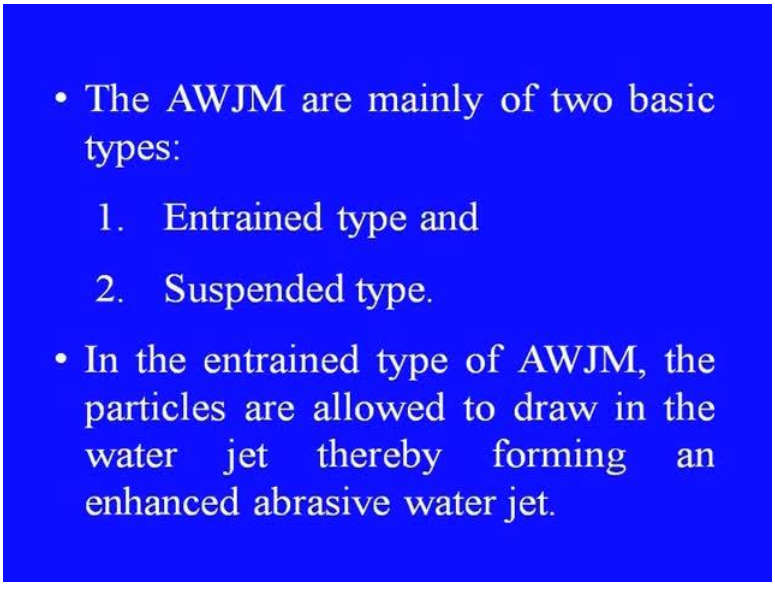

Number one entrained type and suspended type. In the entrained type of this machining, abrasive water jet machining the particles are allowed to draw in the water jet, thereby forming an enhanced abrasive water jet. In the suspended type both are mixed prior to

sending to the jet, at a very high velocity. It helps in developing significantly higher velocities at around 800 meter per second. Almost any material can be machined at such a high velocity of this abrasive jet. Let us look into the distinct advantages of water jet machining and abrasive water jet machining process.

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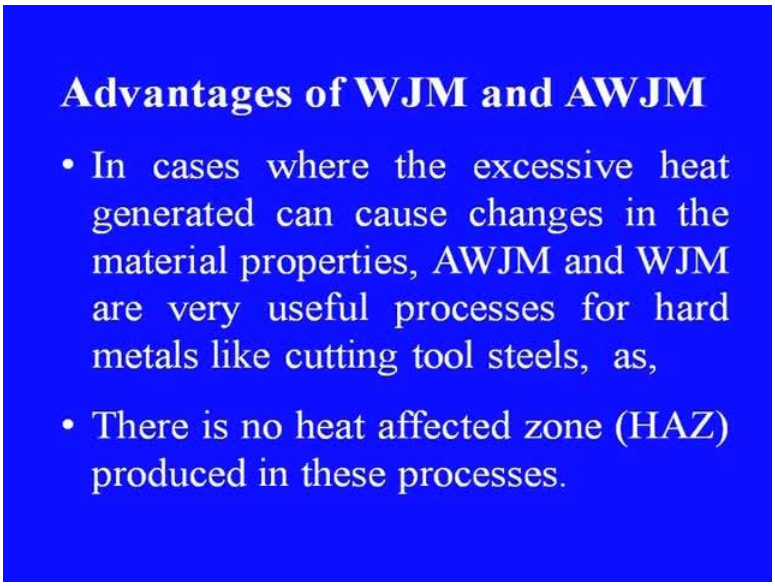

In cases where the excessive heat generated can cause changes in the material properties. This we have discussed already in few cases. However, in case of abrasive water jet machining and water jet machining, there is no thermal rise in the temperature. Therefore, they are very useful processes for hard metal like cutting tool, steels etcetera. As there is no heat effected zone in this processes.

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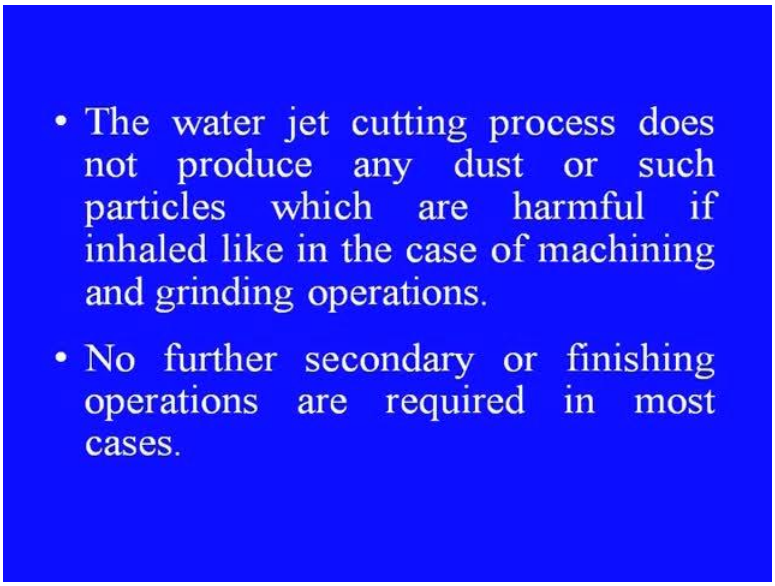

The water jet cutting process does not produce any dust or such particles, which are harmful if inhaled, like in the case of machining and grinding operations. If we recall the earlier session in abrasive jet machining also, the particles, the abrasive particles are also very dangerous for the operator. They need to be handled very carefully, collected very carefully after the work is done. Otherwise inhaling those particles even in the grinding process where grinding swards in the form of fine powders are created, they need to be handled carefully, otherwise that may be hazardous for the people working in an around that environment.

However, in water jet machining this problem of flying particles in the water in environment, nearby to this process or where the machine set up is located, is not there. As I said earlier only the water mist may be there, which is not that harmful as that of abrasive particles or any other chemical particles, as far as the health of this operator is concerned. Also no further secondary or finishing operations are required in most of the cases.

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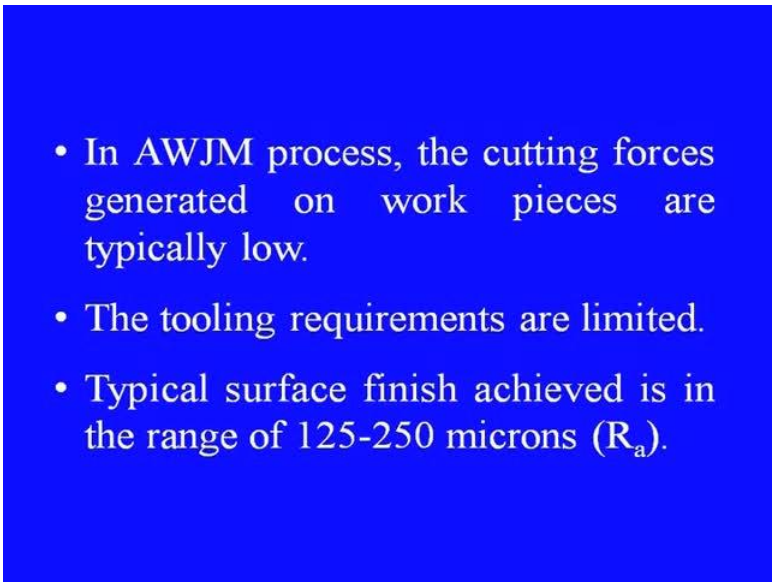

In abrasive water jet machining process, the cutting forces generated on the work pieces are typically very low. The tooling requirements are limited. The typical surface finish achieved is in the range of 125 to 250 microns or average reference, which we call as R a. The material visitors are reduced due to smaller curve sizes. There is no cutter induced metallic contamination. The process also eliminates thermal distortions nearby to the cutting zones.

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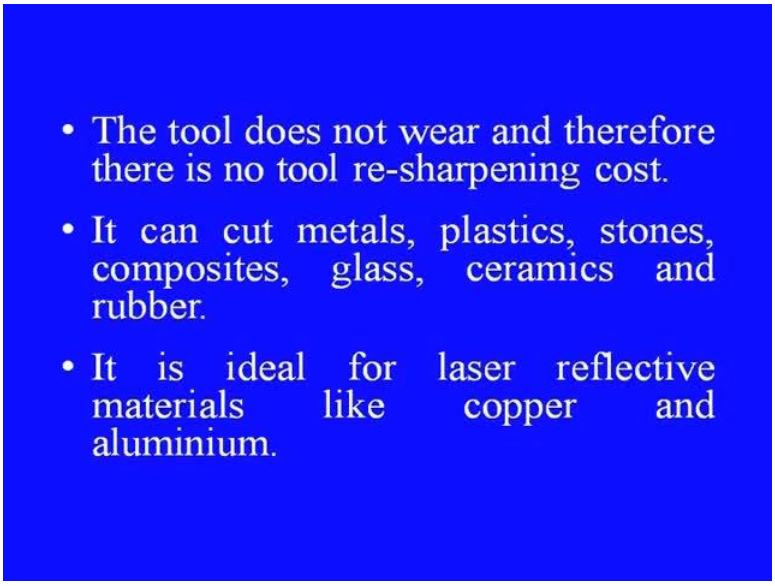

The tool does not wear and therefore, there is no tool re sharpening cost. As such as I indicated in the very beginning, there is no physical tool involved in this and therefore, no tool wear. It can cut metals, plastics, stones, composites, glass, ceramics and rubber. This is another fantastic characteristic of this process. We will find hardly any process which can be as versatile as this water jet machining processes, with respect to cutting the range of materials. In most of the processes it can be very good for cutting metals or it can be very good for cutting brittle metal like glass and ceramics or in some cases the process may be good for rubber or soft materials form like that.

But the very characteristic of water jet machining is that, it is equally good or versatile for all these materials at the same time. It is ideal for laser reflective materials like copper and aluminium, as we know copper, aluminium and copper, these are some of the materials which reflect laser. And therefore very difficult to cut precisely by tool like laser machining or laser. However, with this water jet machining this type of problems do not arise.

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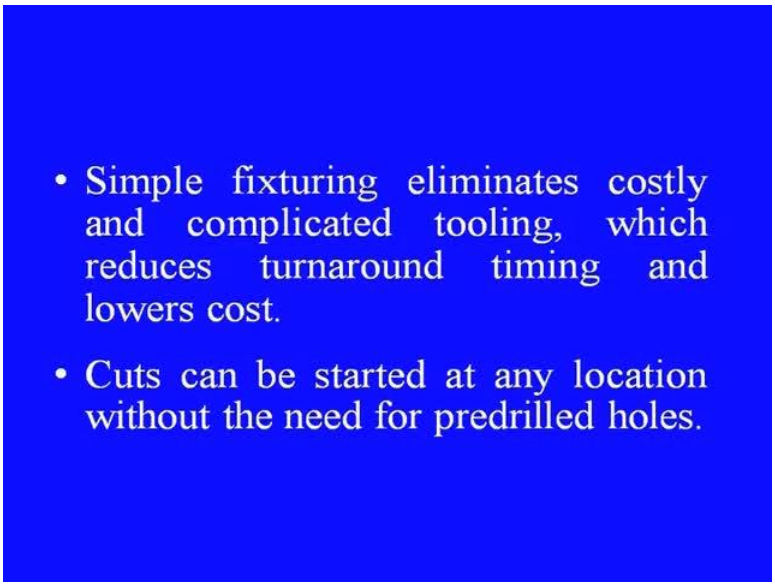

Simple fixturing eliminates costly and complicated tooling associated with some other process, which reduces turnaround timing and also lowers the processing cost. It cuts we can start at any location and without the need for predrilled holes. While talking about the advantages of this process, let us also look at some of the limitations of this process; water jet machining and abrasive water jet machining process.

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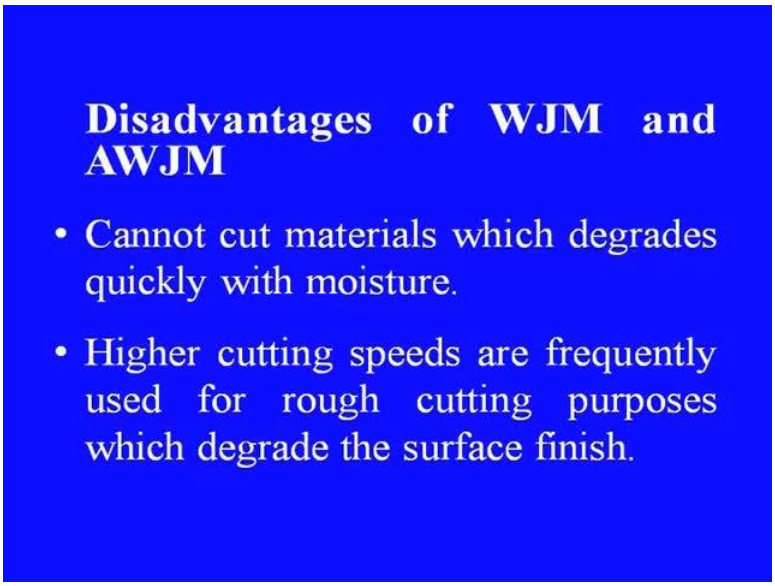

It cannot cut materials, which degrades quickly with moisture because water is essentially lead a component, which is responsible for cutting. Higher cutting speeds are frequently used for rough cutting purposes, which degrade the surface finish.

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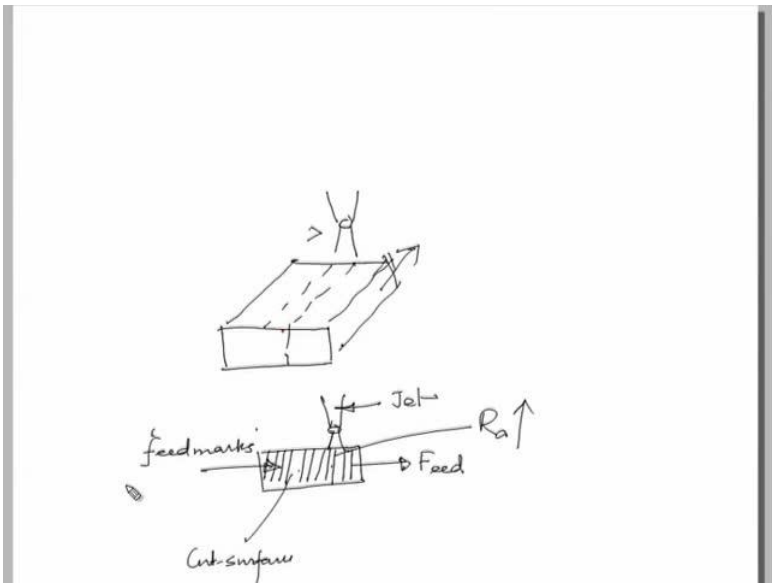

This inaccuracies as far as the surface finish is concerned, this arises something like this. This is the work piece and this is the jet, this is coming through this. As we feed the either the jet or the work piece in this direction, then there will be a relative velocity between this jet and the work piece, which is being feed continuously and because of this

unless we take some precaution, then there will be some sort of feed marks sort of things like this, like this along the surface of this, cut of this. This is the cut surface, cut surface and these marks and these marks will be sort of feed marksm feed marks which will call in case of conventional machining processes.

So, this will also appear in this and this will give rise to the R a value. Therefore, there are certain mechanisms now a days to take care of this kind of problems in the software itself. We can maintain the speed the feed and the angle of this of this jet in such a way that this feed marks can be minimized. This is the feed and this is the jet. There is a strong possibility of cracking in brittle materials and only few varieties of materials could be cut economically. As I told in the very beginning the cutting takes place because of the crack initiation and propagation of the crack.

Therefore, if it is a brittle material, brittle materials as we know they are prone to cracking. Now, this cracking can even go towards the other side or the sideways, rather than the exact perpendicular direction where the cutting is intended. Therefore, it can make the work piece worse, what we do not want in fact. With water jet machining process thick parts cannot be cut accurately and economically. In thicker materials taper generated is also a problem, like as we as we told in the case of abrasive water jet, abrasive jet machining. So, here also the taper problem may be there.

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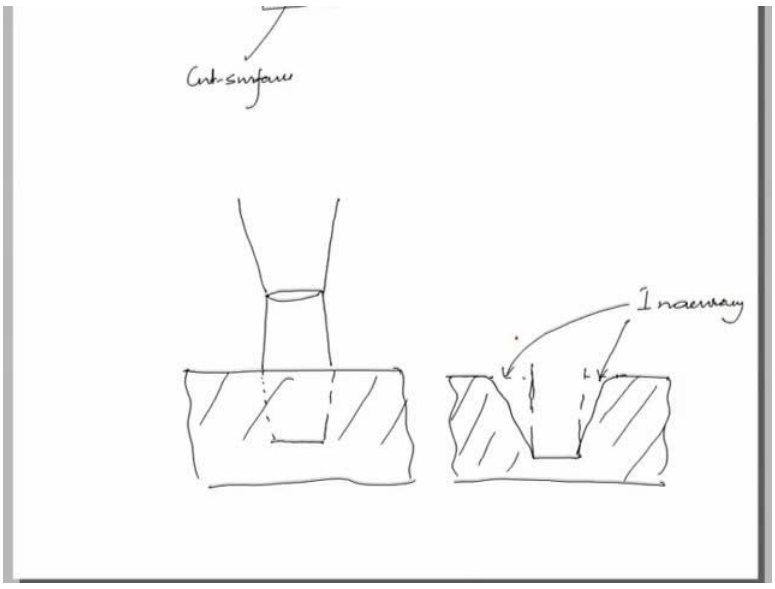

In case of this, like if the jet is something like this and if the jet falls under work surface like this, then therefore, as it cuts through towards the end of this cutting its its effectiveness may get decrease and there may be a taper formation as in the case of abrasive water jet, as we have seen in the previous session. The final cut can be something like this, which we do not want to have in the work piece. This in fact this would have been a hole or cut mark something like this. However, this kind of in accuracies, this is inaccuracies can we say in case of this water jet machining processes.

We are talking about the disadvantages of this process, another major disadvantage is the equipment here is itself is a very costly equipment and it is a big investment in fact. Also there are safety concerns due to noise and high pressure. Noise is really a big issue in water jet machining and of course, high pressure handling, high pressure is always dangerous. Then what are the process parameters? Let us quick have a quick look into the parameters.

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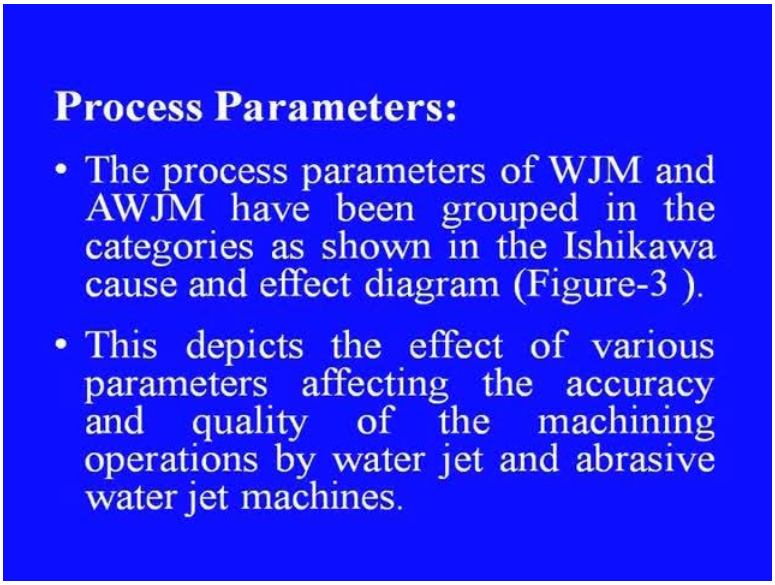

The process parameters of water jet machining and abrasive water jet machining have been grouped in the categories, as shown in the ishikawa diagram as follows. This depicts the effect of various parameters on accuracy and quality of the machining operations by water jet and abrasive water jet machining. So, this is very a familiar ishikawa cause an effect diagram.

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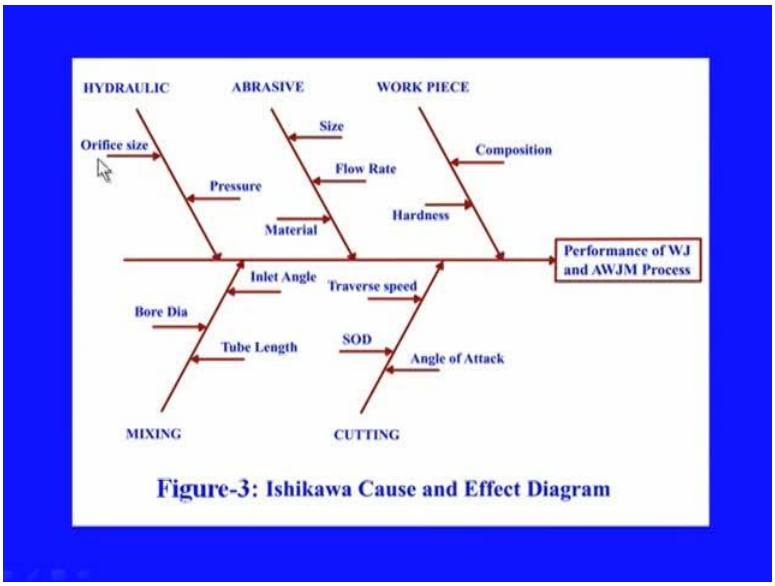

Figure-3: Ishikawa Cause and Effect Diagram

This parameters are hydraulic based parameters like orifice size and orifice and the pressure and fluid pressure. Then abrasive jet parameters are like size of the abrasives, then flow rate, then the material abrasive material itself, which can be silicon carbide or aluminium oxide etcetera and higher the abrasive size, then there will be rate of cutting will be better. But of course, we have to see the life of the nozzle here, which will go down, then the work piece, work piece material.

This may be a composite, may be a pure metal this may be home like materials or rubber etcetera, then the hardness of the work piece material. Since, it basically works under principle of formation of the cracks; therefore, the hardness also plays a very important role as far as the performance of this is concerned, then the mixing parameters like bore diameter, tube length and inlet angle. This will have an effect as I have indicated along with the surface roughness criterias, where the inclination of the jet is also an important parameter.

Then the cutting parameters like stand of distance, then the traverse speed and then angle of attack, all these influences the final product quality and surface finish. As I said the stand of distance is very important parameter in this process also. Lesser the stand of distance the poorer will be the quality and accuracy of the cut.

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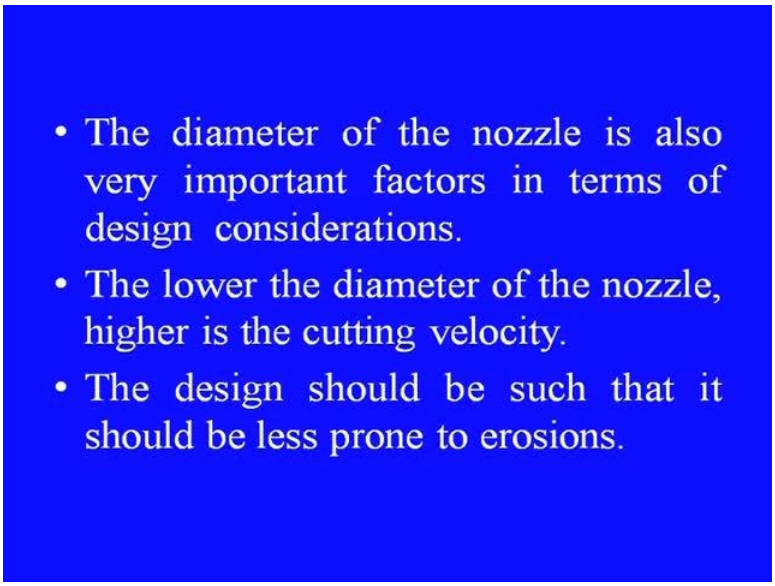

The diameter of the nozzle is also very important, as far as the design of the nozzle is concerned. The lower the diameter of the nozzle higher will be the cutting velocity and therefore, cutting will be faster. Therefore, design should be such that it should be less prone to erosions. A very high degree of polishing and fine radius is provided in it. The life of nozzle is less as compared to other elements which adds to the cost. This is one of the considered one of the major disadvantages of this process, where nozzle is a very costly and a part to be frequently changed, which adds to the cost and down time as well. Let us have a quick look at the applications of the water jet machining and abrasive water jet machining.

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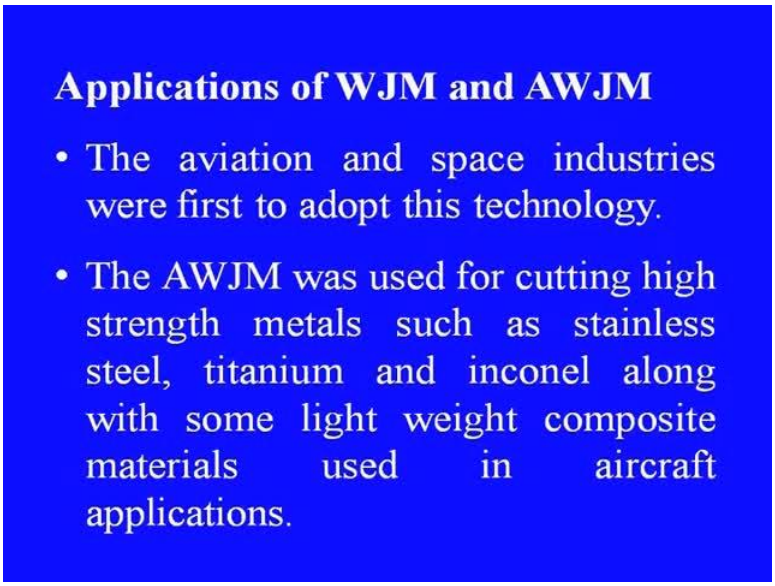

This process is frequently used in the aviation and space industries. Then this was also used for cutting high strength metals such as stainless steel, titanium, inconel along with some light weight composite materials, which are frequently used in aircraft applications. In cutting water jet machining is limited to fiber glass, corrugated wood and low strength materials like plastics and aluminium. Then in drilling the process drills, precision angled and surfed holes in variety of materials for which other processes are too expensive or slow.

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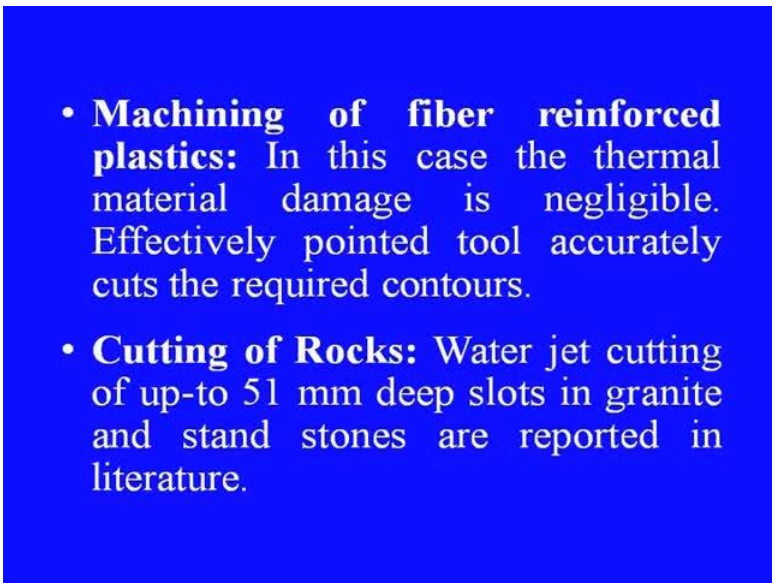

In machining of fiber rein force plastics FRP's, in this case the thermal material damage is negligible and therefore, this process is preferred. Effectively pointed tool accurately cuts the required contours as we know FRp's are in homogeneous. There are two three faces of different material characteristics and therefore, this process is more suited for cutting this type of materials like FRP's. Cutting of rocks, in fact this was the first kind of applications, where the pressurized water was used.

Water jet cutting was up to fifty 51 millimeter deep slots in granites and sand stones are reported. In fact these are the materials granites and sand stones are very hard materials and the conventional tools gets blend very fast, while cutting this materials. Therefore, the cutting cost becomes too high in case of conventional cutting metals, whereas this can be very safely used with water jet cutting process.

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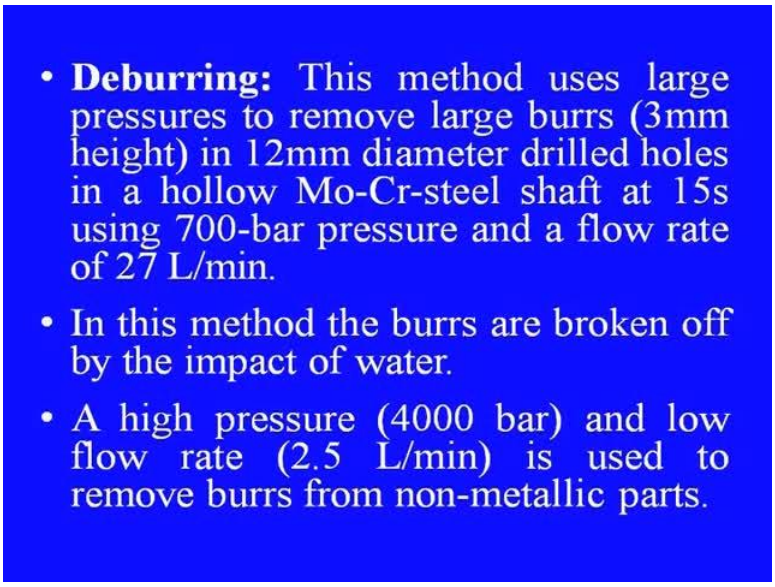

Deburring is another area where water jet cutting can be used. Large pressures of this water is used to remove the large burrs. Say for example 3 millimeter in height to 12 millimeter in height in a hollow molybdenum chromium steel shaft and this can be achieved at only 15 seconds using 700 bar pressure and a flow rate of 27 liter per minute. In this method the burrs are broken by impact of the water a high pressure. As i has 4000 bars and low flow rate 2.5 liter per minute is used to remove the burrs from the non metallic parts.

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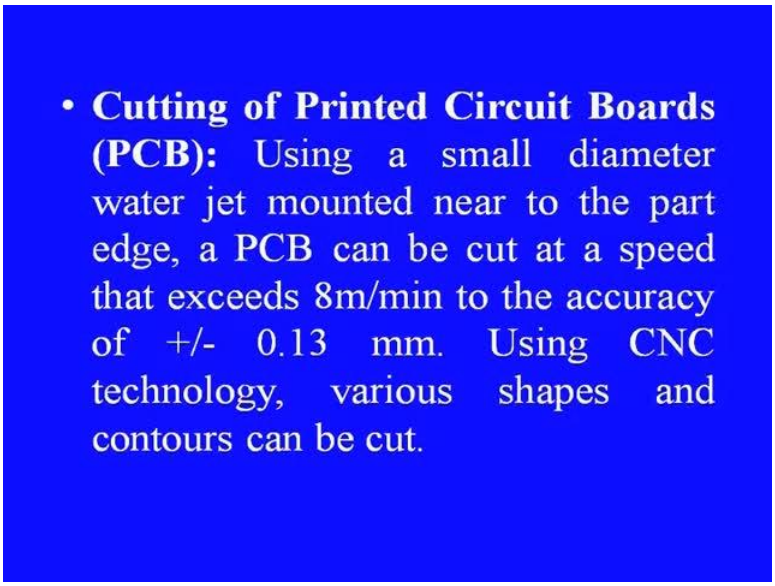

Another application is cutting of PCB's or printed circuit boards using a small diameter water jet mounted near to the part edge, a PCB can be cut at a speed that exceeds 8 meter per minute to the accuracy of plus minus 0.13 millimeter also, using CNC technology various shapes are contours can be cut. Then this process can also be used for surface treatment like, removing deposits and residues without any toxics chemicals, which eliminates costly cleaning and disposal problems.

Then the surface cleaning of pipes, and castings, decorative finishing, nuclear decontaminations, food utensils cleaning, decreasing, polishing, surface texturing etcetera. Then economical surface preparation and coating removal also can be done, using this process.

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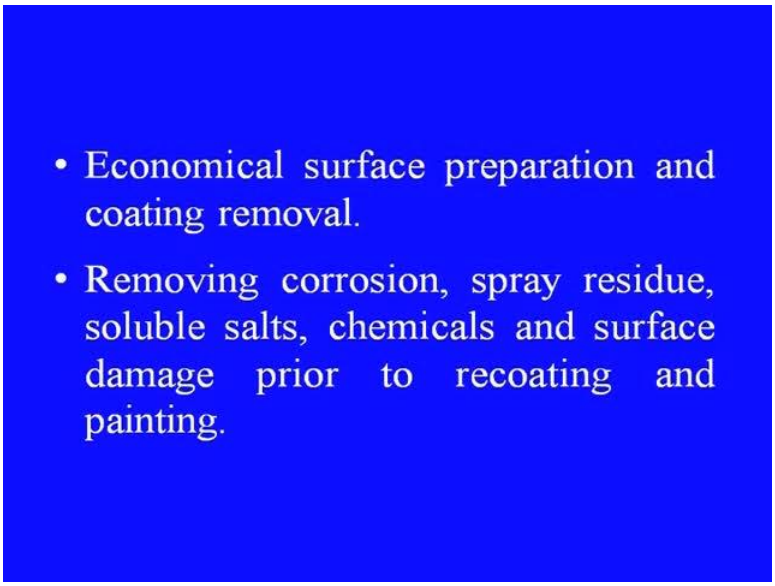

Then this water jet machining can also be used for removing corrosion, spray residue, soluble salts, chemicals and surface damage prior to recoating and painting. Few process and products examples are something like this.

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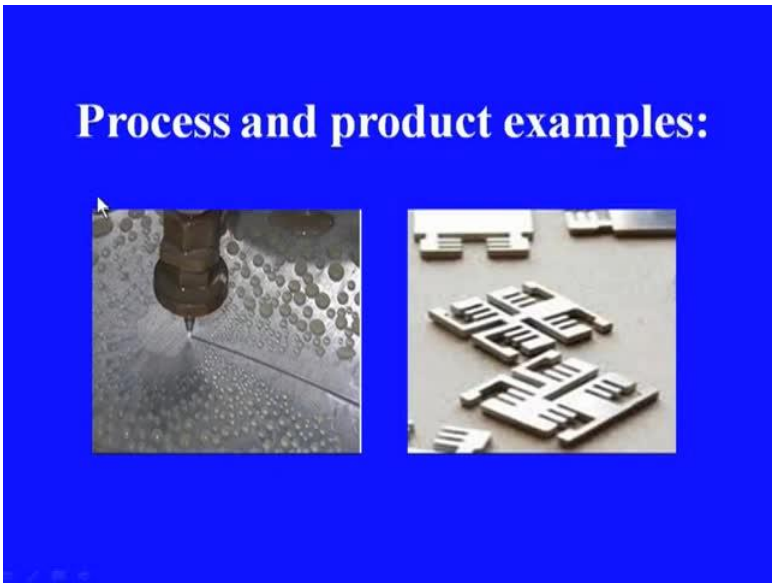

This is typical product that is being produced by or cut by water jet machine. This is the machining head, which cuts like this and here the job is fed rather than the head cutting head. This is the cutting head, through which the pressurized water is coming out and causing the cut or slit. The final product may be something like this or of different

complex shapes. Let us summarize what we have discussed today. We have discussed about the basics of abrasive water jet machining and water jet machining process, equipment used in it, the advantages and limitations of this process. Then we have also discussed the effect of process parameters, few design considerations like the nozzle design etcetera. Applications of the processes that are also introduced, I hope the session was informative and interesting.

Thank you.