Advanced Machining Processes
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Lecture 24
Chemical Machining (Ch.M.)

Welcome to the course on advanced machining processes. Today I am going to tell you about the chemical machining process.

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Now before I really start with this process I would like to tell you an important difference between the chemical machining processes and electrochemical machining processes. In case of electrochemical machining processes what we are doing that we are making tool and workpiece. This is the tool and this is the workpiece and what we are doing? We are connecting them to the power supply negative and positive and flowing the electrolyte in the interelectrode gap and as a result of that electrolysis takes place.

Anddue to the electrolysis, the anode dissolution or the dissolution of the material from the workpiece takes place. That means electrical energy plays an important role. While in case of chemical machining there is no use of electrical energy rather we have a tool here and we have a workpiece here and they are immersed inside the tank. Now that tank is filled with what is known as etchant and there is a chemical reaction between the workpiece and the etchant.

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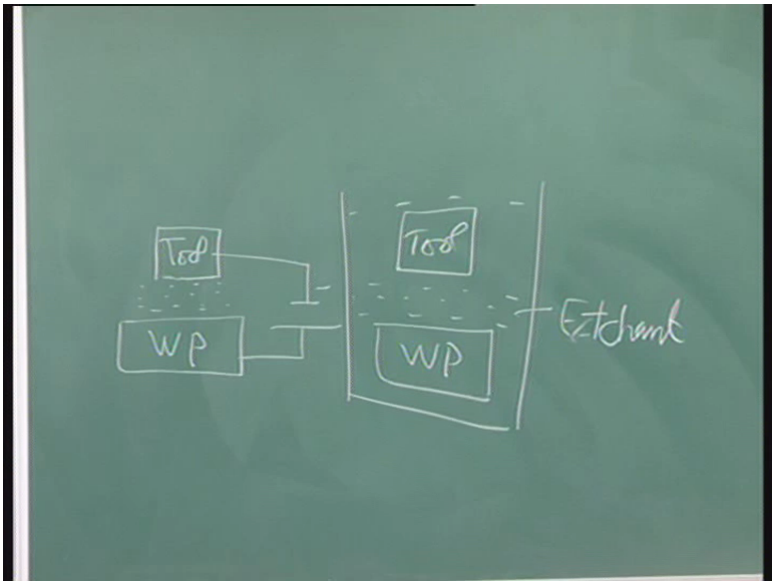

So I am going to discuss today chemical machining. Electrochemical machining we have already discussed in great detail in different lectures. So this difference you should keep in mind so that there is no confusion between the electrochemical machining and chemical machining. So it is an ancient process being used for engraving the metals for making ornaments and other products. This is very old process as long as chemical machining is concerned.

Chemical machining removes material in a controlled manner by the application of maskant and etchant. I will explain what is the maskant? And what is the etchant? Now the function of the maskant is that it does not allows etchant to reach and react with workpiece to dissolve it by chemical reaction. While etchant, it dissolves workpiece material by chemically acting with the workpiece. Now etchant reacts with the workpiece chemically and forms a new product and removes the material from the workpiece.

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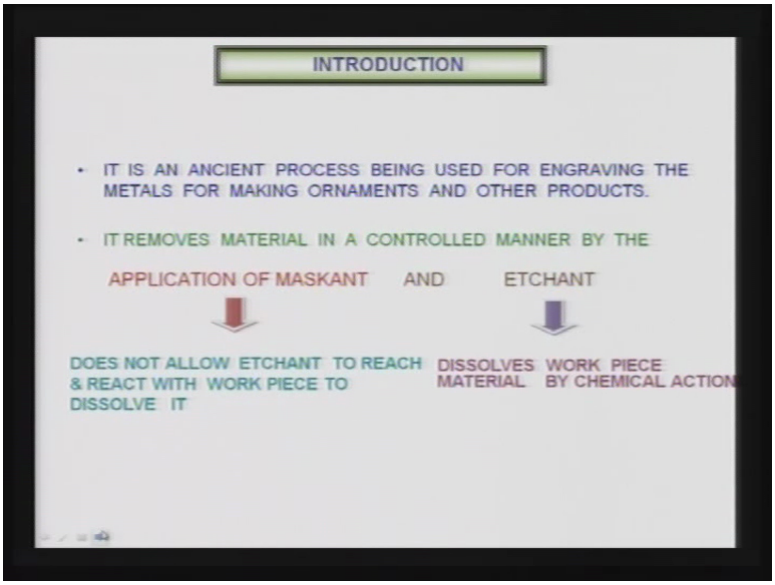

Some salient features of chemical machining are that this is applicable for shallow depth of removal of material, may be 10 millimeter, 12 millimeter or so as the upper limit. It is low cost of tooling and equipment and there is low production runs that means production rate is not very high because lot of efforts made by operators are involved. Material removal rate is quite low as you can see point 1 millimeter per minute, just an example. Burr and stress free removal of the material.

As you can clearly see in chemical machining there is no mechanical force, no thermal energy, it is only chemical reaction which is removing the material. Hence it is burr free and there are no thermal or mechanical stresses on the machine component. Definitely complex designs can be machined or prepared on the component or complex shape components can be made by this particular process. Thin plates as thin as point 005 millimeter or you can say 5 microns can be machined.

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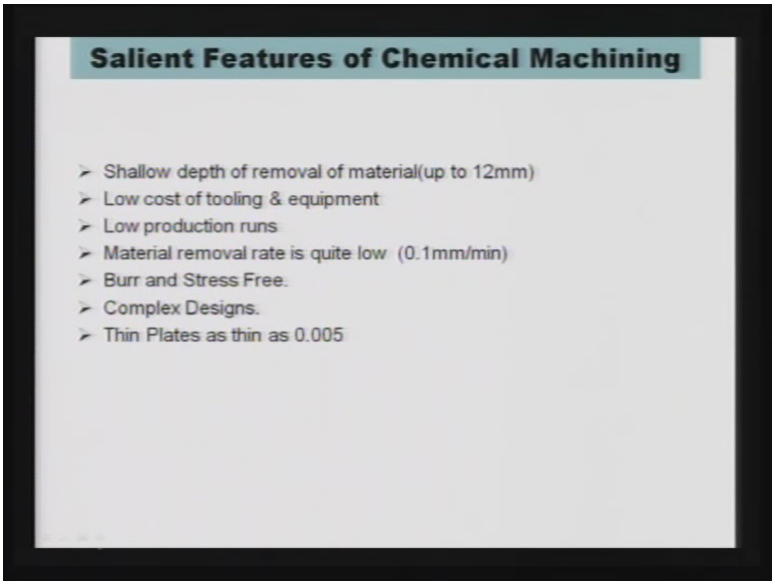

There are various applications of this chemical machining processes. Some of them are stated here. They are successfully and extensively used in aviation industries. It is very good process for making PCBs printed circuit boards, jewellery, turbine engine components, pressure vessel bulkheads, etc. And chemical machining is used for production of blind pockets or you can say it as chemical milling.

Chemical blanking is also done and it is used for production of through cavities or through holes, through slots, through complex cavities can be made by the application or by the use of chemical machining. Various materials which are commonly machined or shaped by this particular process include aluminium, chromium, copper, nickel, steel, lead, zinc.

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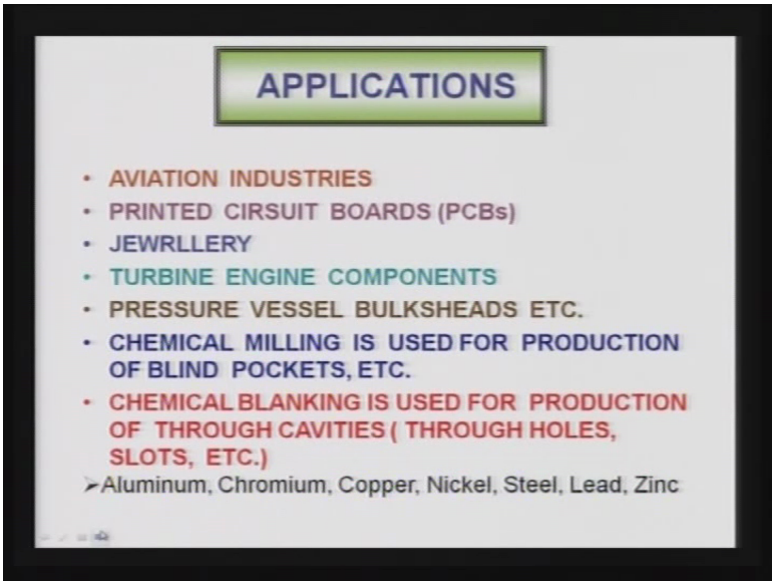

Now for machining these different materials as you can see here like steel, lead, zinc, you have to have different kind of etchant which can chemically successfully react with the workpiece material. Same way you have to also select appropriately the maskant which does not chemically react with the etchant and workpiece both.

Steps to be followed, clean the workpiece first using alkaline solution and then with fresh water so that whatever dust or other things are there on the workpiece they are separated out so that etchant can directly react with the workpiece material. Apply the maskant coat by one of the following methods, cut and peel method, screen method, photoresist method. Maskant as I have just mentioned can be applied in three ways as shown over here.

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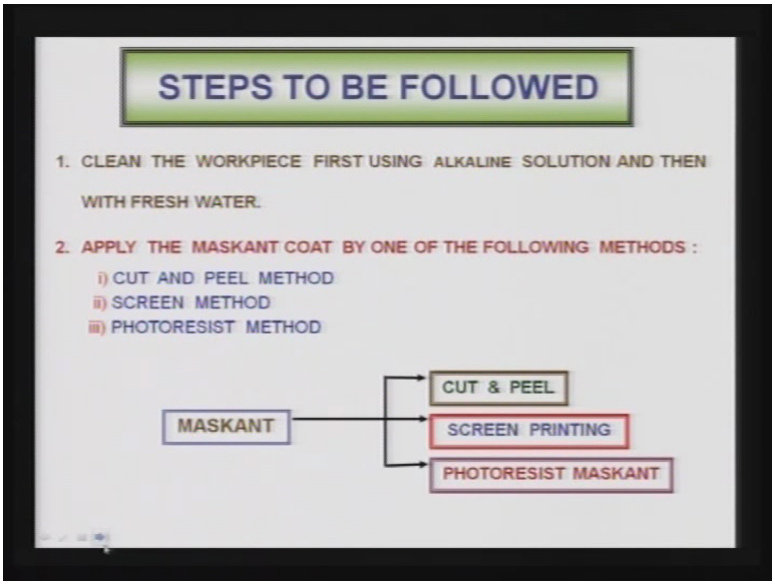

Now this is a basic principle showing figure. Now you can see here that etchant is there which is shown in this particular container. Now workpiece is shown there where B is written. Now this B is the area where there is no maskant and in rest of the portion as shown by etch line that is the maskant. Now etchant resistant lining is there. The container is having etchant resistant lining otherwise this etchant may react with the container and dissolve the container itself. So you have the etchant resistant lining.

Now etchant container is also having as mentioned here heater coils or heating coils. Now what happens by increasing the temperature of the etchant? You can increase the dissolution rate or machining rate. That is why you can control the temperature of the bath in whichetchant is there and that is what for heating coils are used. Now what happens when

this material say from the area B as shown in this particular figure is dissolved? Thenit remains in the area surrounding to B itself.

As a result of that the chemical reaction between the etchant and the workpiece reduces or lowers down or becomes slow. Hence the dissolved material or reaction products formed due to thechemical dissolution of the workpiece should be removed quickly from the area where machining is taking place and for that purpose you have here that is agitator.

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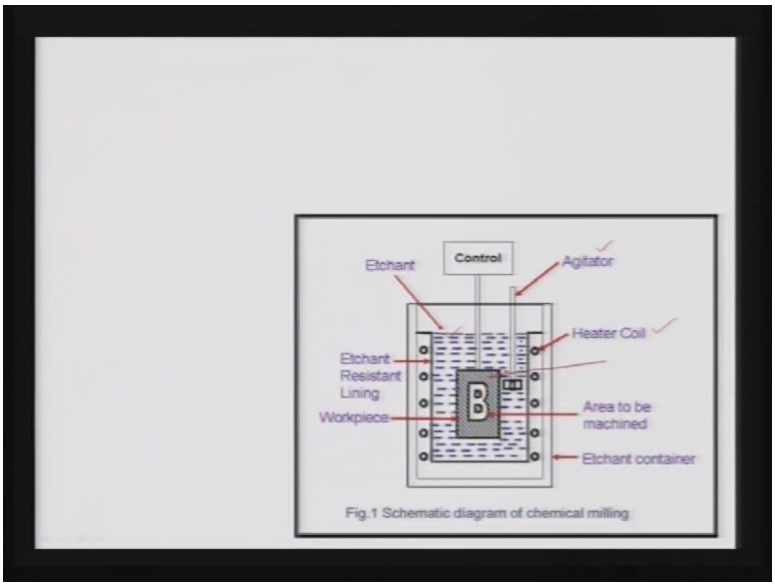

Oncedissolution start, the agitation of the etchant should keep going on so that the concentration of the reaction products is not high in the area surrounding the area which is to be machined say letter B in this particular case. So apply the maskant by one of the methods I have mentioned in the earlier slide that was the either photoresist method, screen printing or peel and cut off methods. Dip the workpiece in the etchant bath and let it be there for the desired time.

That is the workpiece you dip it and then let remain there for the desired period. Then take the workpiece out from the etchant bath after the desired depth has been achieved of the letter B in this particular case on the workpiece. And for deciding this particular time how much time it will take, you have to conduct the preliminary experiments. With the help of the preliminary experiments decide how much time it takes for removal of the material from the (())(11:27) and then once that time is over that means the material has been removed up to the desired dept.

Then you can take the workpiece out with the help of the device where it is written control and it will lift the workpiece and separate it out and then as written here remove the maskant layer from the workpiece whatever is there. Then wash the whole workpiece under the freshwater.

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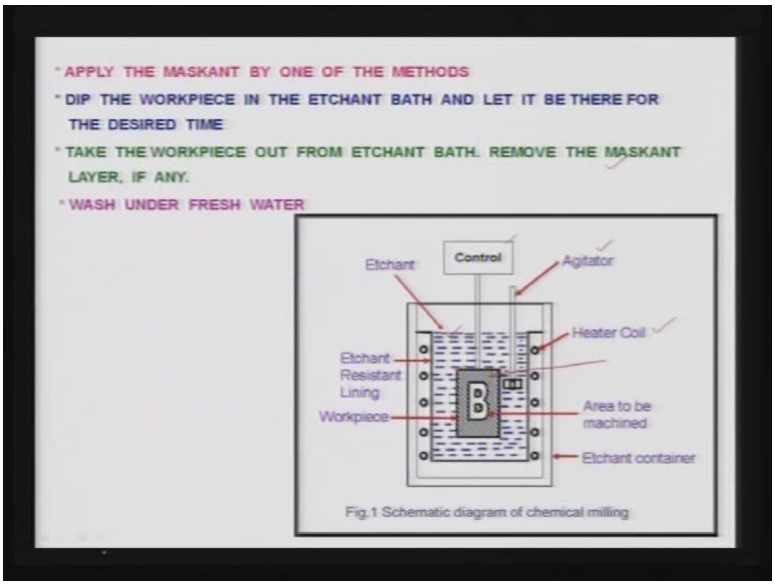

Now you can see here how to apply the maskant. You can apply the maskant by any of the three methods but it has to be finally like this. You can see maskant coated area marked B. Mark the area B there is no maskant and rest of the portion has been coated with the maskant either by screen printing or cut and peel method.

Now if you take the section of this particular one at A A then you see that the maskant layer is there in the last figure and then here the etchant will penetrate and start removing the material at these places because there is no maskant so chemical reaction between the (ma) etchant and the workpiece material will take place. So it is clearly shown in the side view showing maskant filled workpiece and area to etch.

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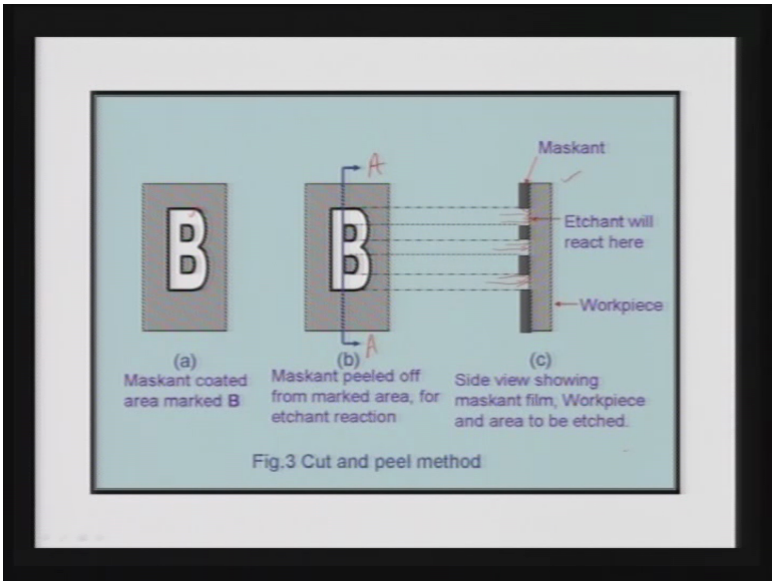

So this kind of the masking in be done either cut and peel method or even with the help of screen printing. Same procedure is again explained for creating a blind cavity. This is the part to be milled. You can call it as chemical milling and then the part with the mask applied you can see(add) layers of the maskant has been applied all around this on all the faces. Then you are supposed to remove the maskant from this area where chemical reaction is to take place.

Then you can put this part inside the etchant part, right? And after that you can see that finally the part is machined to the desired depth and the desired cavity is obtained from this. So finished part with mask removed and here is the mask remaining. You remove themask from the workpiece then you will finally get this particular part.

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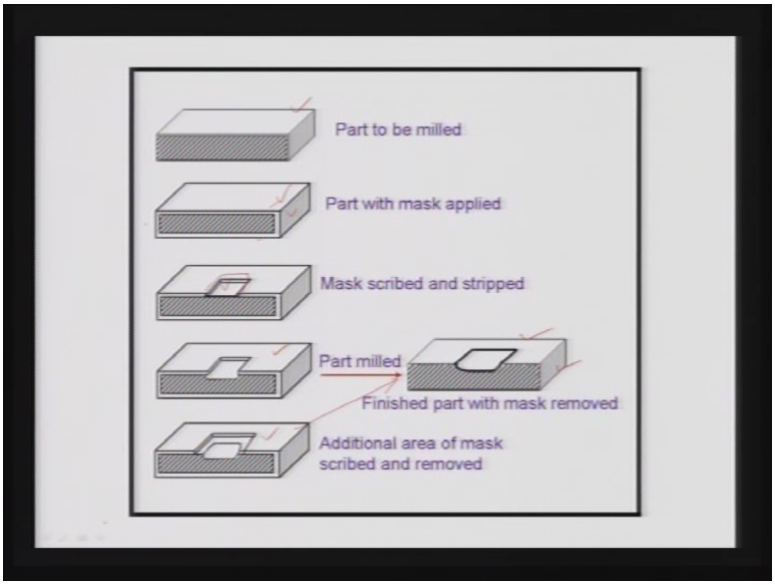

Same procedure is again shown here for the different kind of the parts. Here one important thing is there that you know dissolution is taking place from top side as well as from bottom side. In other examples which I have explained to you there dissolution is taking place only from the top side. So you can see here is the clean workpiece. Now dip the workpiece or spray workpiece to apply the photoresist coating.

And this is the third one photo chemical machining where photoresist is being applied. And after that negative applied to surface. Here is the negative which has been placed on the surface and it is placed on both sides you can see. Top side as well as bottom side.

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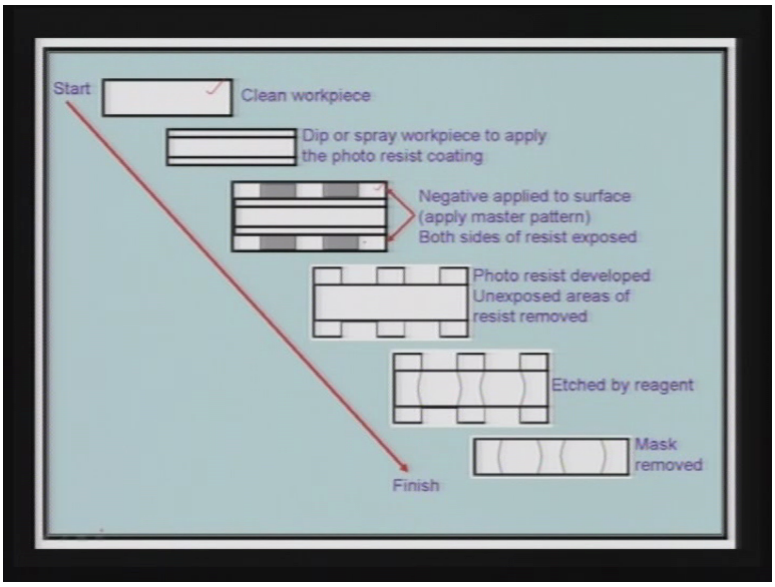

I will explain whole of this process later on also. But just to give the idea that in chemical machining instead of machining from one side you can machine from both the sides so that the machining rate will increase and total time taken will be reduced. Now after applying the photoresist developed unexposed areas of the resist removed. So you can see here these are the areasfrom which the material will be removed.

Then it is dipped inside the etchant bath. And you can see etched by the reagent the material has been removed by the etchant from both sides and you can see the cavity that has been formed over here. And this is the final part that has been obtained.

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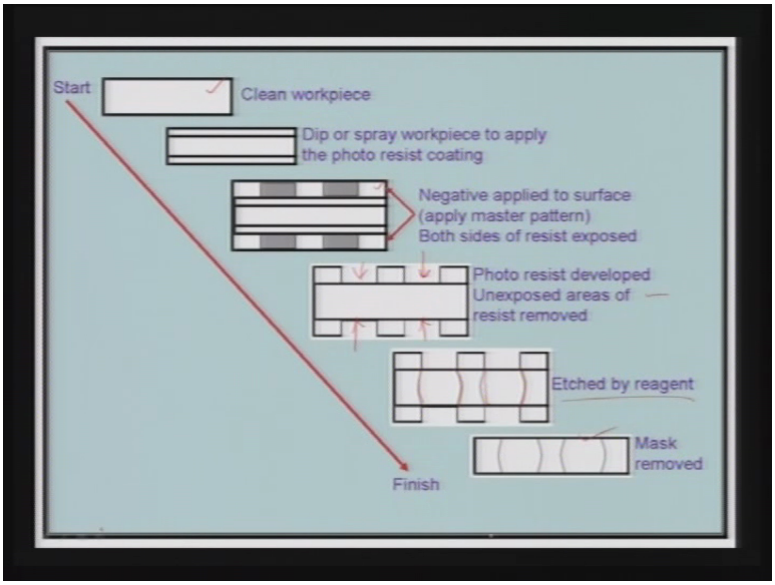

So what I mean to say here is that you can apply the maskant by any of these three methods. Your final aim is to get the workpiece of the desired shape and size in the minimum time. Now what happens sometimes debonding takes place. That meansyou have applied the maskant but somehow that maskant cracks or it is not properly adhered and there is the way for the etchant to go and react the workpiece through that particular area also.

And if it happens then you are going to get the defective part because you are not planning or you have not thought of removing the material from this particular area. Because of debonding the material will get removed.

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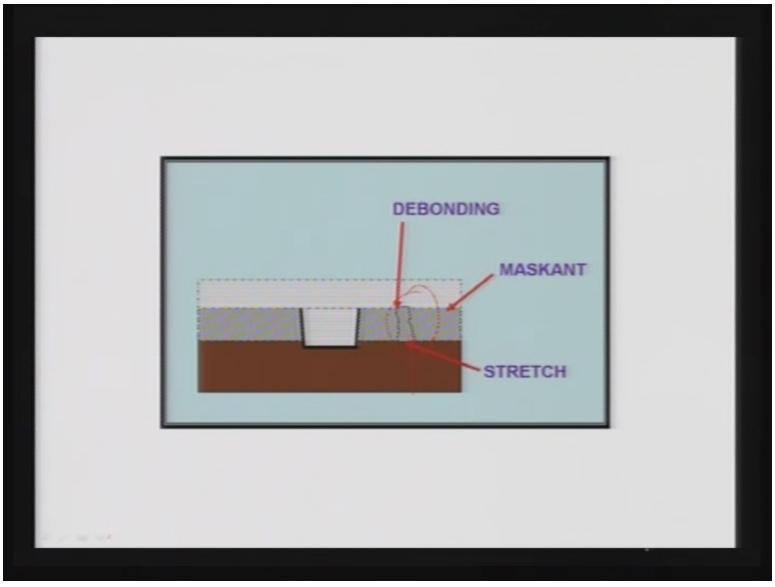

So one should be very careful and one should check carefully that there is no cracking,no debonding of the maskant from the workpiece or on the workpiece so that the material does not get removed from the undesirable area. To ensure proper adhesion of maskant on the workpiece, chemical cleaning is needed.

This is very important point because you apply the maskant, if it does not get adhered to the workpiece then it will be loose and then debonding or demasking will take place and the etchant will penetrate through that particular area and remove the material from the place from where you do not want to remove any material. So if debonding takes place then stray cutting will take place. Whatever I had mentioned just in the earlier slide, if material is being removed from the debonded area then that will be called as stray cutting.

Just like stray cutting in case of ECM process. Type of cleaning will depend upon or is a function of what type of maskant you are using? What is the workpiece material? And what is the depth of cut to which you are going to machine? Cleaning of porous material is definitely very difficult because whatever liquid you are using for cleaning it will get penetrated inside the porous material and it is not desirable.

For higher material removal rate as I have shown you in the earlier figure that is thefigure of the setup, agitation will increase the chemical machining rate and heating of the etchant will also increase the machining rate. However you have to control the temperature of the (electro)etchant. Otherwise lot of loss of etchant will take place and it will make the process uneconomical. And if you are agitating too much or heavily that also may not be desirable.

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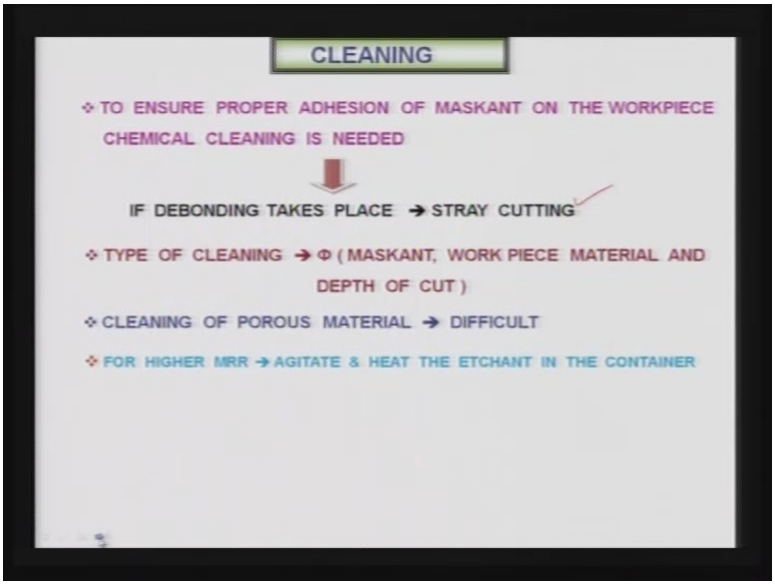

How to maintain high material removal rate is always a question mark as long as chemical machining is concerned because it is a very slow process compared to electrochemical machining process. So what is proposed or what is normally the practice is that filter the etchant before (reg) recirculation because etchant is not thrown after using once. It is recirculated as long as it can react with the workpiece material because it is quite expensive.

So it should be properly filtered out before recirculating or before putting it into the container. Periodical addition of new etchant because it is always getting mixed with the reaction products. So it is always desirable that after a certain period of time say 25 percent of the old etchant is taken out and 25 percent new etchant is added after a certain period of time. Sothat will keep maintaining the strength of the etchant so that the material removal rate does not go down. Discarding some percent of used etchant.

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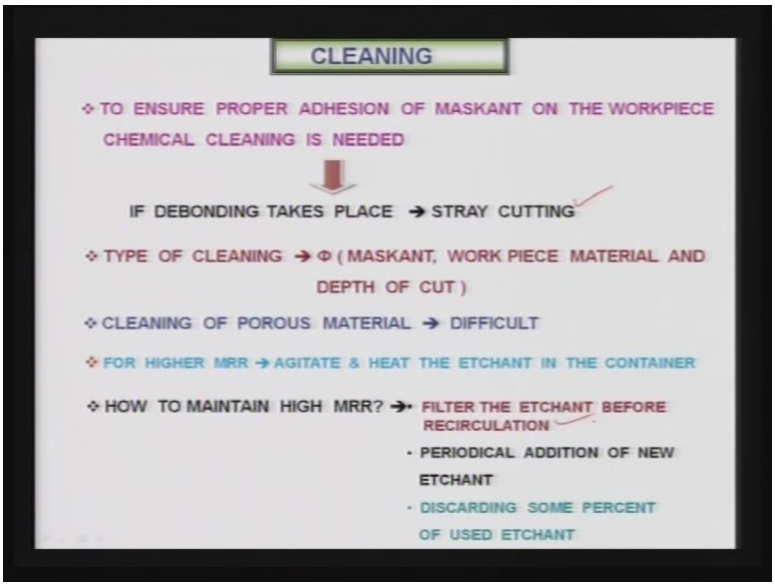

Material removal takes place intwo directions. One is the downward direction and another is the lateral direction. While our objective is to have the material removal rate only in downward direction, not in the lateral direction. But it is a part of the phenomena that is taking place, you cannot avoid it. So downward direction leads to what is known as depth of cut and lateral direction is known as undercut. And undercut is the function of the depth of cut. It is a type of the etchant, workpiece material and (etch) etching time.

More the etching time more is the undercut and we want minimum undercut because it is going to deviate or to give the dimension other than what you have designed the component. So while designing the process of chemical machining you should take this undercut into

(condis) consideration. And there is a term known as etch factor and it is given by undercut divided by depth of cut. For uniform machining do not allow gas to be trapped in the etchant. Rather than the electrolyte call it as etchant.

Now this figure shows what is the depth of cut? This is the depth of cut and here is the undercut. That is what is shown over here undercut and this is the depth of cut. So maskant protects the workpiece surface from chemical attack or chemical dissolution.

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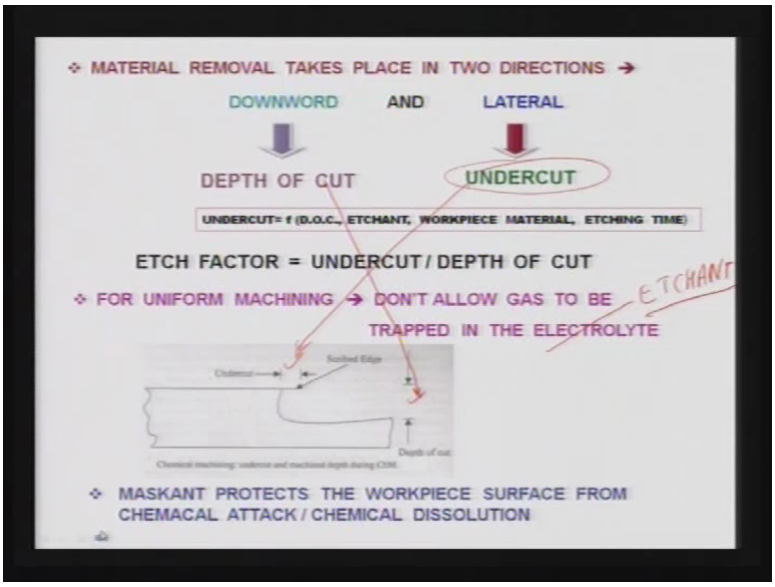

Cut and peel method,neoprene, butyl or vinyl based materials are used as maskant. As I have already mentioned that maskant should be such that it does not react with the etchant and also it should not react with the workpiece material. Now dipping, spraying or flow coating can be used. Means the maskant can be coated by dipping the workpiece inside the bath or spraying the maskant on the workpiece uniformly or by flow coating kind of the things the maskant can be applied on the whole of the workpiece.

Coating thickness varies usually from 25 micron to 130 micron. First apply to the entire surface of workpiece. Now please note it carefully that the whole surface all the faces of the workpiece should be masked and otherwise it will start removing the material from the undesirable surfaces. Then cut and peel off from the area to be exposed to the etchant for machining.

And that I have shown you in the earlier slides also thatpeel off the maskant from the area wherever from you want the material to be removed. Rest of the area or faces should

remainmasked so that no chemical reaction takes place with the etchant. Accuracy usually obtained lies in the range of 130 micron to 750 micron.

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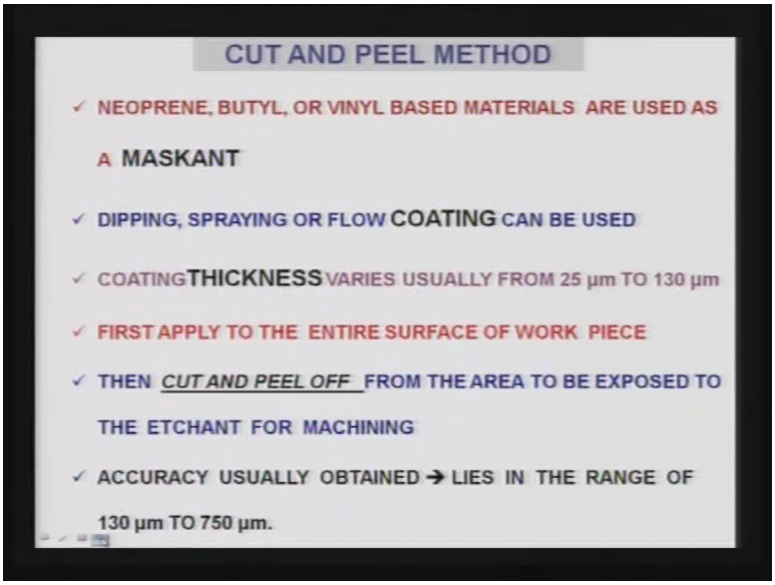

Machine depth in case of chemical machining depends upon etching time and usually the workpiece obtained is tapered in nature. Just like I give you suppose this is the hole that has been made then it will be like this. That means it will be tapered. And actually the maskant is up to this particular point and you will get the tapered. Sowhat happens really is thatdue to the undercut the top diameter increases while the diameter at the bottom of the drill hole or machine hole does not increase to the extent as at the top.

So you get the tapered workpiece. Dipping, spraying or flow coating can be used for application of the maskant on the workpiece surface. Coating thickness varies as mentioned over here. So you can see here that it gets tapered.

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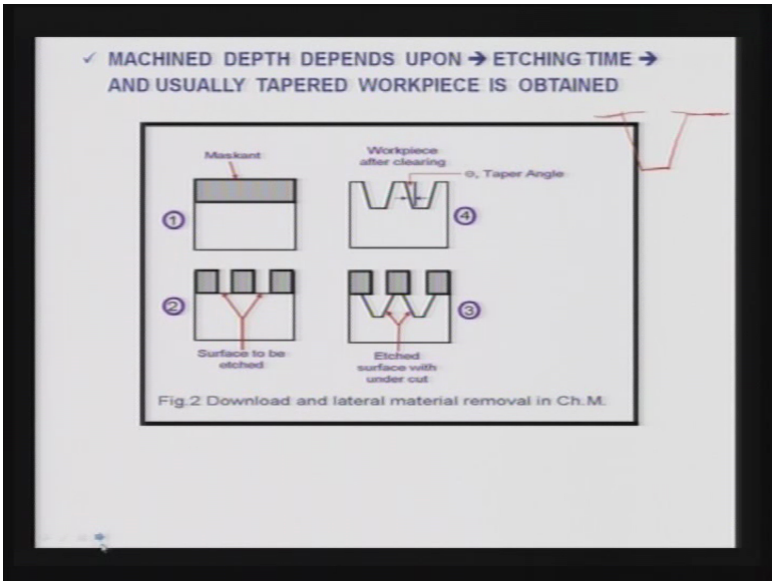

Now same thing is shown over here. Here is the maskant and this is the work piece and now after cut and peel method or by any other method what you do that you remove the maskant from these areas where from the material is to be removed as shown here. Surface to be etched over thereand this should be done very accurately and nicely because if this area were from the material is to be removed is not accurately demasked then you will not get the correct product.

And as you can see here chemical machining, after this you come here,theoretically material should have been removed like this but due to the undercut the material has been removed more than really whatever is the width of this particular demasked area. And that is why you get if you see the part 4 here, you get the tapered cavity rather than straight sided cavity. And you can see thereis a certain angle of this taper that is shown over here as the theta as the taper angle.

So you can see that how really material removal is taking place. For stepped component it is good method and good for large size products,batch production and large depths. Now for large size products actually removal of the material like this is very comfortable compared to other methods where it consumes lot of electrolyte or dielectric and lot of time it takes. Here it becomes much easier if you can mask it correctly. Also very large depth cannot be done by this particular method.

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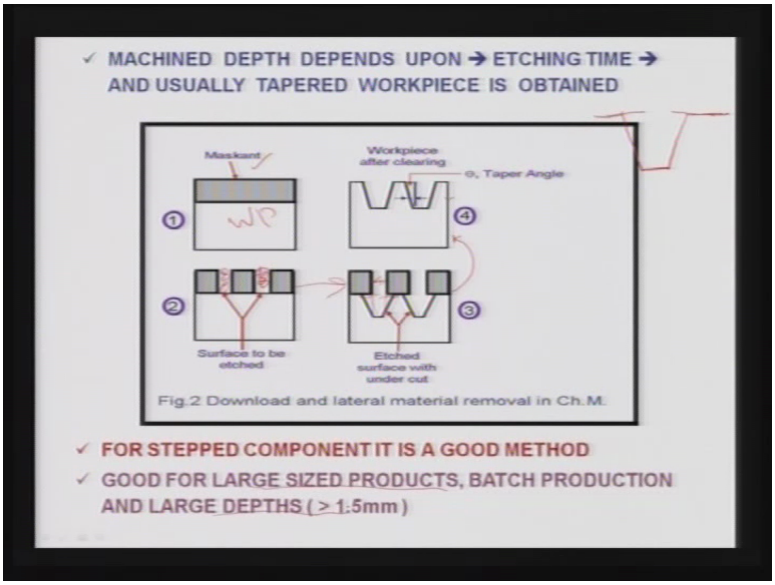

Now screen printing, screen printing is a second method by which you can apply the maskant on the workpiece surface. And in screen printing the maskant is applied only on those areas where from you do not want to remove the material. I will give just an example. See this is the workpiece and you can form a screen like this. Suppose this is the area where from you want to remove the material. Then what you do? You make the screen such that this is covered by the screen of same metal.

Then what you do? You apply the maskant in the rest of the area by either spraying or by brush or by any other means. But the area where from you have kept the metallic pieces or the screen there is no maskant. So what you can do? You remove these two plates then you will get the workpiece of this type. There is no maskant over here but at rest of the places you have applied the maskant by either dipping or by spraying or by another method.

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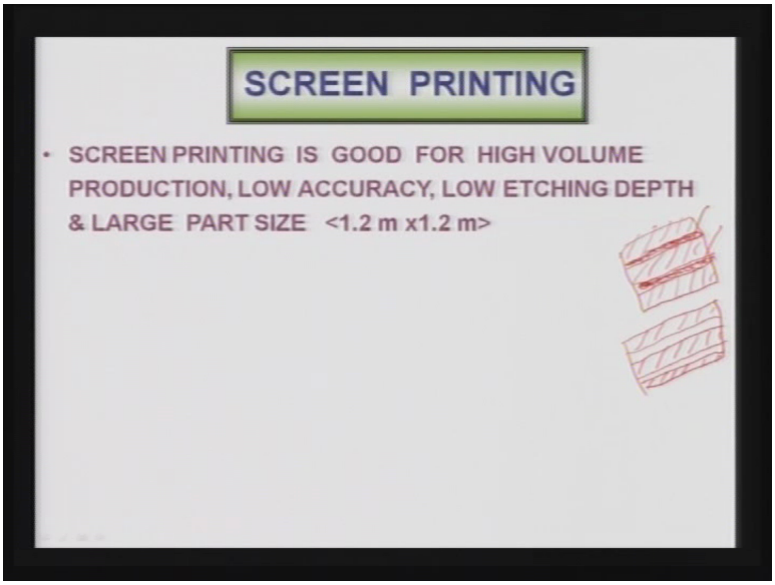

And when you put it in the etchant bath then the material will be removed from this area as well as from this area.

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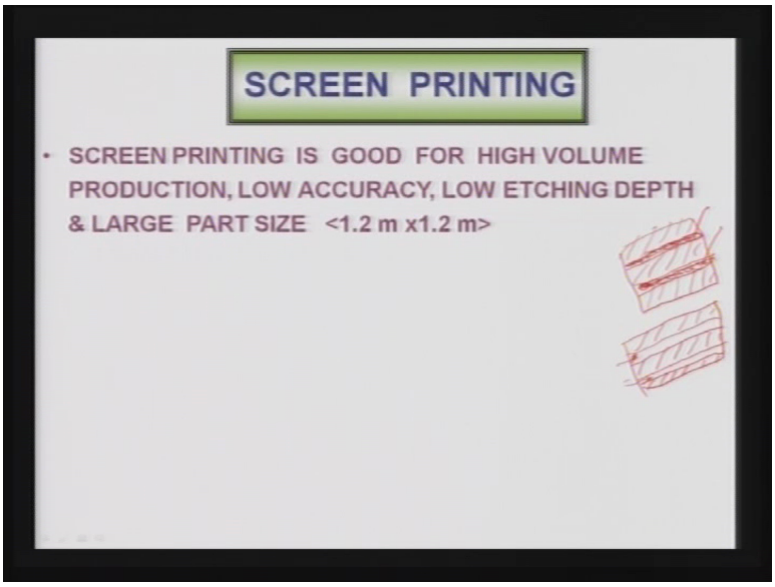

So this is the simple principle of screen printing. So screen printing is good for high volume production because masking rate or the time taken for masking reduces substantially as compared to the cut and peel method. However the accuracy is low because the accuracy in this particular case will depend upon how accurately you have made the screen and how accurately you are applying the maskant. Low etching depth and large part size can be done because screen printing is comparatively easy.

So large size parts if you can make the screen you can easily do the masking and chemical machining.Screen blocks off area to be machined. Rest of the area is covered by maskant. As I have shown here this is the screen which is blocking the area which is to be machined and the rest of the area is having the maskant. That is why you have this as the blank area.

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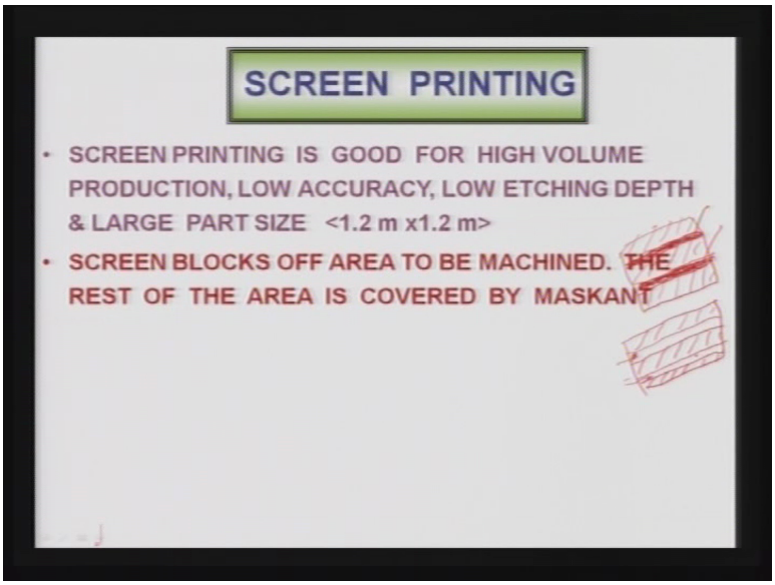

Press the screen against the surface of the part and then roll up the maskant. So instead of brushing or spraying you can also use the roll which are having the maskant andyou rotate or remove the rolls in this area where maskant is to be applied so that the uniform layer of maskant is formed on the workpiece. Remove the screen and dry the part by baking or by heating you can write, so that the maskant sticks or adheres to the workpiece surface and no debonding takes place during chemical machining.

Now do etching and then go for cleaning. After etching in etching again you have to follow the same principle as in case of cut and peel method. That you should know for how much time etching is to be done and you let this workpiece be there in the etchant bath for that particular period of time. And in that period of time you should maintain a certain temperature as you have already decided about it and agitation also should keep going on so that you get the higher machining rate.

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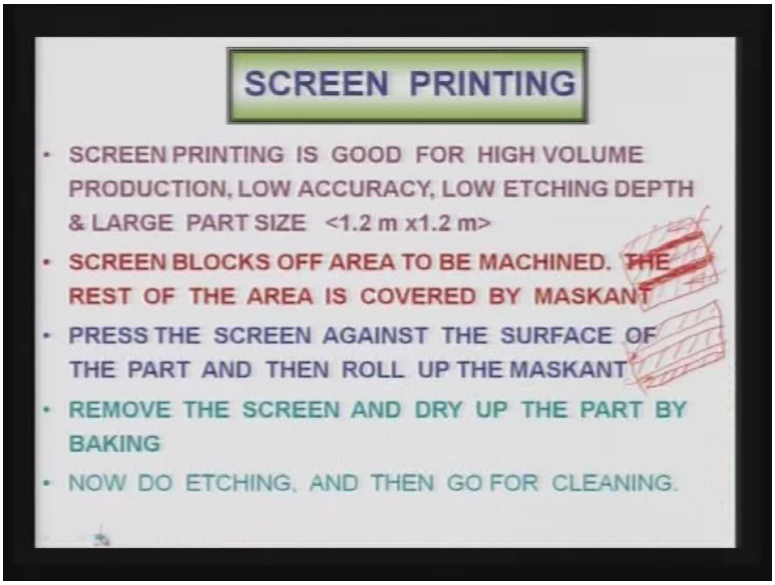

Now this is very important process of masking that is the third process that is the photoresist maskant. Now for complicated and accurate surfaces cut and peel method or screen printing will not work properly and for that purpose photoresist is the most appropriate process. Whatone should do that first prepare the enlarged drawing accounting for undercut and then produce reduced and accurate master transparency or photomaster film by the use of laser pattern generator.

Then clean the workpiece thoroughly that is remove the dirt, oxides, etc.fromall the faces of the workpiece. Then apply a thin coating of photoresist and that is etchant resistant material and dry by baking. Now hold the photomaster and the workpiece together in intimate contact. Throw the ultraviolet light through the photomaster on workpiece and after development remove coating from the areas where etching is to take place.

So that means you are really exposing the area from where material is to be removed or chemical reaction is to take place between the etchant and the workpiece material. Etch, strip off the residual photoresist and then inspect that proper etching has been done.

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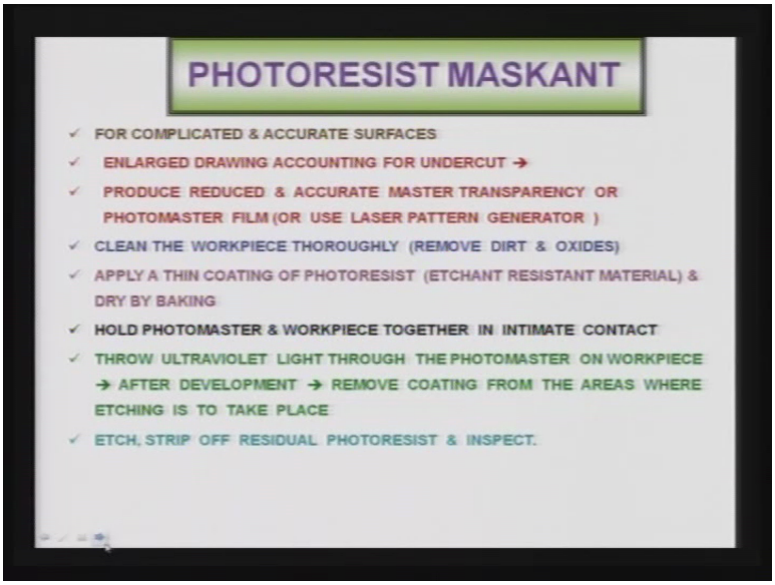

Schematic representation of various steps to be followed in photochemical machining is given over here and this is very important process and very commonly used for production of accurate parts. Now prepare enlarged drawing accounting for over cut. Then prepare the reduced master transparency. Then clean the workpiece thoroughly. Apply the photoresist. Then dry the workpiece by baking process or heating process.

Hold the reduced master and workpiece together for certain period of time but they should stick with each other and then throw the ultraviolet light on the master or that photomaster. Then develop removes undesirable coating from the workpiece that meansremove the coating from the area where etching or chemical reaction is to take place.

Now rest of the process is the same as we have done in case of cut and peel method or screen printing method. So after machining has taken place after that you remove the photoresist, then inspect it, clean it and then you get machine workpiece. And this is the photochemical machine workpiece.

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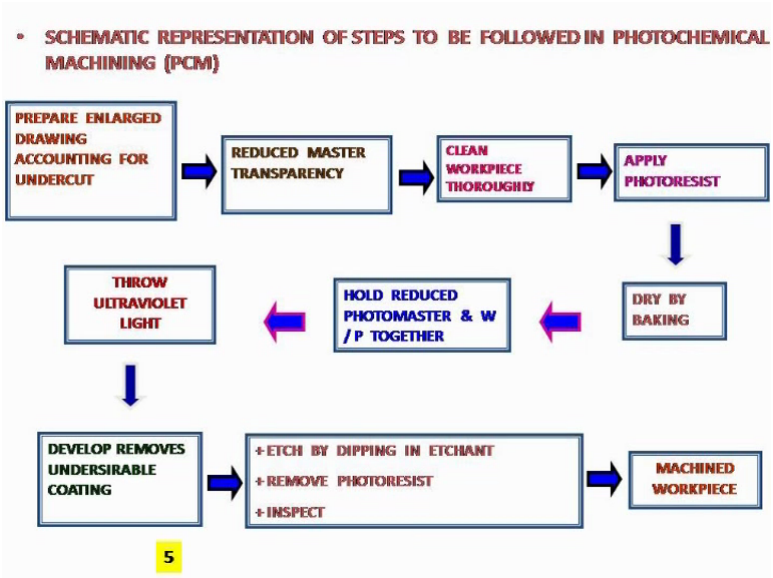

Choice of maskant.which maskant should be taken for the given workpiece it depends upon which etchant you are using because etchant should not react with maskant as well as vice versa. Which type of workpiece material you are using? It should be stable at high temperature. It should not have any chemical reaction or chemical effect on the workpiece.

Etchant changes metal into material salt or after chemical reaction and there are various etchants like FeCL 3 for aluminium, copper, nickel. FeNo 3 for silver, HFfor titanium, HNO 3 for tool steel.

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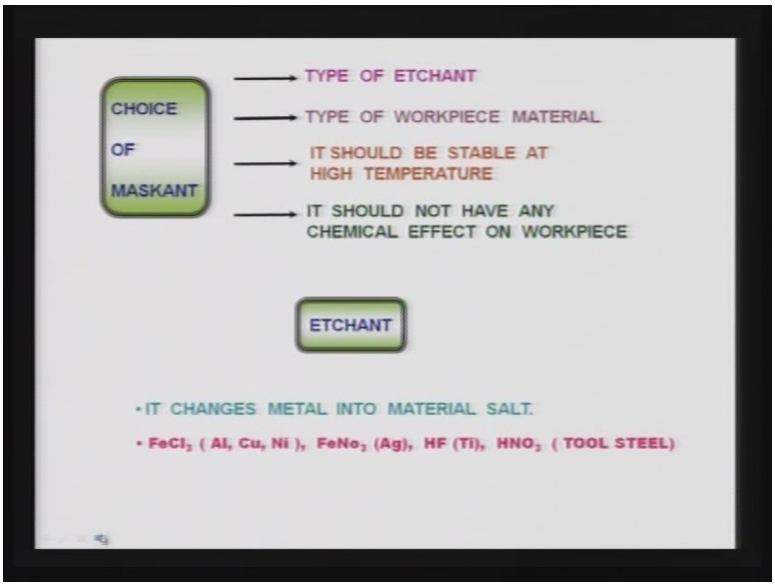

During the selection of the etchant various factors should be considered as mentioned here that the surface finish that is required on the machine workpiece, material removal rate, depth of penetration that is also important factor to be considered, type of the workpiece. Definitely the etchant should be able to chemically react with the workpiece and dissolve the workpiece material. And what type of maskant is being used because etchant should not react with the maskant otherwise you will not get the desired workpiece after machining.

And it should not damage the workpiece in anyway. Very important point is thatetchant should be available and it should not be very expensive otherwise the cost of the product is going to be high and in many cases that may not be acceptable to the users. There are certain merits of this particular process compared to many other processes. First thing is you get good surface finish and you can maintain good tolerances on the machine component. Also you can make tapered and stepped workpiece.

I will explain in the following slides by this particular process. Anddoes not requirehighly skilled operators. In hereit should be, does not require highly skilled, not operation but rather operators.

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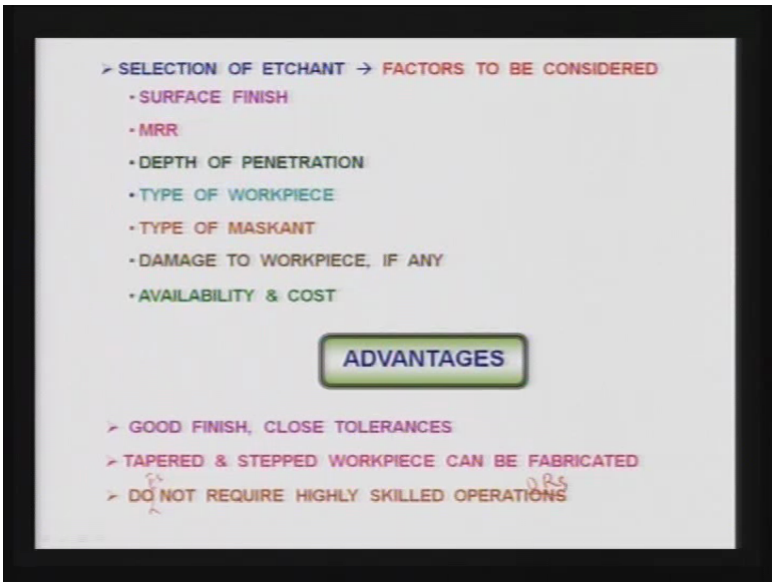

Now this is very important. Machining of a tapered and stepped workpiece. How will you machine a tapered workpiece? I have mentionedin the beginning of the talk of today that is onchemical machining that machining is the function of the time. More time, more material is being removed. If you are giving less time for material removal, less material will be

removed. So if you can vary the time required along the length of the workpiece then you can make the tapered workpiece.I will explain it.

Suppose you take the workpiece of this particular shape initially and you want to make this tapered workpiece. What you should do? You already have a control over there which will control the motion of this particular workpiece. Now you dip it in the etchant bath and slowly move the workpiece downward.

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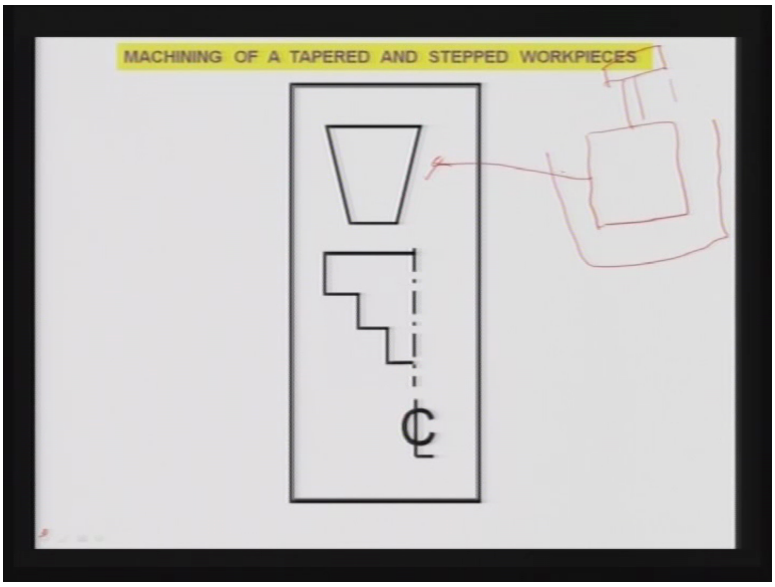

Suppose you dip it when it is like this. I will make another figure. Let us make like this and it is filled with theetchant and you take the workpiece like this and if there is a control over here. Now you start moving the workpiece downward at a very low rate. That you have to decide with the help of the preliminary experiments. And as you keep moving it the material will keep removing.

Now this particular part A is subjected for maximum period of machining while part B over here will be subjected for minimum period of machining time. So you can see what will happen when after proper design of the machining parameters if you remove the material from this particular part then you are going to get the (taper) tapered workpiece like this as shown over here.

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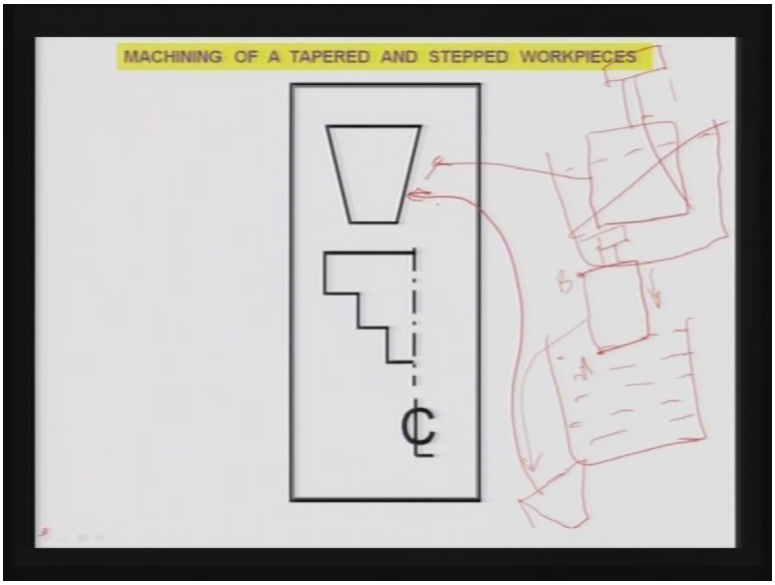

That means you have to continuously give the feed to the workpiece so that it moves slowly at the designed rate in the bath and material keeps removing. So you can get this one. Now you can also machine the stepped workpiece like this. Principle remains the same. What you do? You again same way you have anetchant bath and you take the workpiece like this again and you have the control over here, control.

And thenas you want three steps you divide it in three. Now what you do? Say this is A, this is B, this is C. Now first of allthis is the bath where etchant is there. You take this(po) whole of this A part dipped inside the etchant bath. This is the etchant bath etchant bath.

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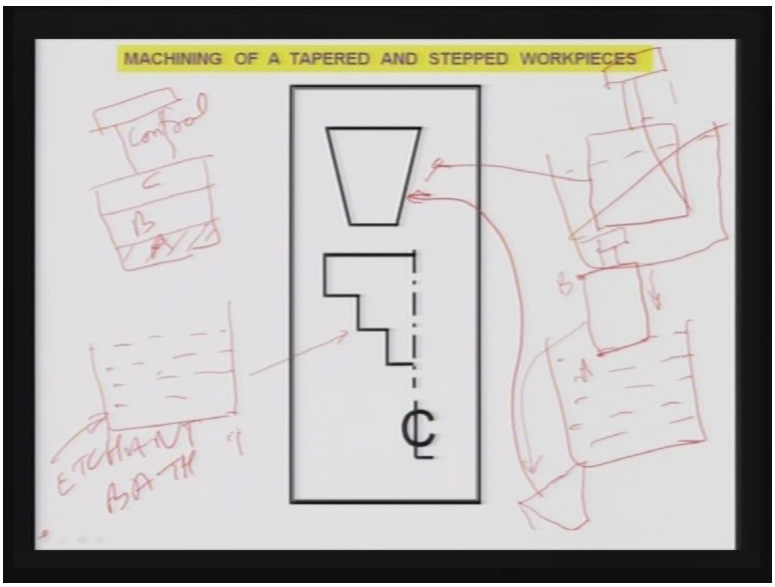

You dip it for a certain period of time sayT 1. So what will happen that certain material will be removed from here and you will get the workpiece like this over here. You will get the workpiece of this shape and againafter thisyou dip B and A both inside this bath and let this be for time T 2. So really speaking part B is dipped for T 2 but part A is dipped for T 1 plus T 2 time. So you will get the material or the shape of the component like this.

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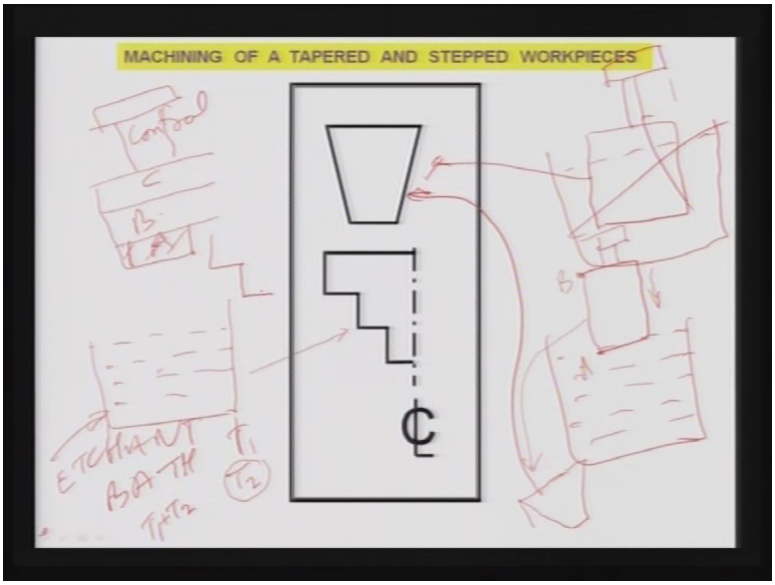

Now you dipA, B, C all the three inside this for time T 3. So what will happen? A has been machined for the time T 1 plus T 2 plus T 3. B has been machined for the time T 2 plus T 3 and C has been machine for the time T 3. So you can control this length of the steps by controlling the time T 1, T 2 and T 3 and you will be able to get the stepped component by this particular process.

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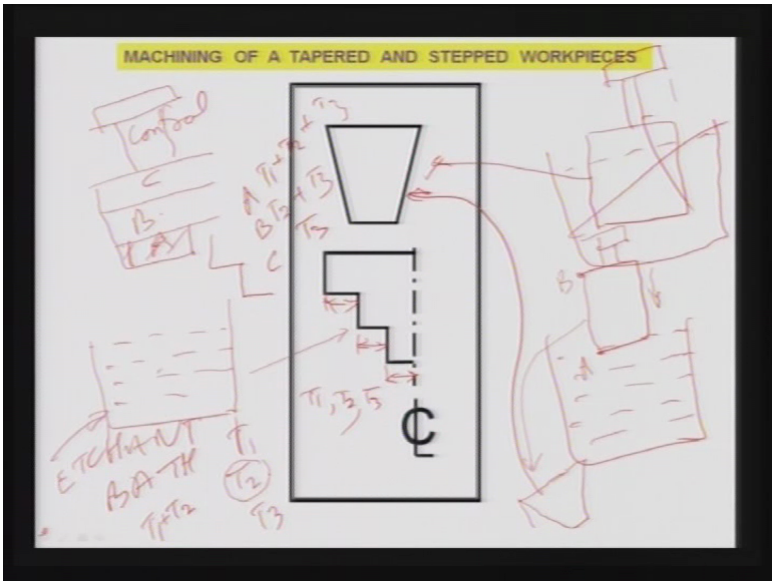

So what I mean to say you can design the process in such a way that you can get the tapered workpiece, you can get the stepped workpiece, they may be cylindrical in nature, they maybe rectangular or square, cuboid in nature. So depending upon your requirement you can give different shapes. Now these are the examples of some of the chemically machined components. You can see the beauty. How fine the components have been machined.

You can see here this is the chemically machined component and very thin arms or riffs are there. Rest of the material have been removed from there so you can make andthese are the files rather not the thick sheets. And you cannot make these kind of the component by other processes so easily as by this particular process.

Say you can use it screen printing or photoresist printing for these purposes and you will not take too much time for dissolving the material by the etchant from that particular area. Soonceyou have prepared a photomaster or the screen for these purposes then you can easily mask the component and then put it in the etchant for the pre-decided or pre-designed time and then let it be machined and you will get a fast or high production rate chemical machine component.

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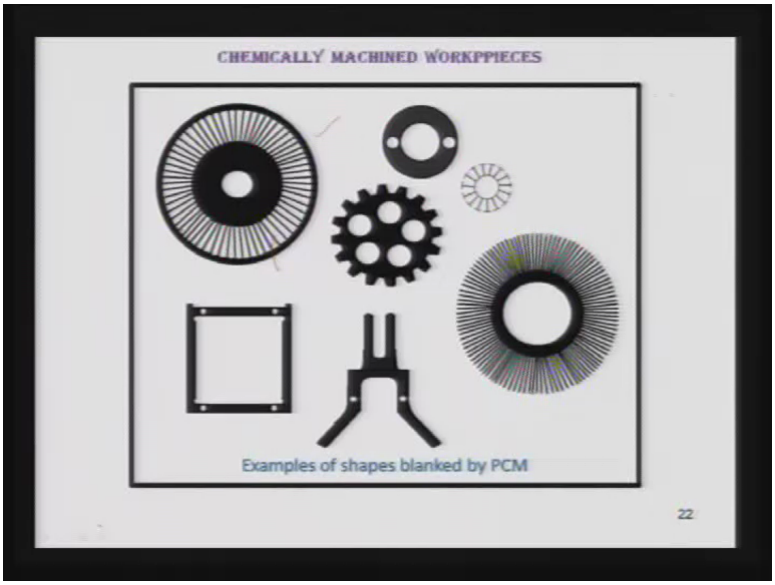

Now there are certain limitations of all the processes. Same is true for chemical machining. Only a few metals can be machined because I have shown to you already that the etchants available for certain materials like copper, aluminium, iron, etc. Now for every material or every alloy you do not have the etchant available. Especially in case of alloy the problem will be multiplied because different elements of the alloy will have differentchemical dissolution rate.

As a result of that you will not get the good surface finish of the machine component. And then there are the evolved gases and these evolved gases will give you the non-uniform machining rate. Then they also will create the problem. It will lead to the uneven material removal and attack the surrounding equipment.

That is another point one has to keep in mind that whatever gases are evolved they should be exhausted from the area where this chemical machining process is taking place because this will attack the equipment surrounding to the chemical machining setup. Also more importantly the operators and other persons working around this setup will also get affected because it is not an environment (frie) friendly process in the sense that evolved gases will have adverse effect on the operator.

Definitely material removal rate is low in this particular case as compared to say electrochemical machining. Further etchants are usually corrosive in nature and toxic in nature. That is what I have just mentioned that they are harmful to the surrounding equipment as well as the operator.

So all these gases whatever areevolved should be exhausted through proper exhaust system out of the working area. Hence harmful to the surrounding equipment and operation. And (diff) differential machining of alloys lead to the poor surface finish. That is what I have just explained.

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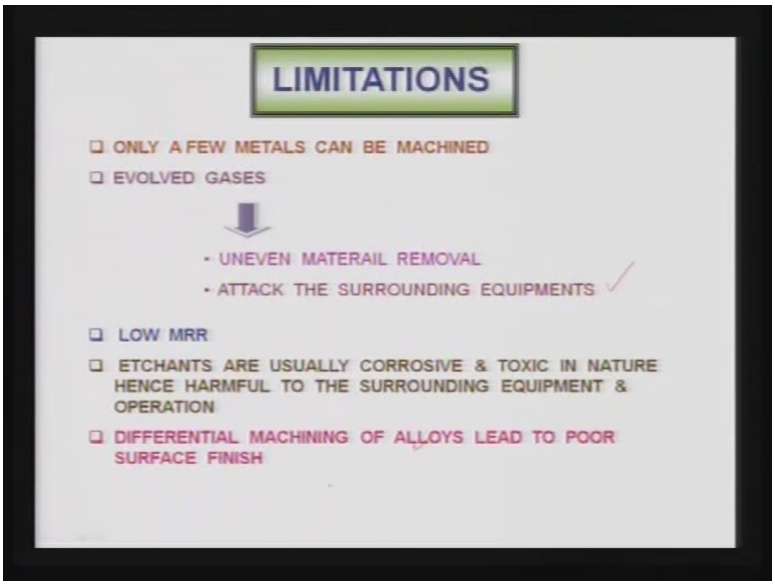

Thank you very much.