Polymer Assisted Abrasive Finishing Processes
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Lecture – 09
Abrasive Flow Machining and Finishing: Part-I

Now, we move on to another area where we will deal with the Advanced Polymer and Abrasive Based Finishing Processes. The first and foremost and important one which many of the people doing currently and they have done abundant work in the area of abrasive flow finishing process, ok. So, now, we will see the abrasive flow finishing process, what is its calibre, where it can be applicable and other things. So, today's chapter is that Abrasive Flow Finishing Process.

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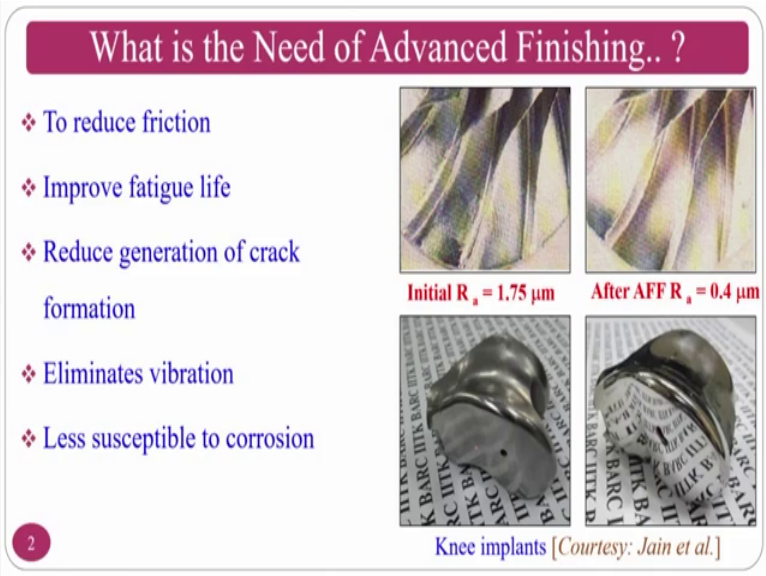

What is the need of abrasive finishing process? That we will see. To reduce the friction, to improve the fatigue life, to reduce the crack formation and eliminates the vibration and susceptible to corrosion. It will also use for the free form surfaces or complex surfaces.

What you can do using the grinding process or the horning process and other processes? Since there it is a solid based tool you cannot go for a free form surfaces, you can go because there is a robotic grinding is there another things is there, but it will be slightly expensive. But in expensive if you want you can develop in house abrasive flow finishing process and you can develop your own medium, and here the medium is polymer rheological abrasive medium which is a semi-solid to liquid based medium that is why you can finish the complex features like turbine blades, rotors and including knee implants that are there that you can see here.

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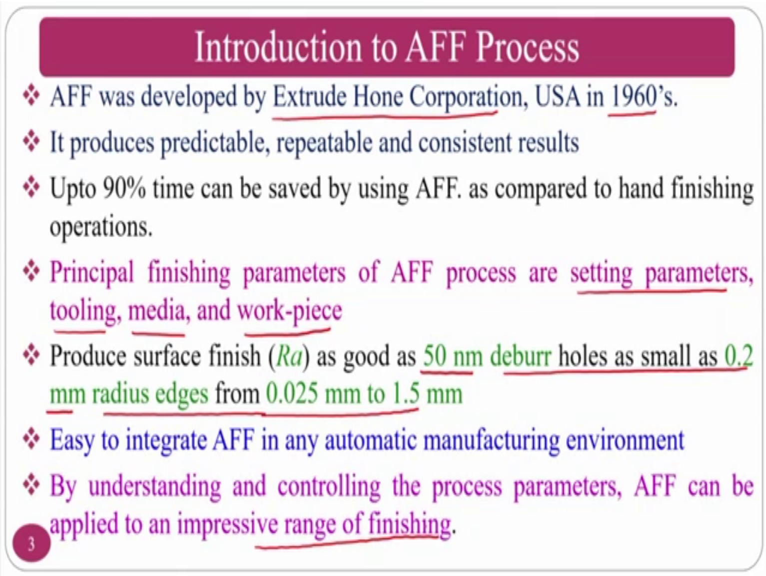

So, introduction to abrasive flow finishing process normally are abrasive flow machining process it is named in the olden ages. So, it was developed by extrude hone corporation where in USA in 1960s, and it produces predictable repeatable and consistent results, and up to 90 percent time can be saved by abrasive flow finishing process. Finishing parameters are setting parameters such as extrusion pressure number of cycles and other things.

Tooling, tooling will decide how to hold a work piece and what is the ratio of medium cylinder to work piece cylinder and other things? Medium or the media varieties of medium and medium parameters are different like what is the number of abrasive particles, what is the size of the abrasive particle and many more? What is a plasticizer amount in the medium? What is the polymers different polymers are there? What is the polymer content of this polymer? What is a polymer a weight percentage of other polymer and the other polymers?

Whenever you see the polymer rheological abrasive finishing process that is abrasive flow finishing process you have multiple number of parameters. And work piece parameters also, whether it is a hard work piece material, whether it is a soft work piece materials are in between. Produces the surface roughness as good as 50 nanometres and deburrs the small holes as 0.2 mm radius and 0.25 mm to 1.5 mm it can do the radiusing. It can get the surface roughness up to 50 nanometres and deburr the holes as small as 0.2 mm and radius the edges up to 0.025 mm to 1.5 mm, ok. So, radiusing and other things you will see in the upcoming slides. Anyhow you know what is chamfering and other things.

Similarly, instead of chamfering if you get some curvature there that is nothing, but the radiusing. Whenever you have a hole that you are drilling in a work piece material the edges on the top side and the bottom side will be very sharp. So, for that purpose normally chamfering will be done for, so that the handling will be easy. If not you can give some radius to it that is called radiusing; easy to integrate abrasive flow finishing in any automatic manufacturing environment. By understanding and the controlling of the process parameter, AFF can be applied to an improved range of finishing.

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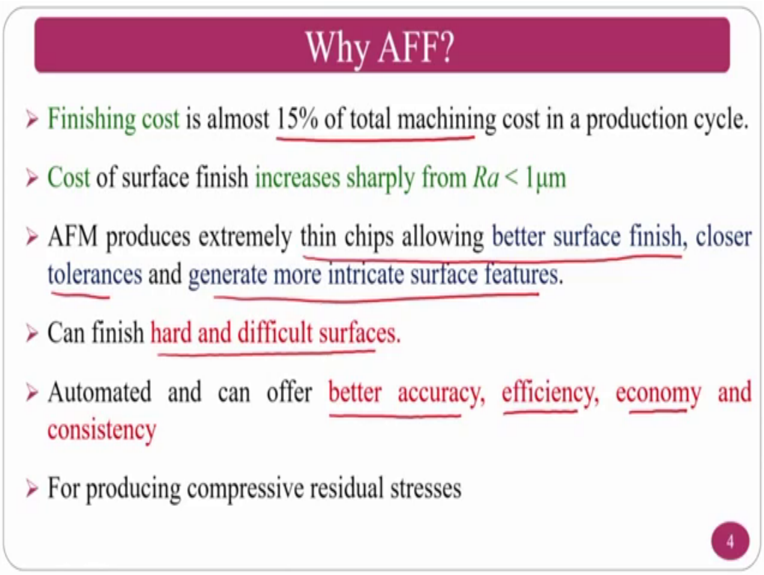

Why only AFF? Finishing cost almost 15 percent of is total manufacturing cost. Normally, in a conventional manufacturing also the normally finishing will be done with the grinding process and other things, there also the finishing cost is approximately 15 percent of total manufacturing cost.

So, the cost of surface finish increases sharply if your requirements are less than 1 micrometer, normally what I mean to say is if your surface requirements is nano surfaces in that circumstances what is the cost of the product escalates enormously. If you want the surface finish 5 microns you can develop by turning process, if at all you want the surface finish of 2 microns are approximately above 1 micron you can do by the grinding process. If you want less than 1 micron then the starts the cost goes up 50 nanometres, 500 nanometres and other things. Nowadays, you can get up to 500 nanometres also is no much problem, but if you want the surface finish below 50 nanometres or below 100 nanometres, normally people will charge more and more. So, that is why abrasive flow finishing process came into existence for the finishing applications of complex features.

Abrasive flow machining or abrasive flow finishing produces extremely thin chips allowing the better surface finish, closer tolerances and generate more intricate surface features. It can finish hard and to difficult materials. Automated can be offer for better accuracy, efficiency, economy and consistency and for producing compressive residual stresses also you can use the abrasive flow finishing process. Because of the reciprocation that you come across in upcoming slides, you have a lower medium cylinder, upper medium cylinder; in between you have the work piece. So, you have to reciprocate because of this reciprocation there is chance that the compressive residual stages also will develop in the product which is useful for some of the applications, ok. So, some of the advanced versions of abrasive flow finishing you can also see that compressive residuals success will increase.

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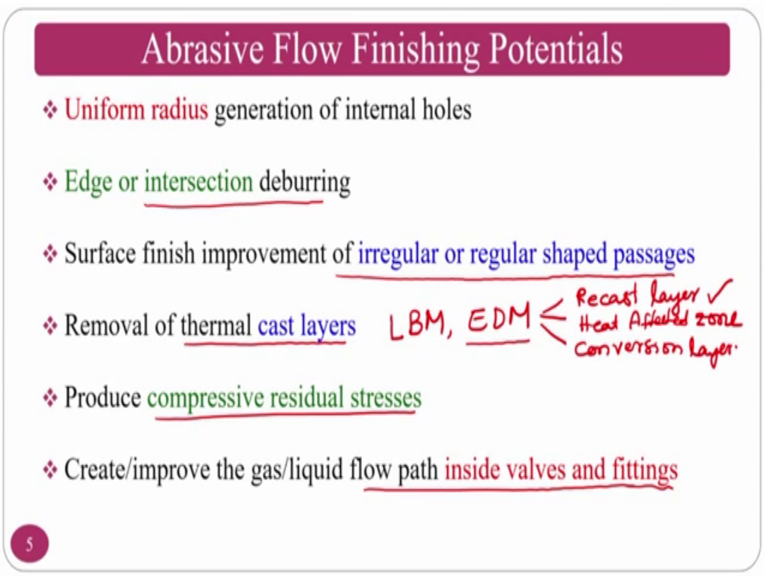

Abrasive flow finishing process potentials uniform radius generation of internal holes. Edge or intersection deburring normally intersection deburring is slightly difficult using conventional finishing processes. Intersection deburring means assume that I have two internal holes where they are meeting and there is a burr because of the machining action and other things, then it will be very difficult to do by a conventional finishing process. Since the abrasive flow finishing process uses polymer rheological abrasive medium which is a semi-solid in nature or liquid in nature it can flow to each nook and corner of the surface and it can finish the surface.

The surface improvement of irregular and regular shape passages can be done. So, whether it is irregular or whether it is regular does not matter because it is a liquid based or semi-solid based. However, whatever the shape is there it will occupy that space, because the abrasive flow finishing medium that is called polymer oriented or which is made with a polymer semi-solids, that is why this medium is polymer rheological abrasive medium can orient according to the shapes that you have seen in the previous slides where knee implant is there and some rotors are there. So, according to the shape it will orient. If it is a solid tool then it will be a difficult thing. If it is a liquid tool or a semi-solid tool it will occupy as per the requirement.

So, removal of thermal cast layers; Thermal cast layers is developed during the thermal processes such as laser beam machining, electric discharge machining and other thermal processes. There are multiple layers recast layer, heat affected zone that is called normally people say HAZ and conversion layer.

What we normally want to remove is recast layer. So, recast layer means re-casting is done what is the mean by casting you have a molten metal is there you have a mould just pour it, it will cast. Here assume that there is a EDM process or laser beam machining process. Laser is fault high temperature melting and evaporation has to be taken place, 100 percent melting and evaporation will not take place. The material at the edge, because if you see the laser beam it is follows normally a gaussian distribution, so at the centre it will be very high at the edges it will be very low.

So, a hole which is drilled will have some molten material which is unable to evaporate that material will solidify because of the atmospheric cooling or whatever the cooling that you are providing there. Because of each what will happen? This molten material will solidify that is nothing but recast layer the casting is done because of unable to evaporate that molten material that is why it is called recast layer.

The same thing you can see in electric discharge machining also, these thermal layers. And produces compressive residual stresses that we have seen because of the reciprocation, because of the indentation of radial forces that is developing it will causes the compressive residual stresses. How the radial force is generated by a liquid or how the radial force is generated by a semi-solid? We will all see in this particular class whenever the mechanism of viscoelasticity comes.

So, it can create and improve the flow inside the valves and fittings because it can finish in a very good way, at the same time it can deburr also so there is no burrs are there and the smooth surface is there. So, what will happen if there is a gas is flowing or a liquid is flowing? Automatically, smooth flow will be there.

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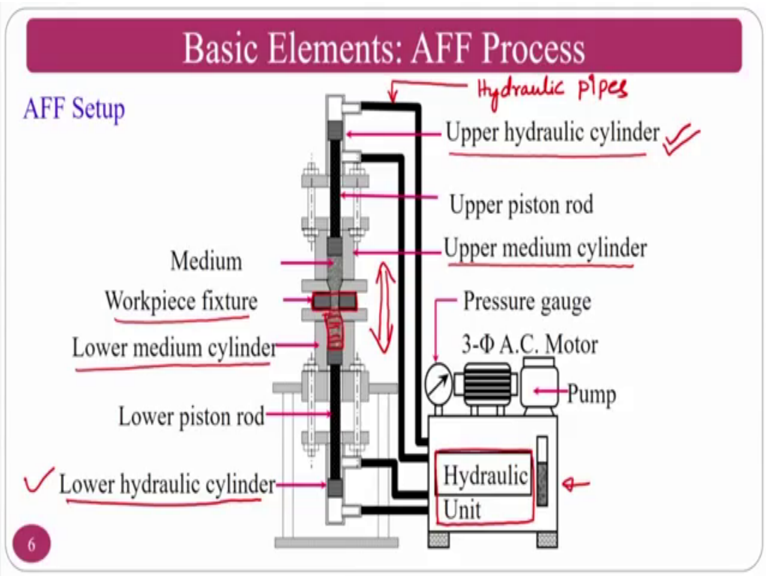

So, abrasive flow finishing process schematic diagram if you see here because most of the time you come across similar set up, watch carefully because in the advancements also you come across magneto abrasive flow finishing process and MR AFF, process magneto rheological abrasive flow finishing process, you come across centrifugal force assisted abrasive flow machining process or a finishing process and so on. But all the systems will have commonly this similar structure, but some of the amendments will be done. For that purpose, just I want to say you that if you can follow here what is a structure that will be there or how the machine set up will be structured are framed that you can understand advancements and hybrid abrasive flow finishing processes easily.

So, let me start. Hydraulic power pack is there you can see hydraulic unit. This hydraulic unit main function is to operate the hydraulic cylinders. So, we have two hydraulic cylinders, one is on the top side that is called upper hydraulic cylinder, it will have a piston which is pushed by the hydraulic unit. This hydraulic power pack or hydraulic unit you will fill with hydraulic fluid, hydraulic oil. So, you have to fill 40 litres, 50 litres depend on the capacity of the hydraulic unit you will fill. So, whatever you are seeing the black ones 4 black ones are there these are the pipes connecting this for example, one I will just write, these are hydraulic pipes. So, this will transform the liquid from hydraulic unit to the upper cylinder and lower hydraulic cylinder. We have upper hydraulic cylinder one, lower hydraulic cylinder one.

This is comprises a unit whenever you purchase assume that somebody want to develop the abrasive flow finishing process, in that process you need to procure a hydraulic unit. The hydraulic unit comprises of hydraulic power pack that is this particular system along with you will get lower hydraulic cylinder upper hydraulic cylinder. This 3 parts will come as a unit. So, you have to fix that one to the developed medium cylinders. You have to develop your medium cylinder that is called upper medium cylinder and lower medium cylinder. The main function of medium cylinder is to place the medium I say said in a previous slides also you have a liquid based or semi-solid based medium will be there, where you place assume that you have to place in the lower medium cylinder.

Then work piece fixture will be there, and the work piece will be and its fixture will be here. So, this is work piece and its fixture. So, now, how it works that we will see here. What is you have to do is you have to first open your work piece fixture and work piece, just load the medium in the lower medium cylinder just you can see here I am filling everything here and I am placing the work piece. Once you place the work piece now, you bring the top medium cylinder and hydraulic cylinder unit down and close. Now, you operate hydraulic power pack so that reciprocation of medium will takes place in the work piece fixture and cross the work piece, in that circumstances the finishing action will takes place. How the finishing action takes place? That we will see; the mechanism of material removal by abrasive flow finishing process.

Hope you understood that the structure of this AFF set up will have two hydraulic cylinders connected to a hydraulic power pack. Hydraulic power pack main function is to pump the oil with high pressure so that the piston that is there in the hydraulic cylinders will move as per the actuation. And because of this movement the medium that is presenting the medium cylinders will also reciprocate.

Assume that I have a medium that is placed in the lower medium cylinder and lower hydraulic piston will start pushing it. Whenever it pushes, 90 percent of the medium will move to upper medium cylinder across the work piece on the journey of this medium from lower medium cylinder to upper medium cylinder it shears the surface peaks, that is there in the on the work piece whenever it is passing across the work piece.

And similarly, whenever it goes to the top date centre of the lower hydraulic piston, then automatically there will be a limits which will be there and this limits which will deactivate. So, that the reciprocation will start from the opposite directions; that means, that now, top hydraulic cylinder will actuate and pushes the medium from upper medium cylinder to lower medium cylinder. That is how it will reciprocate from bottom medium cylinder to upper medium cylinder across the work piece, upper medium cylinder to the bottom medium cylinder across the work piece.

Whenever the medium is flowing across the work piece the finishing surface will get finished that is the simple mechanism of the AFF set up. If you can understand this much set up how it works, now it is easy for you to understand advancements as well as hybrid abrasive flow finishing processes.

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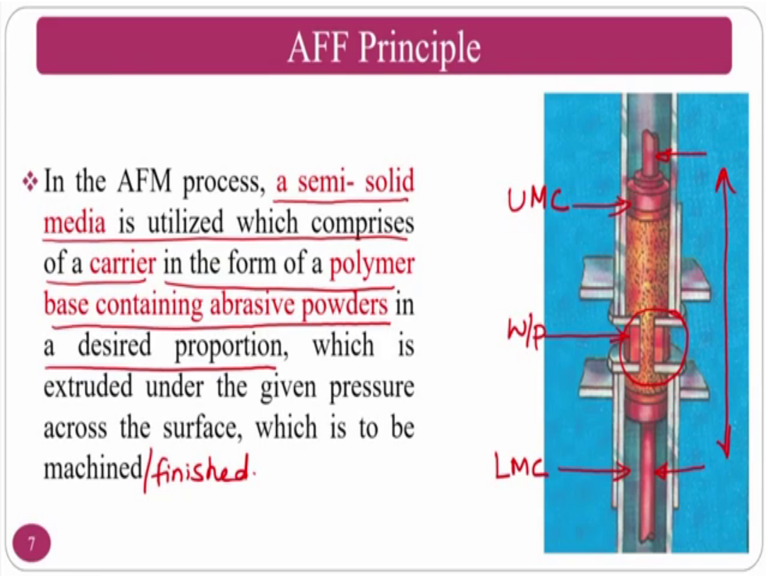

Now, we can see the principle, what is happening in the work piece region. This is my lower medium cylinder, this is upper medium cylinder, and your work piece is placed here. So, your hydraulic pistons hydraulic cylinder is there which we are not showing here, this is connected to hydraulic cylinder this piston will try to reciprocate work along with another piston. This will reciprocate. So, this reciprocation goes across these particular work piece because of which the surface peaks on this work piece will be finished properly.

As you can see the same thing a semi-solid media is utilized which comprises of a carrier, that is nothing but the polymer as our course is polymer based abrasive finishing processes. So, our carrier in the form of a polymer base containing abrasive powders or abrasive particles in a desired proportion which is extruded under the given pressure across the surface which is to be machined or finished. That means that the reciprocation will takes place and finishing will takes place.

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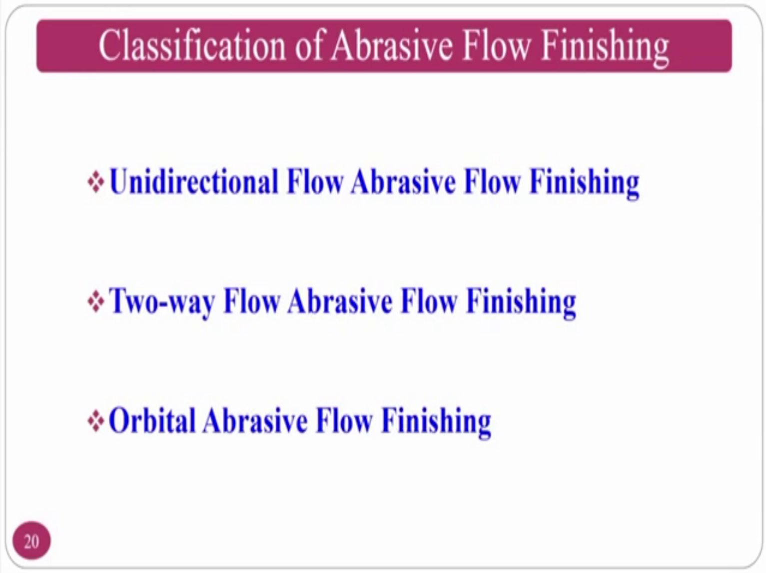

Now, we move on to the various classifications of abrasive flow finishing process. The first one is unidirectional; that means, that only one directional flow will be there and two-way and orbital. There are the 3 varieties of abrasive flow finishing processes are there depend on the applications.

If you have different types of work pieces, assume that I have a blind hole then you have to go for one variety, if I have a through holes you have to go for one variety of the abrasive flow finishing process, depend on the applications these are 3 divisions are done.

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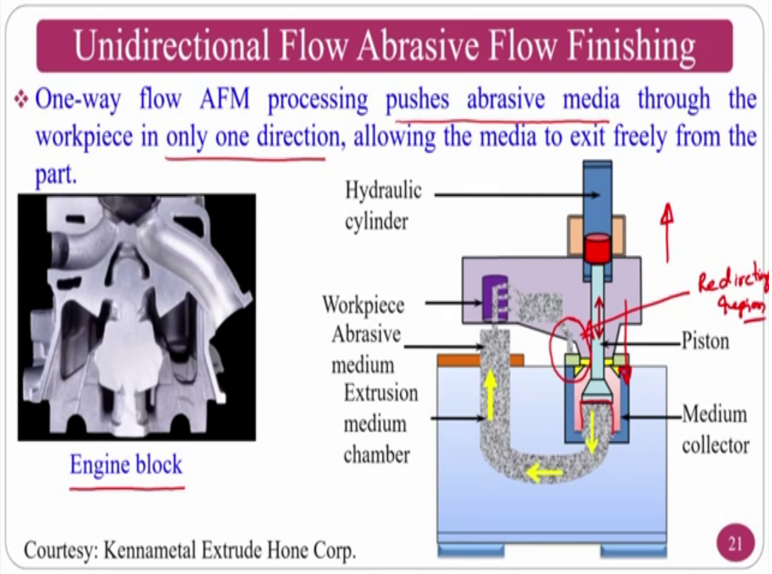

The first one is unidirectional abrasive flow finishing process, wherein only one directional pushing by the hydraulic power pack will be done, ok. So, what you can see? This is the work piece and how to finish the work piece which has some, the work piece which has some holes, ok. So, in that circumstances the medium cylinder is there, medium cylinder means filled with the medium and the hydraulic piston will be pushing the medium down in that circumstances the medium will flow as you can see the yellow arrows and it will come to the work piece and it will go through or across the work pieces or the holes that are to be finished and it will come out then there will be a lid will be there and from here it will come and join.

But for that purpose, this joining of the medium will takes place when the medium goes back to the original position, ok. One way abrasive flow finishing process pushes the abrasive media through the work piece in only one direction, this will push only in one direction and automatically medium will accumulate by coming from the back side when the pistons will go to its original position. And the common examples or engine blocks.

Suppose if you have this type of work pieces what you have to do is you have to finish this work pieces in only unidirectional only, because if you want to use two directional from backside also if you push it will be not possible. So, it will be pushed from one direction and exit will be done on another direction and it can be redirected into the medium cylinder as you can see here. So, this is the redirecting region. This is redirected when the piston will goes to its original position.

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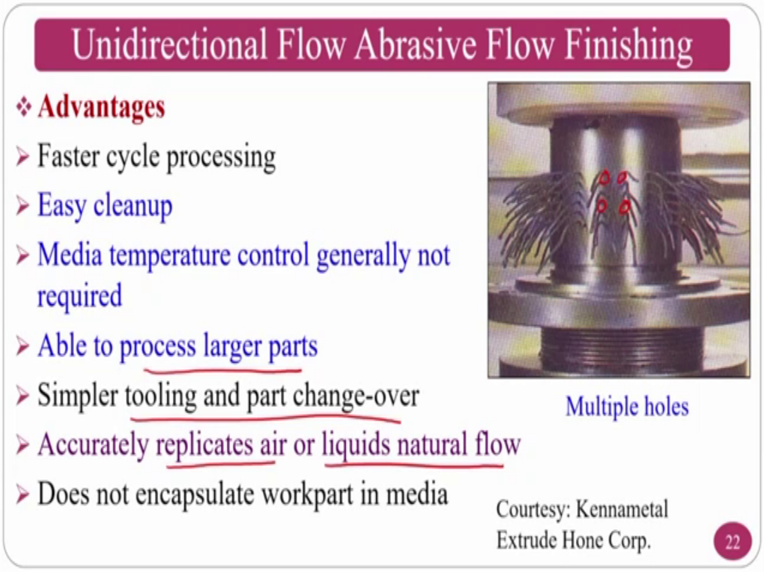

So, some of the other applications if you see there are multiple holes in a cylinder in that circumstances also you can use unidirectional because the medium will come out threw through these holes and you can collect this medium and you can reuse the medium also.

The advantages, it is faster cycle processing and easy clamping is there and medium temperature control generally not required because the medium is not going for multiple cycles. Here medium is going for only one first stroke itself, it is not a cycle also one cycle means the medium goes up and come down is a cycle, but here it is only one direction just you are pushing that means, that half of the cycle; that means, that only one stroke it is taking place. One stroke means half of the cycle, forward stroke and backward stroke completes one cycle.

Able to process larger parts, simpler tooling and part changing over is easy and the accurately replicates air liquid and natural flows and does not encapsulate work part in the medium. There is no requirement of placing the part inside the medium, like whenever you want to go to finish a knee implant other things you have to submerge in the work piece fixturing zone so that the medium will completely encapsulates the finishing region.

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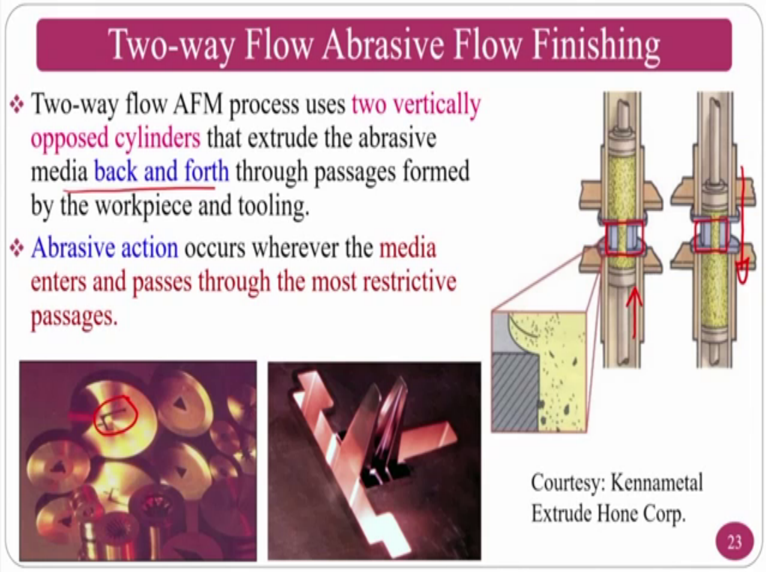

Normally, two-way is the one that we understands in the initial stages of abrasive flow finishing also. When I was telling you should understand the set up how it works and other things. It is simple to understand the two-way abrasive flow finishing process that is why we always explain you the two-way abrasive flow finishing process as the common abrasive flow finishing process. What I mean to say is whenever we say abrasive flow finishing process; that means that it is or I am talking about two-way abrasive flow finishing only, it is not the unidirectional abrasive flow finishing process or another process. It is the only two-way is a commonly used for abrasive flow finishing process.

Two-way abrasive flow finishing process uses two vertically opposed cylinders that extrude abrasive medium back and forth through the passages formed. The abrasive action occurs whenever the medium enters into this region, anyhow we will see here. You as I said that medium is pushed from lower medium cylinder to the upper medium cylinder, then upper medium cylinder to the lower medium cylinder through which the work piece passage will be finished. These are normally used for the dice application or the industrial dice are used. So, these dice are normally finished using two-way abrasive flow finishing process.

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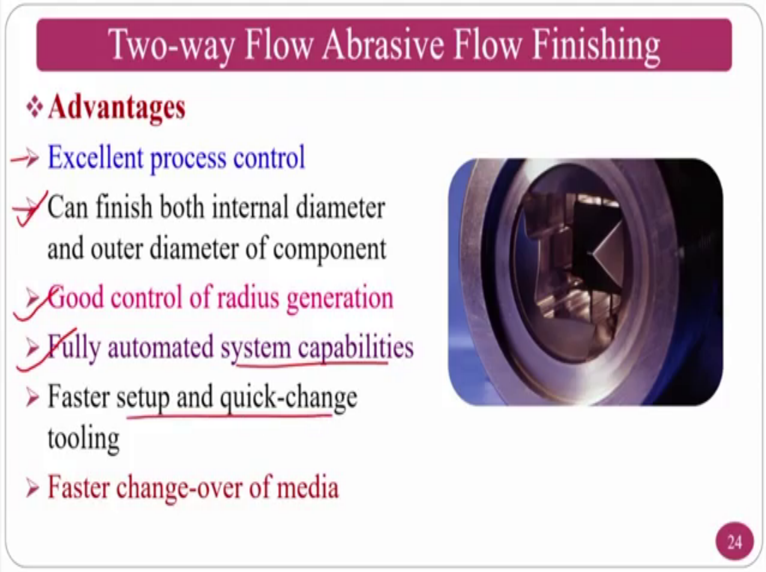

Advantages, excellent process control will be there, can finish both internal diameter as well as external diameter, then good control of radius generation, full automated system capabilities, faster setup and quick-change, and faster change-over of the medium, medium can be changed at the fast. What I mean to say is two-way abrasive flow finishing process is commonly named as abrasive flow finishing process. Whenever somebody talks in a normal way abrasive flow finishing, so they are by default talking about two-way they are not talking about orbital or they are not talking about unidirectional.

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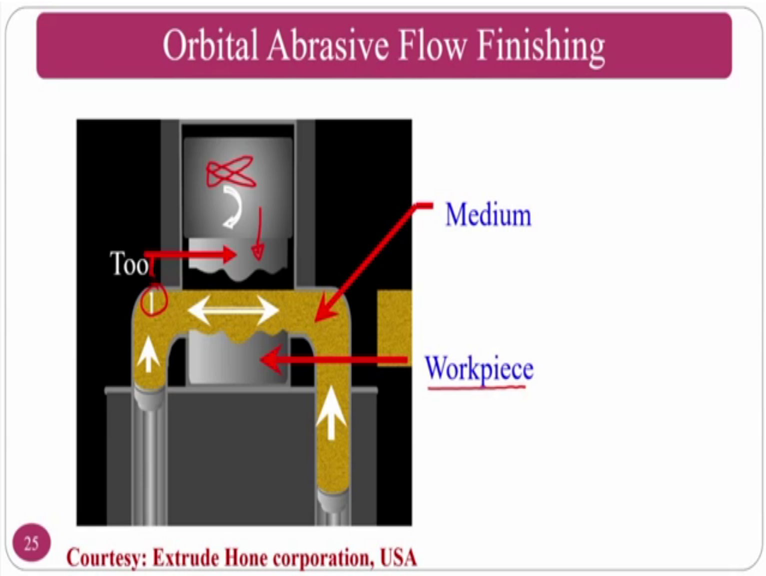

So, orbital abrasive flow finishing process, in the orbital abrasive flow finishing process you can do the finishing action for the blind surfaces. If you see the tool and you have the converse shape work piece medium is reciprocated, and the medium is reciprocated at the same time orbital motion will be given to the tool so that it can do the finishing action. Whenever the medium is reciprocating this orbital motion one will come to down and it will do. There will be a slight gap between the tool and work piece that will be filled by the abrasive medium, that is reciprocating that is why the orbital motion is given to the tool that is why it is called orbital abrasive flow finishing process.

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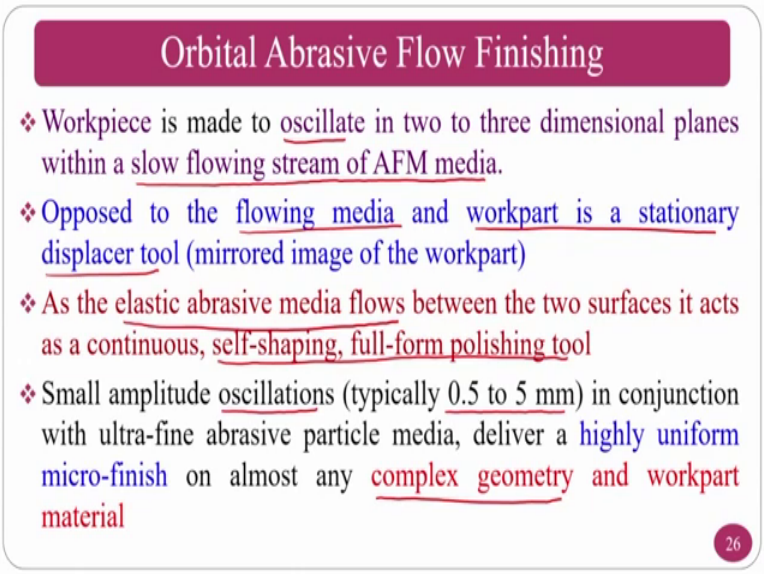

The work piece is made to oscillate in the two or three dimensional planes within a slow flowing stream of abrasive flow machining medium. Opposed to the flowing media work part is a stationary and dispenser tool which is a mirror image. As the elastic abrasive media flows between the two surfaces as continuously and self sharpening and full from polishing tool.

The small amplitude of oscillations typically 0.5 to 5 mm in conjugation with ultra-fine abrasive particles media, delvers a high uniform micro-finish are most any complex geometry or blind geometry can be developed. That means, that oscillatory motion is given to the tool and work piece both are there and both should be mirror image. at the same time medium will be frowned in between then the finishing action will takes place in orbital abrasive flow finishing process.

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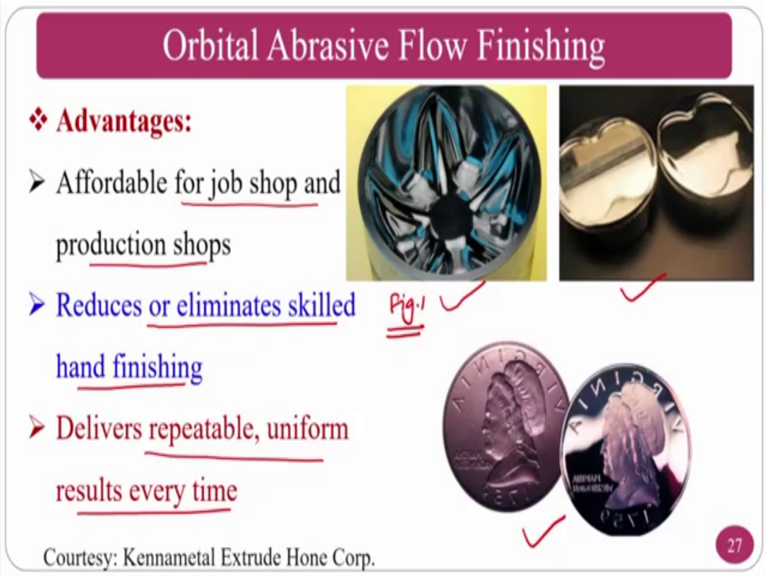

Some of the applications if you can see these are the blind images, blind hole type of images that can be finished using the orbital abrasive flow finishing process. Affordable for job shop and production shop. Reduces or eliminate the skilled hand finishing process, if at all I want to polish assume figure one; one has to go for hand polishing. If at all hand polish it will be difficult; this hand polishing which requires a human skilled labour. If his skilled labour also may sometimes do the mistakes for that purpose automated orbital abrasive flow finishing process can easily take care of this things. Delivers repeatable uniform and results every time, because it is not controlled by the human emotions. Why I called human emotions? I will come to the point and the skillness and other things.

Assume that why I said the emotions or something, because if it is finished by a human assume that he is a skilled labour also, I cannot say skilled labour he is a skilled person today he may be in happy mood, so he can do better job, tomorrow assume for example, of something happened in his personal friend, so he may not be happy. So, there may be a small change in a nanometric level of the surface finish that is why I just referred the emotions even though he is a skilled labour. These are all can be eliminated if you can make the process automated. And if you can use automated orbital abrasive flow finishing process you can do a better job.

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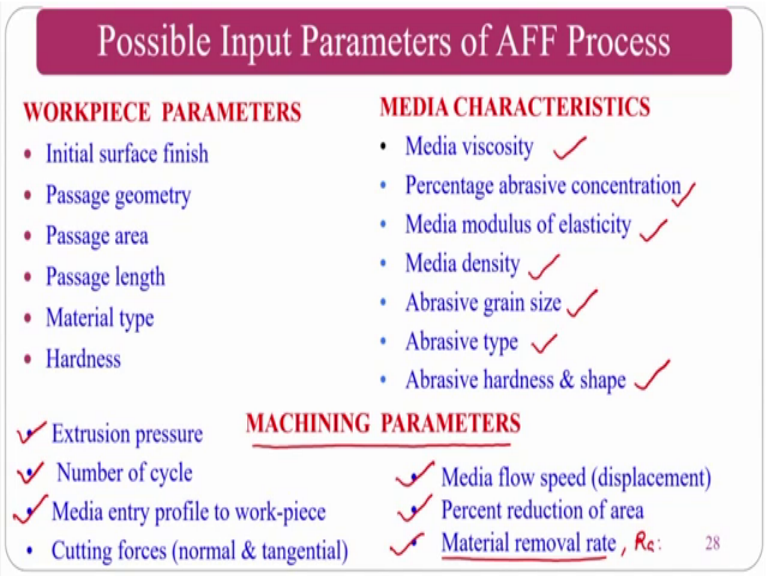

Possible input parameters of abrasive flow finishing process, work piece parameters initial roughness surface passage geometry. Initial surface roughness, initial surface roughness is most important input parameter you cannot ask the supplier by giving a 10 micron work piece you need a 1 nanometre because it is very difficult to achieve. That is why if you are going to give 100 nanometres to the supplier if you ask 10 nanometres or 5 nanometres it is easy, because if it is too rough surface it is very difficult to get the nano, sub nanometre surface finish that is why always initial surface roughness should be as minimum as possible so that the finishing can be achieved as better as possible.

Passage geometry, passage geometry will decide depend on the medium cylinder sizes and other things. If the medium cylinders are very big and passage geometry is very small then the reduction ratio is very large. So, restriction will be very high. Passage area, passage length these are all comes under the passage geometry material type like hardness another things. Medium characteristics, medium viscosity play a major role, percentage abrasive concentration, if the abrasive concentration ask more that more amount of material will be removed because high number of abrasive particles take part in the finishing action.

If the viscosity is very high then the elastic component will be very high. Then indentation and finish will be good. If you still increase a viscosity the elastic nature will increase if the elastic nature increases indentation will be predominant and surface finish may deteriorate.

The medium modulus of elasticity, medium density, particle size if the particle size is very big the indentation obviously will be big, abrasive type if the abrasive is much much harder than the finishing ability will be easier. If I am going for diamond particle, so the abrasive particle hardness is much much compared to your work piece, assume that the work piece is aluminium align and that tool or the abrasive particle is diamond in that circumstances finishing can be easily achieved in few number of cycles.

Abrasive hardness and shape, machining parameters are the finishing parameters which are controlled by the abrasive flow finishing set up, one is a extrusion pressure. If your extrusion pressure is high the medium flow will increase number of cycles if your number of cycles are high; that means, that number of times shearing of that particular peak will be more. So, the finishing will get better and better. Medium entry profile to the work piece how it is entering and cutting forces that is the finishing forces. Medium flow speed, percentage reduction in area as I said medium cylinder diameter to the work piece, material removal rate this is output responses, how much material will be removed, what is the surface roughness achieved and other things are output responses.

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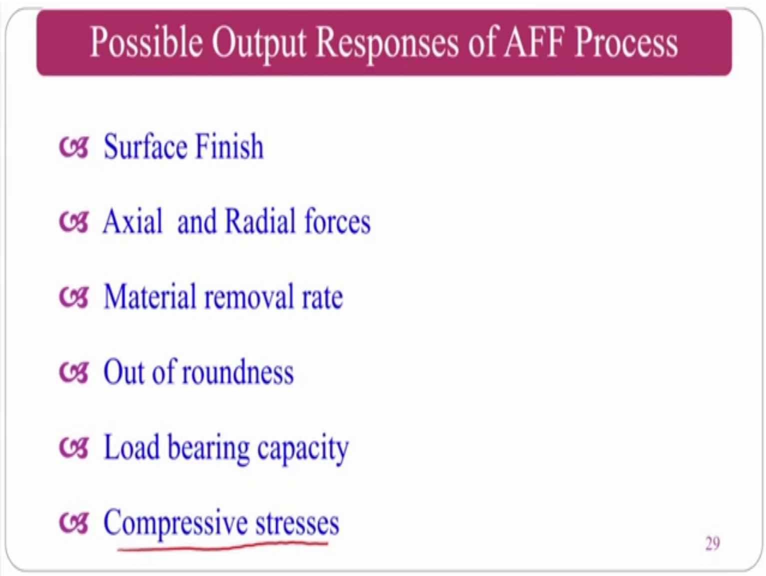

Possible output responses surface finish, what is the best surface finish that he achieved. Axial force and radial forces, this axial forces and radial forces one can measure using a ring type dynamometer and other things Professor Gorana Aton, Professor V K Jain group has done some experimental measurement of axial and radial force using a ring type dynamometer. So, if somebody want to work in that area, it is wide open area where you can get there good dynamometer and you can use it for measurement of the forces.

Material removal rate, how much material removed for unit time. Out of roundness if you are going to do the finishing of cylindrical holes then you can measure out of roundness, how much the deviation is taking from the perpend perfect circle. Load bearing capacity of this particular cycle, if you can measure various surface roughness parameters you can also measure the load bearing capacity, kurtosis, skewness and all those things. And compressive residual stresses compressive residual stresses also we can measure. Some of the systems nowadays are readily available where you can also measure other parameters or clubbed like x r d system, nowadays will come with inbuilt compressive residual stresses measurement system and other things.

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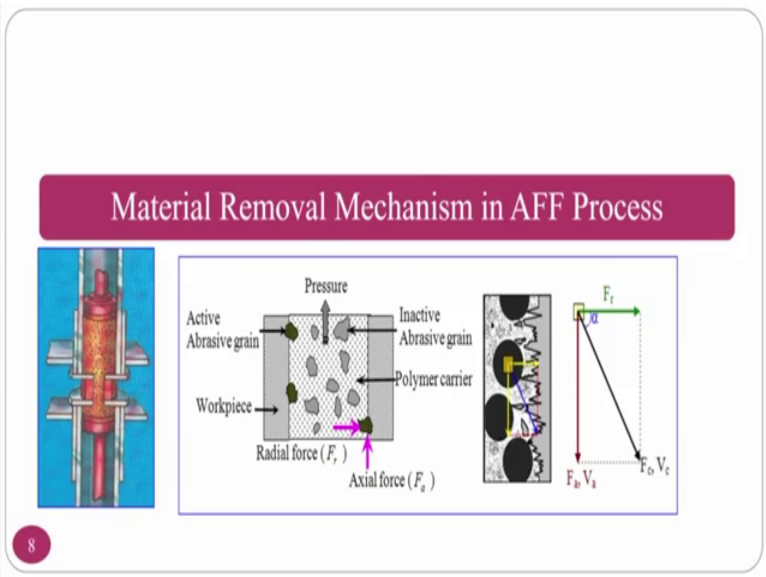

Then, now the mechanism of material removal; if you see the mechanism of material removal in the abrasive flow finishing process if you have understood the previous slide and to previous to previous slide it is very easy. Now, we move on to the medium, how it will react with respect to the extrusion pressure and other things. So, this is how the mechanism works and in detailed how the mechanism is going to work.

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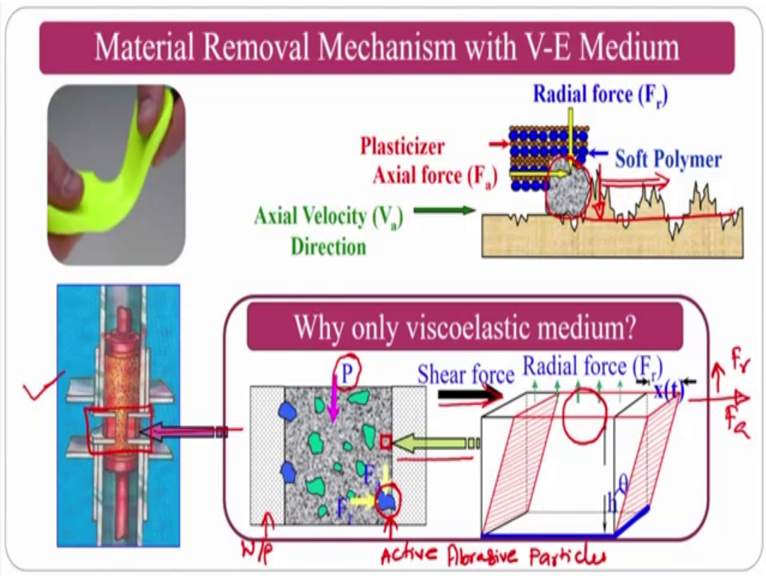

So, first what you have to see is you have understood already this particular picture in the previous slide. So, if you take out this particular finishing region and if you watch here, so I have this work piece and I have the medium. Medium have two different colours of abrasive particles, one is green this are inactive, these are the active abrasive particles. Active abrasive particles means those are participating in the finishing action; that means that those are touching the work piece.

Whenever, you are going to apply a pressure p on the viscoelastic medium or polymer rheological abrasive medium which is basically a viscoelastic in nature, and how this polymer V is going to help you. Since, this particular course is polymer assisted abrasive finishing processes, so how the polymer is going to help the abrasive particle that we have to understand. Here only I will explain in a clean way, but later on in a other advanced and hybrid processes you may not get that by chance to understand because already I am explaining here.

So, if I take any element of the viscoelastic here, what is happening? If I am putting a shear force the because of viscous nature it will flow along this direction, because of the elastic nature it will flow along like this. This is called Vizamber's effect. Now, if I see if I put in abrasive particle here, if how this is going to help it because of this radial force this is going to indent on the work piece because of the axial force, it is trying to move in a straight line along the direction. In that circumstances what is happening? Radial force can make the abrasive particle to penetrate into the surface to be finished and the axial force try to pull along the direction of medium flow so that it can shear the work piece.

The same thing now we will see in the above picture. I have the surface roughness where my abrasive particle is interacting. So, because of the radial force work piece will in the indent like this on to the surface because of the work radial force it will indent on the surface because of the axial force it will start to move in this direction. So, the shearing action will takes place. Hope you understood.

I have a viscoelastic medium; that means, that I have viscous component I have elastic component, if the viscous component is to flow along the direction of applied pressure. Assume that I have a water, it is purely viscous. So, if I throw what will happen? It will move mostly or dominantly in the direction of how you are throwing. If I have a eraser assume that this small kids whatever they erase that you are using, if you press what will happen? It will start moving in perpendicular direction, ok.

So, similarly viscous and elastic if you are clubbing both what will happening? The viscous component tries to move in the applied direction, but the elastic component will move perpendicular to it because of these what will happen if you are blending the diamond particle, blending the silicon carbide particle or alumina and other particle. What will happen? This viscoelastic element if there is abrasive particle viscoelastic element is there it will elastic element will push into the work piece and axial or the viscous component will try to move along the direction of applied pressure because of which what will happen, the shearing of the peaks will takes place.

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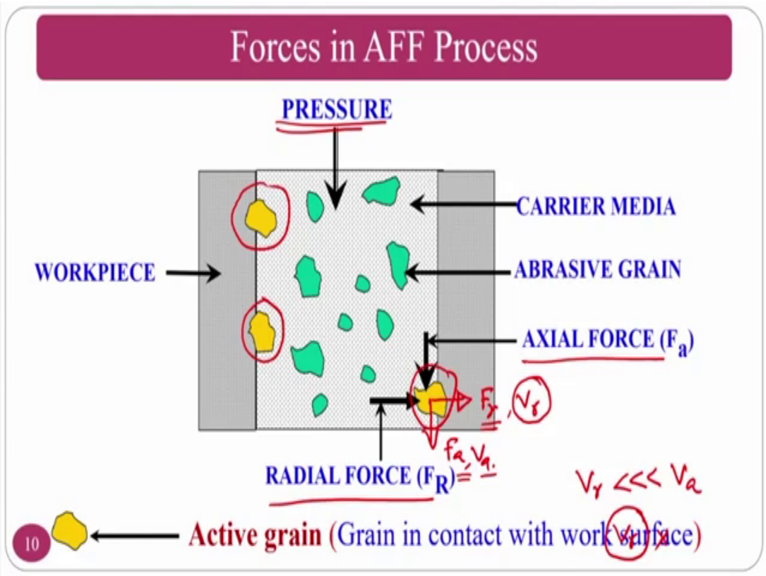

So, you can see here the active abrasive particles how the axial force is acting, how the radial force is also acting. So, the radial force tries to act in this direction axial force in this direction because your force direction is down. So, this is the axial force and this is the radial force because of this forces and you are going to have axial velocity also, ok. Axial velocity means how fast the medium is pushing with respect to extrusion pressure that is called axial velocity.

But radial velocity will not be there or radial velocity assume that you have a radial velocity also, radial velocity is nothing, but the velocity at which abrasive particle is indenting into the work piece. That will normally your radial velocity is much much less than your axial velocity, that is why normally radial velocity is not considered in respect to abrasive flow machining process or abrasive flow finishing process.

These are the active grains which are in the active region of finishing; that means, that which are integral part of finishing. That is why the basic problem of abrasive flow finishing process that you also should know at this moment of time because these abrasive particles which are not in contact with the work piece are simply going to the other medium cylinder. For that purpose, these are all not involving at all, for that purpose some of the advancements comes in the next classes I will teach that, but anyhow I just I want to give the introduction to it, because to enhance the active number of abrasive particles they are going to introduce a centrifugal rod at the centre or drill beat at the central.

So, centrifugal forces is the abrasive flow finishing process, drill beat guided abrasive flow finishing process, spiral polishing, these are all are going to use some rotation systems or interruptions at the centre. So, that number of active particles will be more at the work piece and medium interface.

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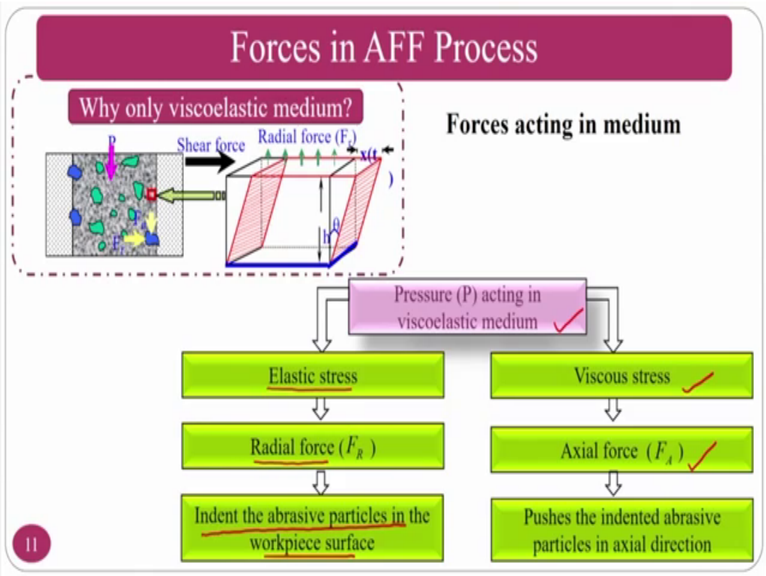

So, now you can see the pressure acting on the viscoelastic medium because of elastic stresses that is, because of the elastic nature of the medium you have a radial force which try to indent a of the abrasive particle into the work piece because of the viscous stresses nothing but the viscous component will makes the axial force that makes the chip. Indentation will be done, and shearing direction is auxiliary action. Once it is indented surface then axial force moves in along the direction because of which indentation then moves. So, the microchip formation will be done because of axial force, axial velocity and radial force.

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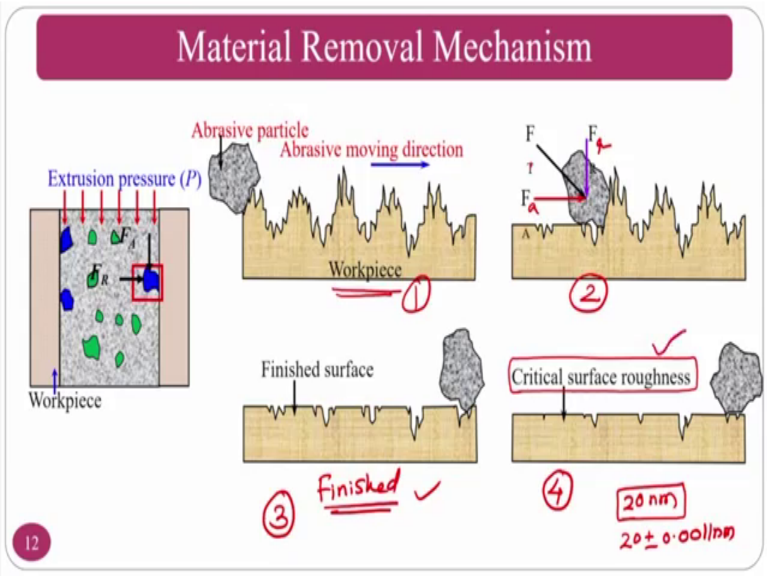

So, that is how the schematically you can show this is the initial work piece because of the viscoelastic nature of the medium, you have the axial force and radial force and this is the finishing force or you can say another forces. So, the finishing takes place after number of cycles. So, this is the finished surface.

But there is another term called critical surface roughness. Critical surface roughness means the surface here assume that it is a finished surface. Do you think it is not improved further? You can improve it, ok. So, any finished surface you can improve. But whenever you achieve to a critical surface roughness or a critical surface finish what will happen. The difference when you call a surface achieved its critical surface roughness if the change in surface roughness is very very minimal, in that circumstances you can say that it is or this particular process achieved its critical surface roughness. That means, that beyond which this is figure 1, figure 2, figure 3, and figure 4. In figure 4 if you are increasing the finishing time still the change in roughness assumes that I am going to get here is twenty nanometres.

What you are achieving after another 10 cycles is 20 plus or minus 0.001 nanometres you can say it is negligible if you are increasing another 10 cycles you are achieving 0.00 assume that you are going to get or a 011, so it is negligible. That means, that particular surface is achieved its critical surface roughness beyond which if you are going to increase number of cycles it is waste of our input energy, but the output is approximately same, but there is a negligible affect is there then you can stop that particular process and you can say that this is achieved the its critical surface roughness value. That means, beyond which even though you put your efforts it may not result in good results or improvement in the roughness that is nothing, but critical surface roughness.

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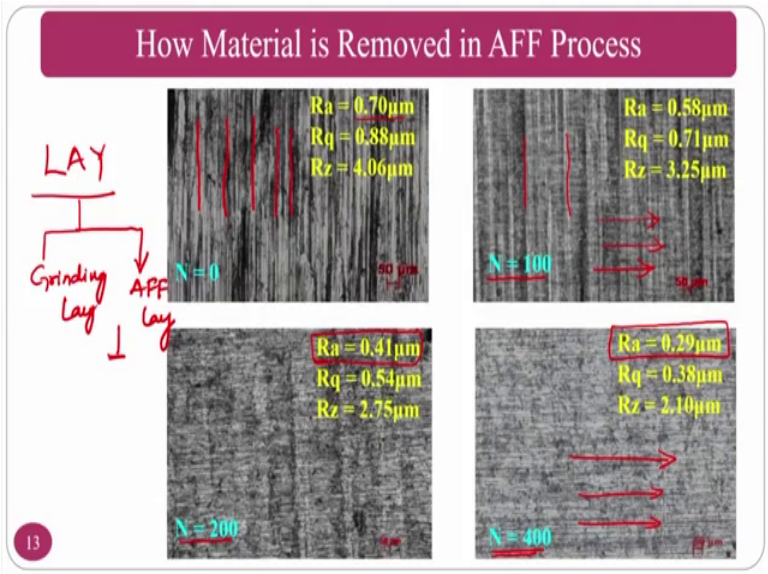

So, how the material is removed? Experimentally you can see here initially it is taken surface roughness values 0.7 micrometres, this is a ground surface or the grinded surface you can see the surface pattern or lay. Lay is nothing your predominant surface roughness directions. So, after 100 cycles, you can see these are the grinding marks, but you can see a very small small abrasive marks are there. So, always one should remember whenever you are doing abrasive flow finishing process try to place the work pieces perpendicular to the finishing direction.

What I mean to say is that if you are grinding direction is this your abrasive flow finishing direction should be perpendicular to that one. That means, that your lay what I mean to say is grinding lay and AFF lay, these both should be perpendicular to each other. If I have the grinding direction in this direction so my finishing direction should be like this. So, that my surface peaks can be sheared like this, that is the principle or caution that the people who are going to use abrasive flow finishing process. So, if you are going to use some of the advancements of abrasive flow finishing process then it is a different story. What I mean to say here from this particular slide is your finishing direction how and initial surface roughness direction. If it is perpendicular to each other then it will be better.

After 200 number of cycles you can see that your peaks are slowly diminishing and the achieved surface roughness is 0.41 micrometres, and after 400 cycles you can see that very minimal grinding marks are there, but it is predominantly occupied by the finishing marks of abrasive flow finishing process. And the final surface roughness is approximately 0.3 microns; that means, that 700 nanometres to 300 nanometres it is achieved in 400 cycles.

Normally, you may understand that oh this many number of cycles this number of cycles is also play an important role and this number of cycles will vary set up to setup, ok. So, if my setup medium cylinders are very small my number of cycles obviously, will be increased, if my medium cylinders are very big I can achieve the finishing in very few number of cycles, like 10 number of cycles itself. So, the number of cycles will be the function of how much medium you can accommodate in the medium cylinder.

Medium cylinder capacity may be big also, so how much you are putting. One time how much you are passing it through the work piece that is also a function of number of cycles. If your medium cylinders is double what I am using you can achieve the same surface finish in half of the what I am got; that means, that instead of 400 you can get in 200.

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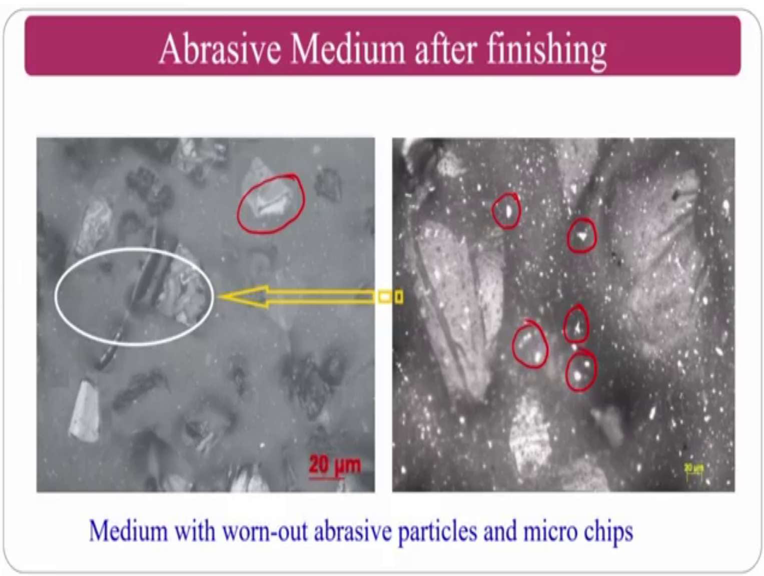

Abrasive medium after finishing what you can see is abrasive particles will become blond that is obviously, so that the finishing action will reduce. At the same time you can see the chips also will be loaded. You might have observed what is a tool life another things you know the crater wear, flank wear, notch wear, catastrophic failure these are the common words in metal cutting and other places. How do you decide the discarding of the medium? In case of single point cutting tool you can say that if the crater wear and flank wear achieved this much value say 0.5 mm flank wear. Now, you discard the tool, assume that is a status.

Now, you have certain standard to discard. But what is a standard to discard? Abrasive flow finishing medium because it is a semi-solid or liquid based medium at the same time you have abrasive particles are there each abrasive particle will have multiple cutting edges. So, it is very difficult, ok. For that purpose literature says that you have to discard the medium whenever it achieves or whenever it attains 10 percent of more than its original weight; that means, that if I am using 1 kilogram of the medium after 100 say skills or after 100 components assume that my 1 kg is increased to 1100 grams then I have to discard the medium.

This also will attribute to the wear of the abrasive particles also. That means, that your abrasive particles also cutting edges will goes down, at the same time lot of work piece materials are coming in and other things will happen that is why you have to discard otherwise you may not find the improvement in the finishing and other things.

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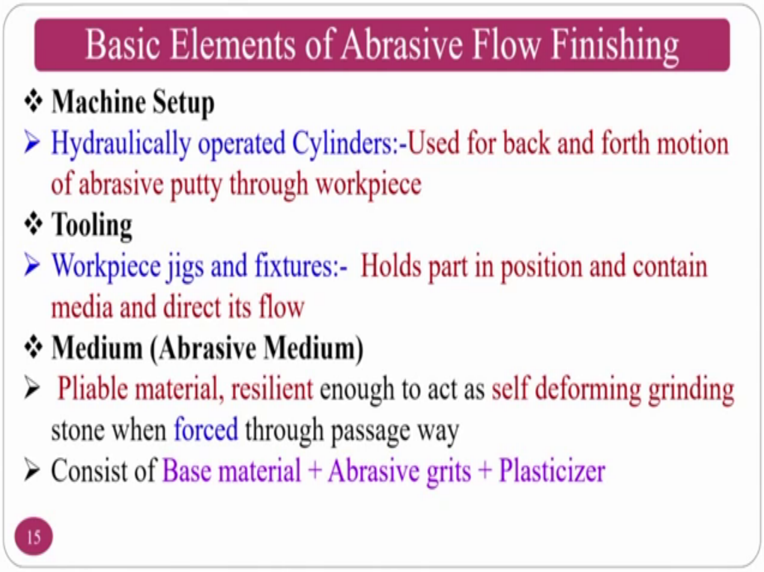

Basic elements of abrasive flow finishing process the machine setup, and the tooling and medium. These are the 3 things that one has to understand whenever they want to know about abrasive flow finishing process.

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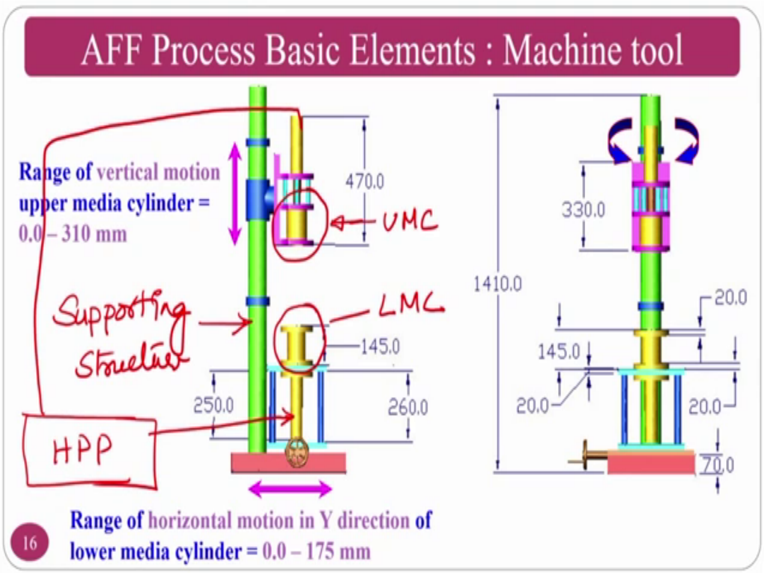

The machine setup we will see the machine tool. So, the machine tool can be like the structure and it consist of medium cylinders and it assisting elements. So, the whatever you can see here this is a supporting structure this supporting structure is most important to support the medium cylinders, and these are the medium cylinder. This is the lower medium cylinder, and this is the upper medium cylinder. So, these two will be accompanied by another set that is called hydraulic power pack. Hydraulic power pack assume that I have an hydraulic power pack here. This will have two things, one is upper hydraulic cylinder and piston lower hydraulic cylinder and piston these are the upper hydraulic cylinder and lower hydraulic cylinder. This will comprises of the machine tool

So, and another case you can have different motions and other things and you can even develop your abrasive flow finishing setup on your radial drilling machine also. This is the drawing that is shown for the radial drilling machine only. So, you can mount the upper medium cylinder on the slider whatever is there and the bottom cylinder and piston bottom piston you can have a separate system and you can brought in.

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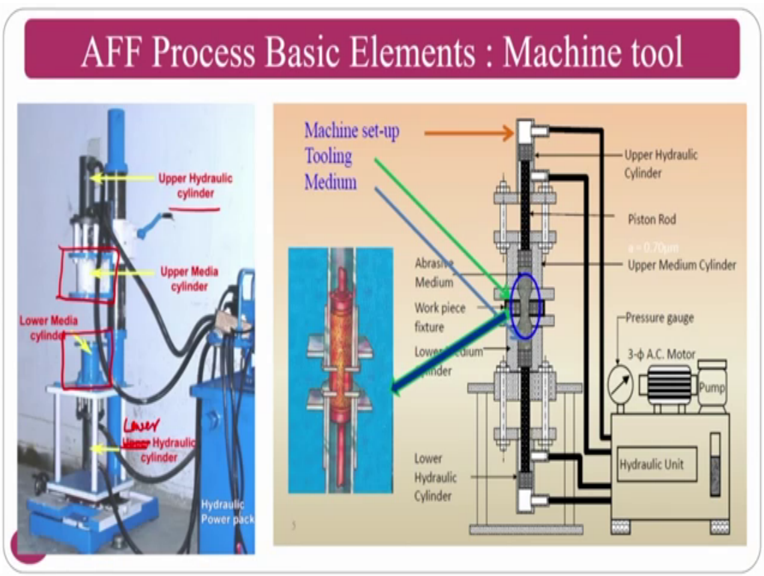

So, this is the system that is fabricated at IIIT, Kanpur. So, courtesy to Professor V K Jain and Professor Ram Kumar, this is their laboratory. This is the medium cylinder lower medium cylinder, upper medium cylinder which is connected to a upper hydraulic cylinder and lower hydraulic cylinder and this is a hydraulic power pack, ok. These are the elements of the machine tool.

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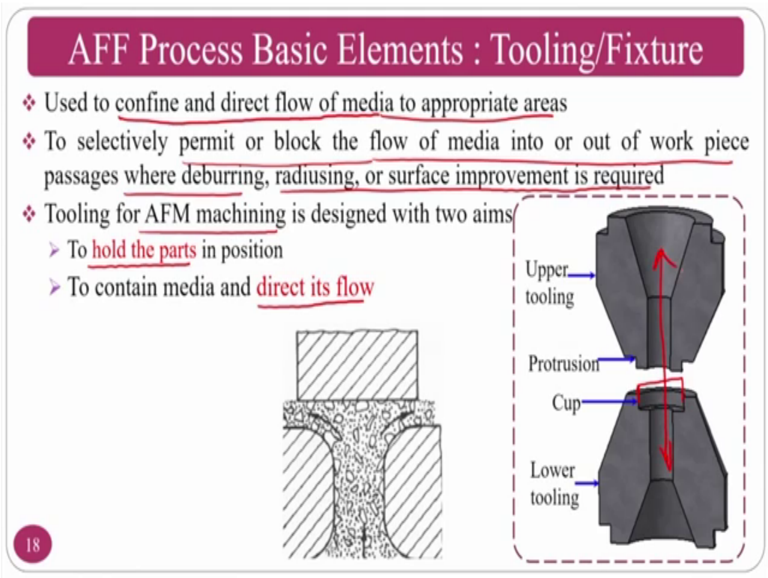

The next important is tooling or fixture. So, the basic function of the tooling is to confine and to direct the flow of medium to the appropriately areas or across the work piece.

I have a work piece to be finished. My motto why I am using the tooling or fixturing is, first thing is it has to hold the work piece firmly, the second is it has to flow or it has to direct the medium across the each nook and corner of the work piece surface. If you see here selectively permit or block the flow of the medium into the out of the work piece; that means, that it has to flow only across the work piece, it has direct passage where the deburring radiusing and surface improvement is required. That means, that wherever the deburring or radiusing or surface roughness improvement is required there only the tooling has to direct the abrasive medium or polymer abrasive medium.

In abrasive flow finishing process the tooling is required to hold the parts or the work piece and to direct the flow and normally what you this is the tooling that is developed at IIT, Guwahati. So, you can have the work piece and you can hold and so that you can direct the medium across the reciprocation. This is for a simple geometry like a cylindrical work piece

The third important is till now what we have seen is tooling and setup itself, abrasive flow finishing setup where you have seen all the hydraulic power pack, medium cylinders and hydraulic pistons and other things. Second tooling where you have to hold the work piece and you have to direct the medium, and the third and most important and pertaining to polymer assisted abrasive finishing processes is abrasive medium. Abrasive medium looks like only abrasive is there, but it is not so you have polymer rheological abrasive medium that is where this particular course polymer assisted abrasive finishing processes is much suitable to this particular process because base polymers are the primary things for abrasive flow finishing process. If you see a setup you can easily develop it, but it is very difficult to develop the medium and other that is why it is very difficult and very few companies only sell the medium.

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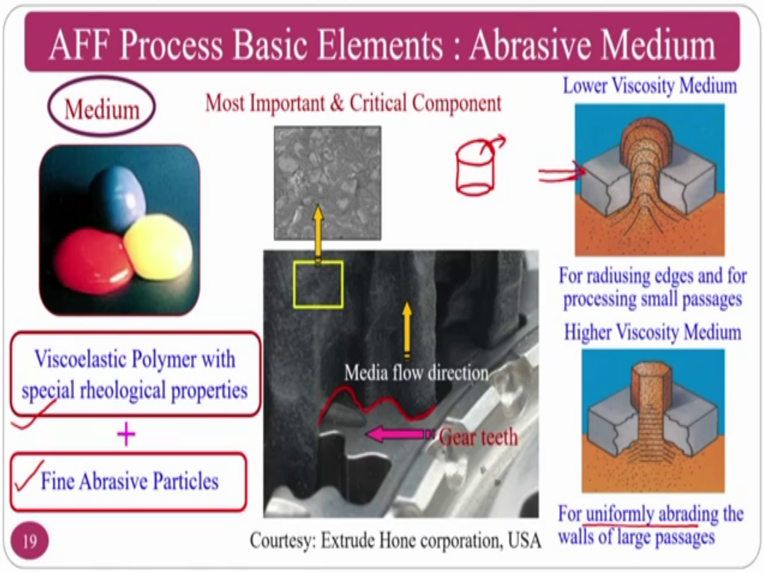

The medium will consist of viscoelastic polymers with special rheological additives and fine abrasive particles, that medium will have multiple features that is self deformability, better flow ability, and better upgrading ability. These are the 3 unique features it will have. And if you are going for the low viscous medium normally you can do the finishing action at the same time radiusing also. Assume that whatever I am seeing here if I have a hole on a cylinder assume that this is a hollow. So, edges are very sharp or; so, these can be done using the lower medium cylinder. So, that the edges will be round off that is nothing but radiusing.

If I am going for high viscous medium then it will be normally for the finishing applications only. You can clearly see from this fixture where the finishing action. Now, we can clearly see how the medium is changing its shape, because of its self deformability nature and better flowing ability this is deforming as per the requirements of the component itself.

Now, we have seen what are the input parameters that can be given and output responses also. Now, we move on to another important aspect that is called Rheology and the Medium Rheology.

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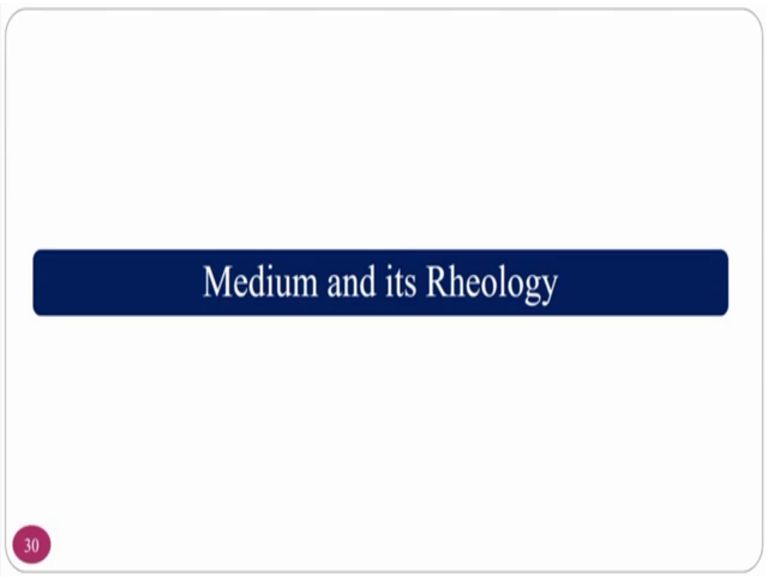

What do you mean by Rheology? Rheology is nothing but the science of flow and deformation. Why this is important? As our course is polymer assisted abrasive flow finishing process and we have to study what about the polymer rheology or rheology of polymer rheological abrasive fluids. What is a composition it has and how this composition is going to effect the rheological properties?

Why we need to understand the Rheology? Because assume that I have a knee implant or I have certain component which has the complex features, I have to understand how this polymer rheological abrasive fluid flow to the each nook and corner how it will deform and other things. Since the medium has it 3 characteristics, one is self-deformability. What do you mean by self-deformability? Self-deformability means if I am making a spherical ball of this medium and putting on a flat surface with respect to time the bottom side of the sphere will become very flat; that means, that atmospheric pressure is acting on the sphere and it will slowly deforming into a flat surface of the bottom with respect to few minutes. That means that it is self-deformable.

Better flowing ability, the better flowing ability is required for the medium whenever the hydraulic provisory is applied so that it can flow to each nook and corner of the surface. And better upgrading ability, better upgrading ability will be function of how the abrasive particle is held by the polymer as well as a rheological additive some other things. These three things how we have to understand for the finishing, if at all I want to understand the finishing I have to understand the medium rheology because medium is the one that is going to directly interact with the work piece surface roughness.

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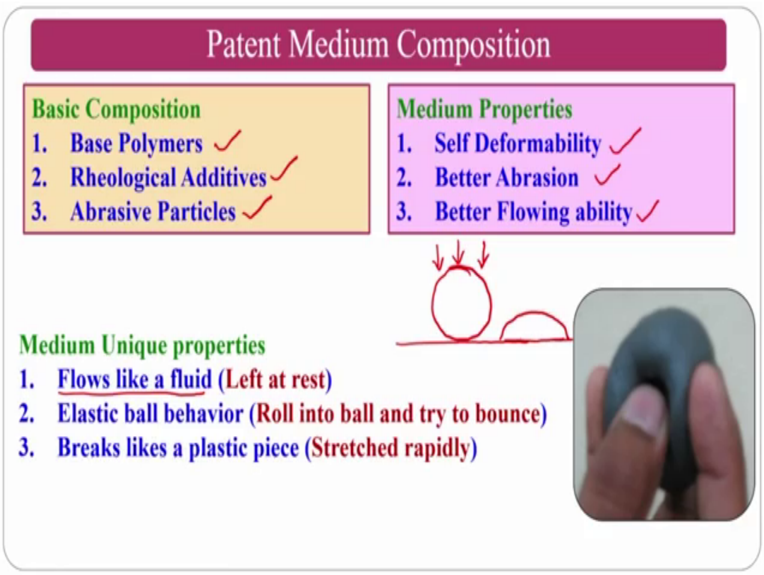

So, patented medium composition this says patented by so many groups. Some of the groups are we at IIT, Kanpur, we have pated the medium and some other group at IIT, Roorkee has also patented. Many people are patenting this medium their own medium or different. Our medium is contains of base polymers, rheological additives, abrasive particles. As I said medium properties are self-deformability the deformability with at possible pressures better upgrading ability and better flowing ability it will it should have so that it goes to each nook and corner.

So, medium why? If you see here it flows like a fluid whenever you live at the rest; that means, that if you are making a sphere, this is my flat surface if you are making a sphere and put because of this atmospheric pressures what will happen after sometime it will become like this. That means, that it is deforming with respect to atmospheric pressures.

You are not a self-deforming person because you are not going to deform with respect to atmospheric pressures, but this semi-solid can deform that is one characteristics.

If you make a elastic ball second thing and if you hit on to the ground it will bounce like your tennis ball, ok. You just make a sphere and you hit it, it would not stick to the surface it will jump like a elastic ball. So, this is the second characteristics. It breaks like a plastic piece whenever you are stretching rapidly; that means, that if you stretch slowly it will come like a bubble gum it will extend. If you stretch very fast it will break into pieces.

Now, you have to understand here it is flowing like a fluid because of the atmospheric pressures, it is behaving like a tennis ball whenever you are hitting to the wall or hitting to the floor, whenever you are pulling slowly it is coming like a bubble gum very smoothly, whenever you are pulling rapidly it is breaking like a plastic piece. Now, the flow characteristics because it is flowing like a fluid, and at the same time it is breaking and a deformation characteristics are completely unique. So, the flow characteristics if you see as a human it will be different and deformation characteristics also different.

Now, how to understand this particular? For that purpose only the science of flow and deformation is used for particularly to this polymer rheological abrasive medium which comprises of multiple amounts of rheological additives, rheological polymers and abrasive particles and other things. That is why we took the help of rheology and we try to understand what it want to convey, what the complex composition has to convey.

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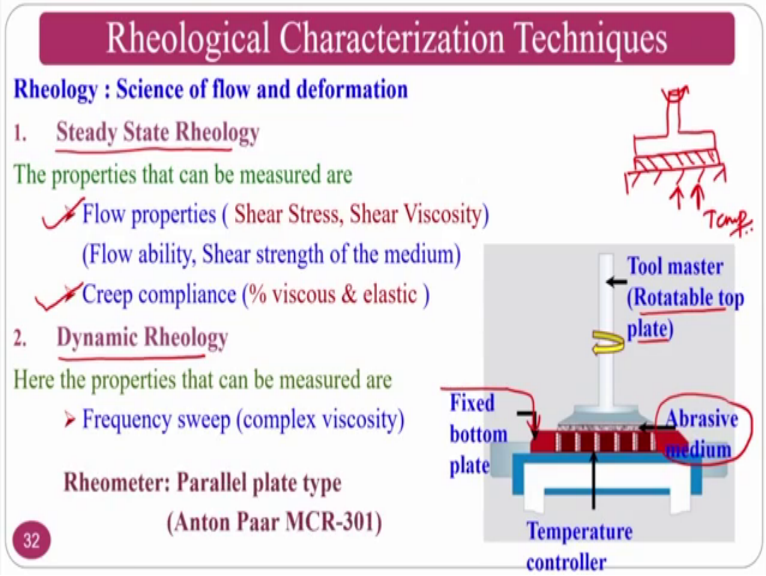

So, Rheological characterisation rheology is nothing but the science of flow and deformation two are done, one is a study state rheology where without time effect one is the flow properties, another one is a creep compliance properties and the dynamic properties or the dynamic rheology is also conducted. The schematic diagram if you see here this is the bottom fixed plate, and abrasive medium is here at the top tool master or the rotating plate.

You have a bottom plate which is fixed, you have the medium on top of it you have top rotating plate. So, the bottom plate is fixed and the top plate is movable that is what you can say, but the top plate you can give the temperature also. This is the schematic diagram. And we will see how we are going to do the original experiment. The used is parallel plate typed rheometer MCR-301.

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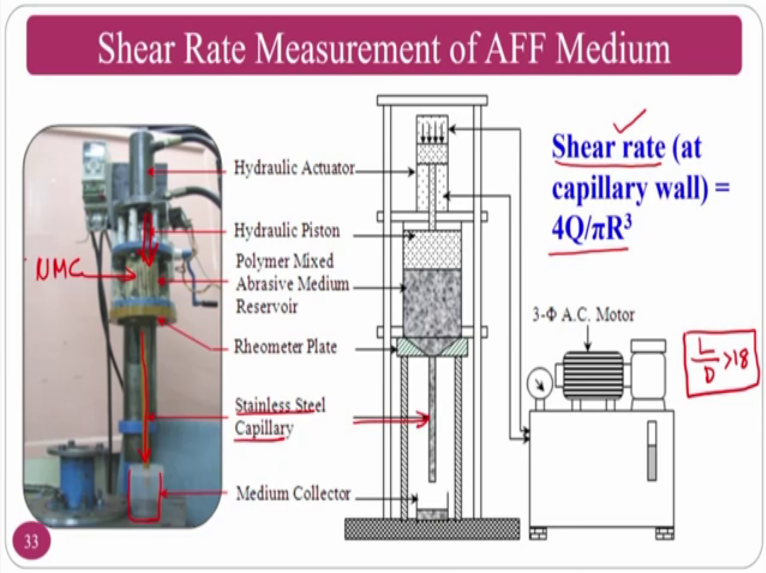

Before going to rheology one has to understand your natural system; that means that where you want to use this particular medium. I want to use this particular medium for abrasive flow finishing process. If at all I want to understand the abrasive flow finishing characteristics what I have to do is I have to take this medium there and I have to do some of experiments. What experiments that I have to do? That is another a big question.

Now, if at all I want to measure the shear stress upper end viscosity or another viscosities what I require is shear rate. How to calculate the shear rate? Whether I can give 1 shear rate or 100 shear rate or 1000 shear rate, how to determine? For that purpose you have to understand your system, for that purpose what the researchers has done is top medium cylinder this is the top medium cylinder or the upper medium cylinder you place the medium and upper hydraulic piston is there you just put a capillary rheometer.

This is called stainless steel capillary is there, schematic diagram also you can see on the other side. Normally, L by D ratio should be more than 18 for this one. So, L by D ratio stands for length to diameter ratio. Assume that if I am going to use 1 mm internal diameter then my length of my capillary should be more than 18 mm for example; I am just saying, ok.

So, now you apply different pressures. If you are going to apply different hydraulic pressures, your hydraulic piston is going to push the medium and it will come through the capillary and it will be collected here. You can take this plastic container weight, initial weight and final weight. So, now, you can understand how much material based on the rheological properties of the medium we are not touching the rheological properties we have given certain composition of the medium with certain extrusion pressure it is discharged some amount. I am increasing the pressure; I am changing the pressure in fact, so that the discharge will be different. If you know the discharge and the amount of time that came out and other thing you can easily calculate what is the discharge amount and other thing, from there you can calculate what is a shear rate.

How to calculate the shear rate? Shear rate at the capillary valve is 4 Q by pi R cube, where Q stands for discharge and R stands for the radius of the capillary. Then you can understand or you can calculate the shear rate. Once you know the shear rate because the shear rate values, you can input to your rheometer that you are going to see in the upcoming slide.

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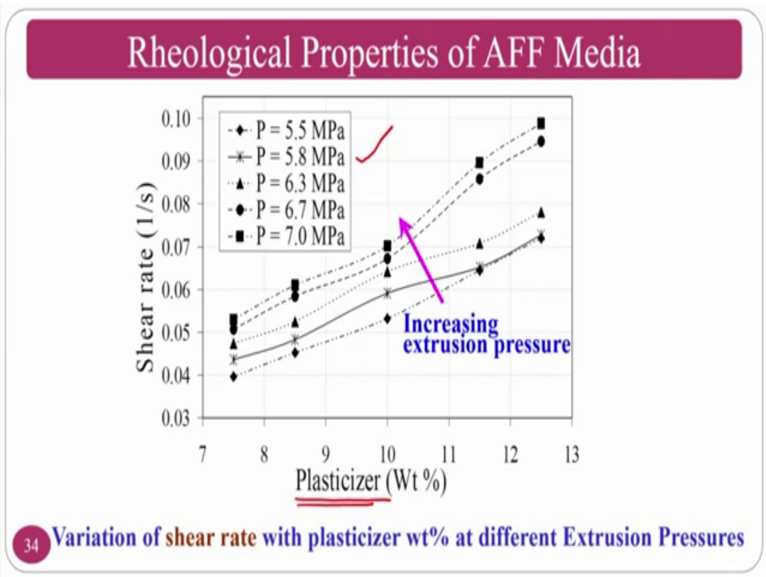

Once you are going to put the shear rate, if you want the understand the shear rate the plasticizer is there here and you are given extrusion pressures, and you are extruding using the capillary rheometer and you are getting the shear rates. These are the standard shear rates particularly for the abrasive finishing set up that we have used in a previous slides. Once I know the shear range because whenever I want to give this particular value you mine shear rate is one, ok. You have to give my shear rate between this to this you just measure the viscosity, shear viscosity, shear stress and other things.

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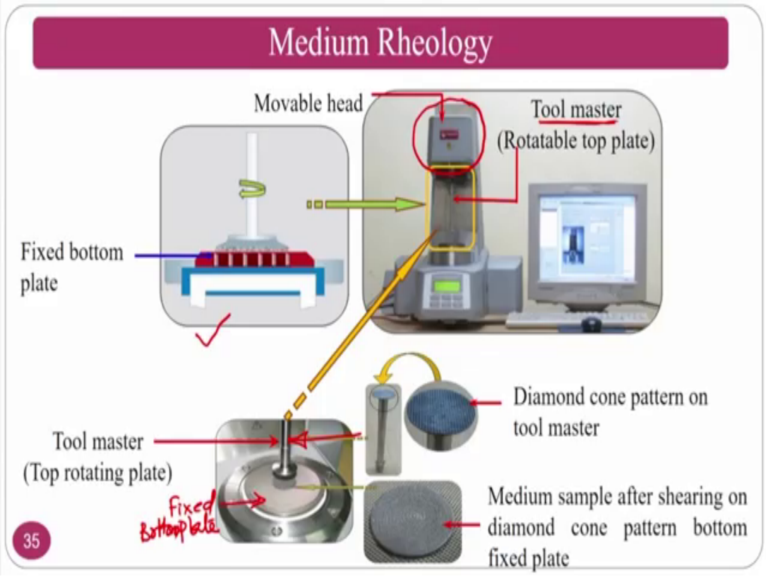

So, now I know the shear rates. Now, I am going to give to the rheometer. This is a shear rates which you have to measure the shear stress. The schematically this one you have seen already and if you see here this is the fixed plate, fixed bottom plate.

In fact, this is a top rotating plate in between you have a medium this is the medium, ok. This you are going to use for the measurement of rheology. You have a bottom plate, in between you have a medium and you have a top plate. Now, you are going to rotate the top plate, whenever you are going to rotate the top plate what will happen? The medium try to oppose, and this is also called as a tool master, top plate is also called as a connected to a tool master. This tool master is connected to a torque sensor on the top, the torque sensor will be there on the top portion and it will sense and it is connected to a close loop assume that it has to rotate 10 rpm because of the medium restriction it cannot rotate.

Assume that it can be able to rotate only 8 rpm then the torque sensor will give a feedback that I have to use more power and other things. So, that torque that is extra effort it is putting may be internally converting into the viscosity and shear stresses. That is completely the software that the machine do which we do not want to go into much details about the software another things.

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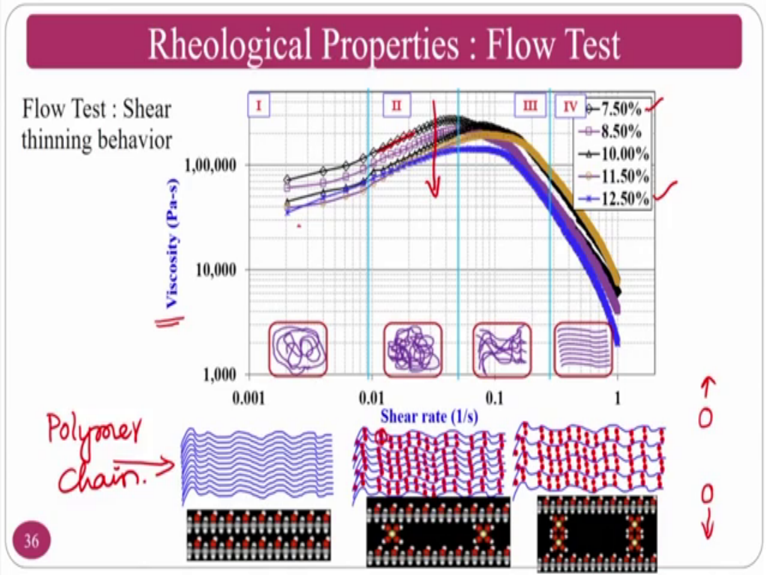

So, flow test, the first flow test will be normally done at the viscosity verses shear rate. Since the shear rates that whatever we want is already achieved from the experimental setup itself, we have done a capillary test and we have measured the shear rates for what is a plasticizer content that is a oil content and polymer content what with respect to abrasives and other things. The medium is there, what extrusion pressure and what plasticizer content, what is the discharge, from discharge 4 Q pi R cube is measured from there we have measured the shear rates.

Now, we know the shear rates we have given the experimental shear rates between 0.001 to 1 and we are measuring what is the viscosity. If you can see the initially if my shear rate is low; that means, that my tool master which is on the top of the medium is rotating slowly; that means, that they would not be much change in the polymer molecular chains. If you still increase the shear rate; that means, that rotation is increased further whenever you are increasing what is happening here is the curve, you can see all the curves follow the same trend and that is why I want to explain you stage by stage. Stage one, since rotation is slow and polymer molecular chains are at normal condition and the stage two as the polymer molecular chains are the normal stage.

Now, the shear rate is increased. Shear rate increased means your polymer molecular chains are going to claim one over each other. Whenever it is climb one over each other what will happen? The resistance to the tool master which is rotating will be more that is why your viscosity is more, but every chain or every person have their own strength levels beyond which if you still increase what will happen it will break. That is what happened in this stage 3. And then the stage 4 this broken polymer molecular chains are aligning along the direction this is what is observed in the basic static rheology.

First the shear rate is slow; that means, that rotation of the top plate is slow. So, there would not be much change, as you increase the shear rate, as you increase the rotational speed the chains are climbing each other and abstracting so the viscosity will go up. Then beyond which if you increase again the rotational speed what will happen, the chains will break and start aligning along the direction of rotation of the top plate. That is what happened in the all the curves because all the curves are following the similar trend.

Now, we will see what about the y axis. Means, how this will act across the curves vertically downwards. If you see here 7.5, 8.5, 10, 11.5 and 12.5, these are the plasticizers. If you have low plasticizer content, and if you have a high plasticizer content for example, it is for your understanding only. What will happen? What is a plasticizer? Plasticizer is a low molecular weight material, plasticizers are normally oils, polymers are high molecular weight materials.

If I am going to add the oils to the polymers what will happen? This oils go in between the polymer chains and kick apart. For example, these are the polymer chains, these chains are embedded with the low molecular weight plasticizers, this red dots in the second figure is polymer molecular. Chains are moved apart because of low molecular weight materials entrapping.

Then, if you go on adding a low molecular weight plasticizer what will happen? The distance between two polymer molecular chains go on increase; if it go on increase the cohesive strength of this polymer molecular chains go down. That means that viscosity will go down. That is what you can observe in the graph also 7.5 and 12.5. The 7.5 stands for the black one and the 12.5 stands for the blue one. So, normally the blue one is at the bottom because the polymer molecular chains are wide apart because of which its viscosity go down.