Advanced machining processes
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Lecture 31
Abrasive Flow Finishing
Rotational Abrasive Flow Finishing Processes

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Welcome to the course on advanced machining processes. Today I'm going to talk about abrasive flow finishing and traditional abrasive flow finishing processes, these are the nano finishing techniques which you will come to know in the following one hour talk and this has been prepared in association with Ph.D. scholar Mr. M Ravishankar.

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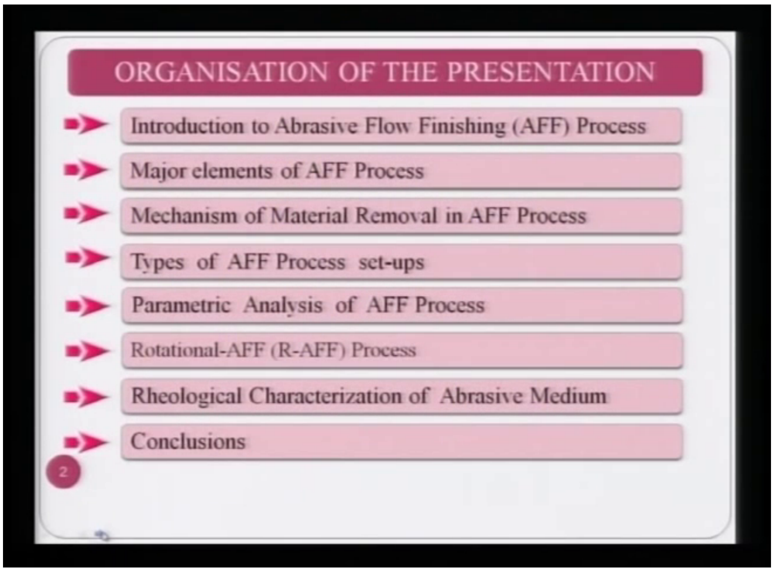

The organization of the talk is as follows, introduction to abrasive flow finishing process. Major elements of abrasive flow finishing process then mechanism of material removal in AFF process. Types of AFF process setups. Parametric analyses of AFF process. Rotational AFF process that is rotational abrasive flow finishing process then little bit I will talk about rheological characterization of the abrasive medium which is the main component of the abrasive flow finishing process and finally some conclusions about these 2 processes will be mentioned.

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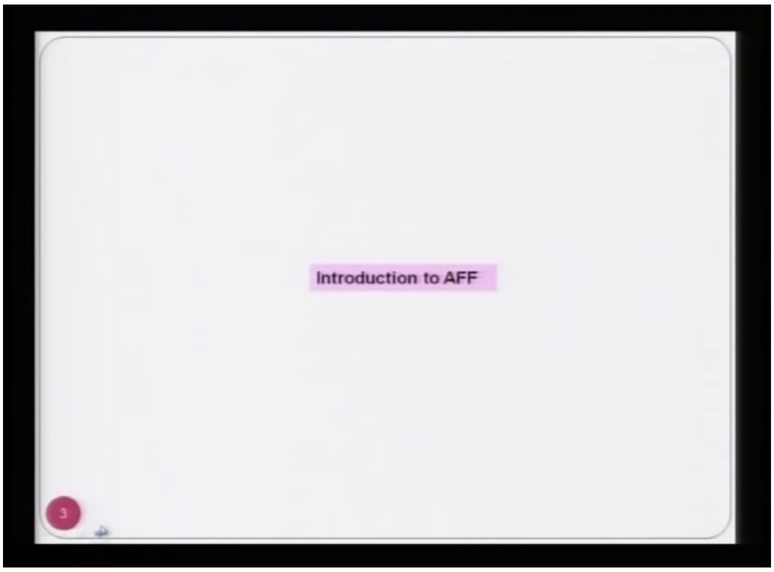

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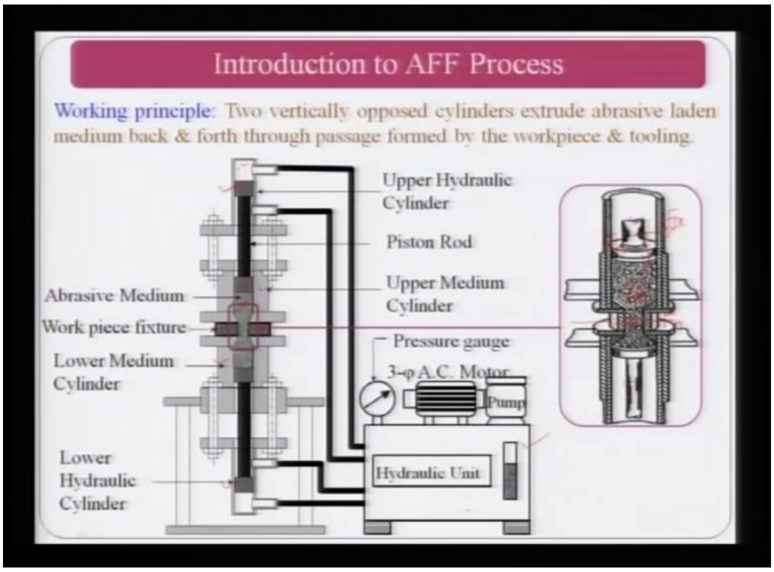

Let us see the introduction to abrasive flow finishing process. Now as long as working principle of abrasive flow finishing process is concerned they are vertically opposed cylinders they are extrude abrasive laden medium back and forth through passage formed by the work piece and tooling.

As you will see here there is the upper hydraulic cylinder and this is connected to the upper medium cylinder with the help of a piston rod or connecting rod and here is the medium as you can see abrasive medium and here is the work piece fixture and work piece is shown over here which is in contact with the medium then you have the lower medium cylinder and lower hydraulic cylinder.

Now what is happening really is that, the hydraulic the fluid that pushes this particular piston than this piston hydraulic piston is connected through a piston rod to the medium piston over here and here is the medium. So once this hydraulic this fluid pushes the hydraulic piston it pushes the medium piston and then in turn this piston pushes the medium that passes through the work piece surface and this medium consist of abrasive particles.

These abrasive particles remove the material from the work piece, there are 2 types of forces acting on this particular work piece Fn is the normal force that is responsible for the penetration of the abrasive articles into the work piece surface and there is a axial force Fa which is responsible for removal of the work piece material in the form of the microchip and you have the hydraulic unit which pushes the hydraulic piston and turn the medium up-and-down.

Now this clearly shows the enlarged view of the work piece medium over here, this is the medium piston upper and this is the medium piston lower and here is the medium and this is the work piece. Now this is the abrasive mixed medium and as I showed earlier that 2 forces are acting, one force is acting normal to the work piece surface that is Fn and another force is acting due to the motion of the medium up-and-down that is Fa and Fn is responsible for penetration, Fa is responsible for removal of the material in the form of the microchip.

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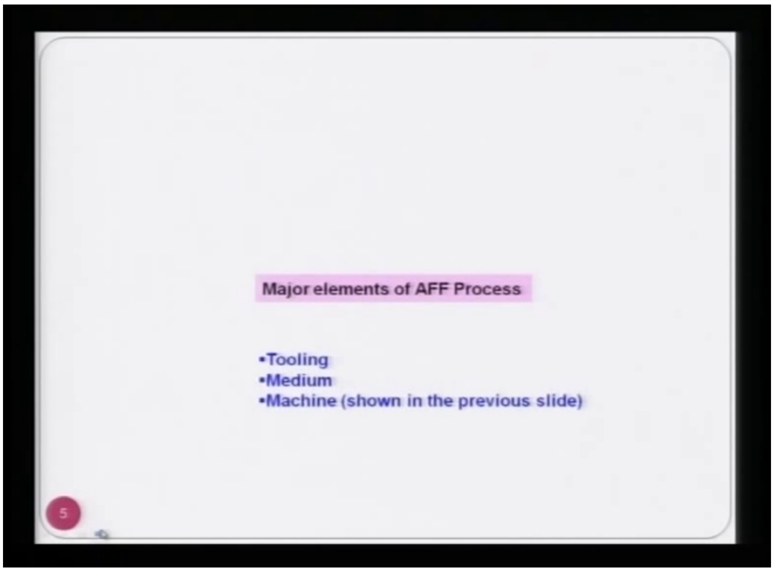

There are 3 major elements of the abrasive flow finishing process, one is the tooling another is the medium, third is the machine that I have shown to you in the just earlier slide.

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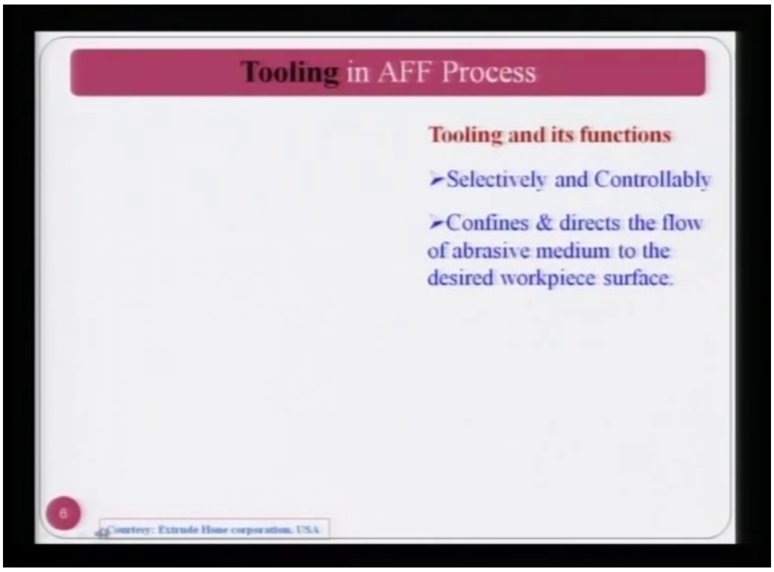

Tooling and its function are tooling makes it possible to remove the material or to finish the work piece selectively in the desired area and you can control it through the rheological properties of the medium but it does not have the facility to control the rheological properties of the medium online and tooling also confines and directs the flow of abrasive medium to the desired work piece surface area wherever you want finishing only there you can pass the medium with the help of the tooling rest of the area of the work piece need not be subjected for finishing according to the requirement of the product.

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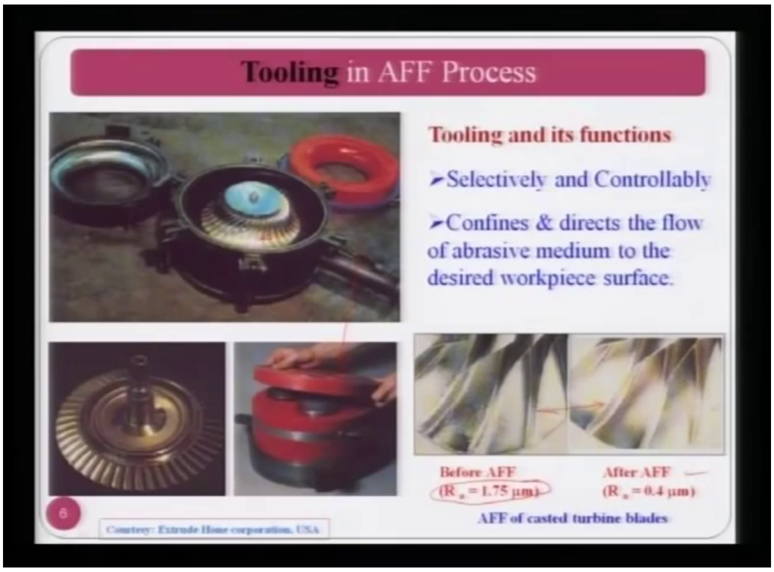

You can see here clearly here is the component which is to be finished there are so many blades of the component which are to be finished simultaneously and you can see this is being held by the container and these are the things which are to be kept up and this is the top one as you can see in this particular figure, how the tooling is arranged? This is the other component which can be finished by this kind of the arrangement and you can see this is the medium which is coming out from the tooling after finishing her completing half cycle then it will go again then complete the full cycle.

Now you can see here on the left side, the component various blades are shown over there and there Ra value is 1.75 micro-meter before abrasive flow finishing process and after abrasive flow finishing process is Ra value has come down to 0.4 micro-meter that is 400 nanometre you can clearly see the difference qualitatively in the unfinished and the finished blade of a casted turbine blades.

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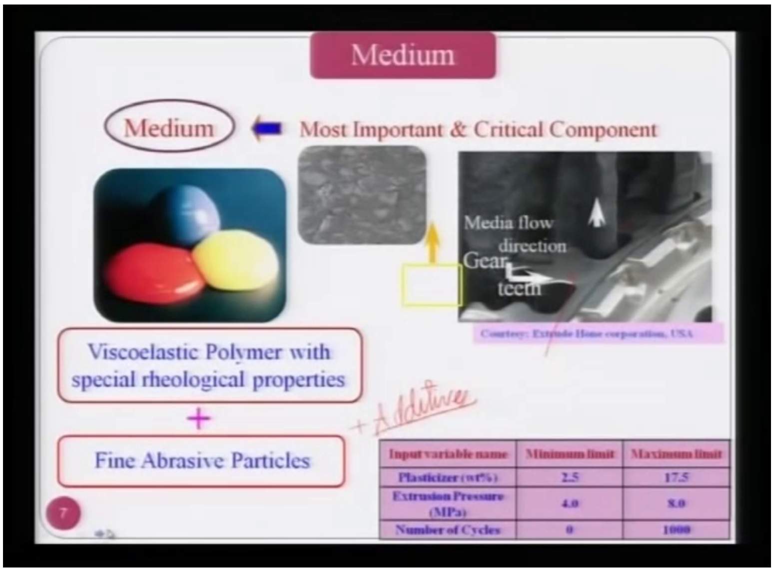

Medium is the most important element of the whole setup because it is responsible for finishing the component. Now please see it very carefully, here is a gear and this is the medium and this is medium coming down and going up and it is coming in contact with the area to be finished and all teeth of this particular gear can be finished in one go, you need not to finish individuals teeth separately which normally you do when you are finished doing it mechanically by hand or otherwise.

Now these are the medium you can have it in different colours and they have different rheological properties. Now this medium is mixed consisting of viscoelastic polymer with special rheological properties and it consist fine abrasive particles plus some additives, these additives also play important role which I will explain later on. Now here is just one composition of the medium which we had used in the lab at IIT Kanpur. Plasticiser varied weight percentage from point 2.5 to 17.5 percent, extrusion pressure in mega-Pascal vary from 4 to 8 and number of cycles of finishing upper limit was 1000 leaving aside the exceptional cases.

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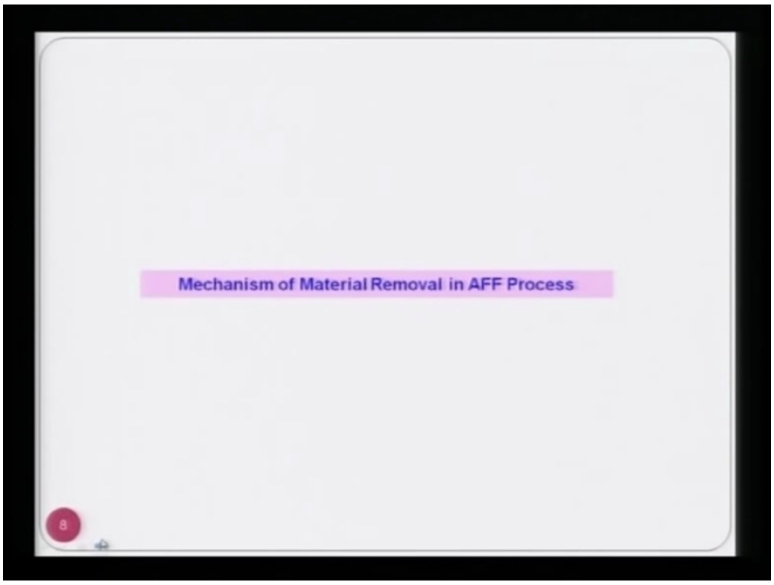

Now mechanism of material removal in abrasive flow finishing process. It is important to understand how the material is being removed during finishing operation? One thing we should keep in mind that when we are talking of finishing we are really not concerned in removal of bulk material or large amount of material or creating any feature, no. We are just interested in changing surface characteristic of the feature or the surface.

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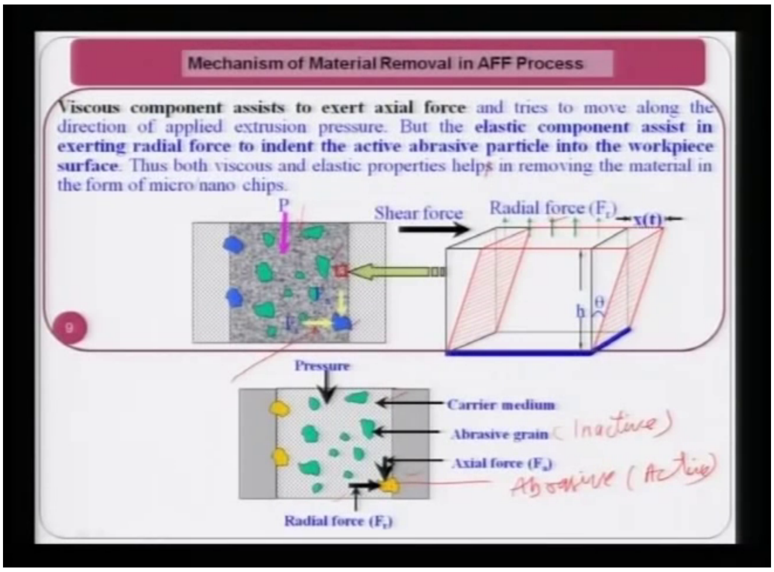

Now here just see viscous component assist to exert axial force and tries to move along the direction of applied extrusion pressure. Now you can see here this is the pressure being applied in this particular direction and as we have seen earlier in the second slide or so that medium is being pushed by the upper medium cylinder or lower medium cylinder, so this medium is being pushed downward.

Now here if you see clearly, here is the medium and there are the abrasive particles in blue colour and they are the active abrasive particles which are in contact with the work piece surface and green colour are the abrasive particles which are inactive they are not in contact with the work piece surface. Now what is happening let me read it and this axial force tries to move along the direction of applied extrusion pressure.

But the elastic component assists in exerting radial force to indent the active abrasive particle into the work piece surface. Now you can see here, here is the normal force Fr which says this is due to the elastic property of this particular rheological medium which is responsible for making the abrasive particles to penetrate inside the work piece surface and axial component of the force Fa is responsible for pushing this abrasive particle forward, so that the material is removed in the form of the microchip thus both viscous and elastic properties help in removing the material in the form of the micro-Nano chip.

Now this viscous property is helping in applying the axial force in the axial direction. Now the same thing is shown over here, if you see when you are applying the shear force and here is the radial force which is being shown by Fr and here is the axial force and due to this shear force, shearing is taking place and that you can evaluate shear rate with the help of the shear and with the help of the angle Theta and other details given in this particular figure.

Now this clearly shows the axial force Fa, radial force Fr which I have explained in the earlier figure, here is the carrier medium, this is the abrasive grain which is in active and here is the abrasive grain which is active because this grain is penetrating inside the work piece and removing the material in the form of microchips that is why it is known as active abrasive grain.

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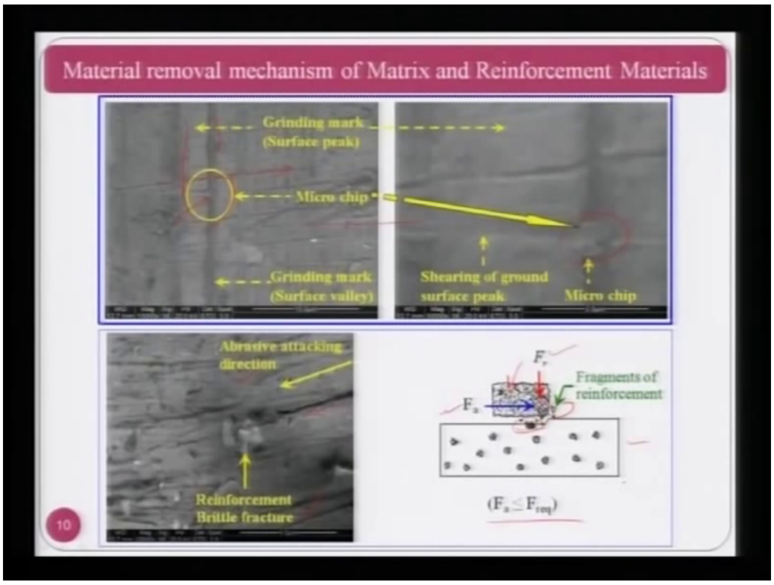

Now material removal mechanism of matrix and reinforcement material. A large amount of work has been done in the removal of the or finishing of the metal metrics composite, some of those results I'm going to show here in this particular talk, other results I have shown you earlier when I was talking to the introduction to the Nano finishing techniques.

Now the case of metal matrix composite finishing is slightly different from the normal alloy or pure metal or pure material finishing because here the reinforcement is having very different properties compared to the matrix material or base material that is why you will see here difference in the mechanics of material removal, you see here these are the marks of the grinding because these work pieces initially we have prepared by grinding and when finishing is being done, finishing is being done in the direction normal to the grinding lay.

Now you can see here in this particular part microchip is there which in large view is shown over here although not very clear but it is showing that how the material is being removed from this particular portion in the form of the microchip that is over there and here the shear in this particular direction is taking place. Now if you see to the next figure, bottom figure left side.

Now abrasive attacking direction if you see here this tunnel being formed over there and this is the direction in which abrasive particle of the medium is attacking the work piece surface. Now it comes in or it counters with the reinforcement and because there is a large force being applied by the medium in the abrasive particle, on the reinforcement so brittle fracture of the reinforcement takes place and part of the material from the reinforcement is removed and the same thing is shown here schematically that if you see here this is a fragment of the reinforcement and this is the reinforcement shown over here which has not fully removed and this is the medium which is consisting the abrasive particle and on this abrasive particle again radial force Fr is acting and axial force Fa is acting.

Now here this condition is very important, in this particular case or in any case for removal of the material axial force should be more than the required force, required force is nothing but the resistance being offered by the work piece material for the formation of removal of the material. Now if Fa is less then or less than the required force then what will happen either the abrasive particle will remain entangled in the work piece surface or it will rotate and decrease its depth of penetration and remove the material.

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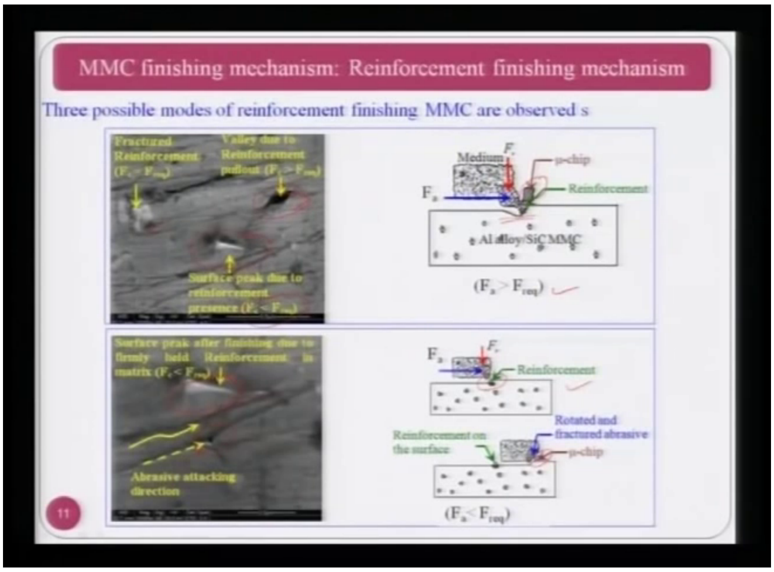

There are 3 possible modes of reinforcement finishing off metal matrix composite that are observed during finishing operation and the same are shown here with the help of the schematic diagram. You can see here that here Fa is greater than required force and you can see clearly that material is being removed in the form of the microchip shown over here, it's the same Fr and Fa forces are acting and reinforcement is also taken out.

This is the Alumina alloy silicon Carbide metal matrix is composite. In the second case the reinforcement remains intact with the work is surface because Fa require, axial force is smaller than the required force and you can see here this remains intact it is not able to remove the material and it may jump over the reinforcement without really removing it. In the third case as I have explained earlier that fracture of the reinforcement takes place as shown over there and part of it remains inside the work piece and part of it is taken out by the medium.

Similar things have been observed during experimentation which are shown on the left hand side in the pictures, I will show you here fractured reinforcement as you can see over here, here Valley due to the reinforcement pullout this is very important when the axial force is large enough and you're able to remove the reinforcement from the base material or matrix material then such kind of valleys are formed and they deteriorate the overall surface finish.

Now a surface (())(17:15) due to the reinforcement presence, in some cases as I have mentioned then when Fa is smaller than the required force than reinforcement remains in the matrix material and they give very high surface roughness value if surface finish is measured over this particular reinforcement. So this is another way here Fc or Fa is smaller than the required cutting force that’s why you have the reinforcement over there.

Now abrasive attacking direction is shown in the last figure over here and you can see somewhere some valleys are there where pullout of the abrasive particle, sorry reinforcement has taken place or depending upon what kind of obstruction, here if you see reinforcement is there, so the abrasive particles or medium has changed the direction of motion. So that is how really the material removal in metal matrix composite is taking place and it is quite complicated as compared to simple alloy or other materials.

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Now let me tell you different types of the abrasive flow finishing process setups. What I have shown earlier to you is the one type of the abrasive flow finishing setups but according to the requirement of the work piece shape and size you may have to have different types of the setups they are shown over here which are properly used.

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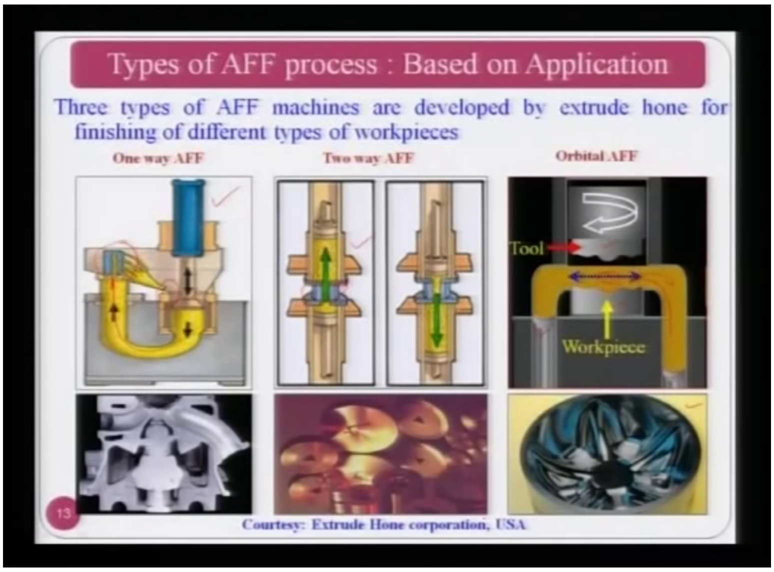

3 types of abrasive flow finishing machines are developed by exclude hone for finishing of different types of the work pieces. You can see shown over here this is why the courtesy of extrude hone USA. Now this is the one way abrasive flow finishing process, here is the component which has the blind cavities 5 cavities are shown over there. Now you can see yellow colour is the medium, this medium is being pushed through those 1, 2, 3, 4, 5 cavities and here is the system which is pushing the medium.

Now after this medium is pushed it will come out through those cavities and since the medium is coming out and the medium consist fine abrasive particles, these fine abrasive particles will come in contact with the work piece surface. So what I have shown in the earlier slides in the same way they will remove the material from or they will remove the or they will shear the piece of the work piece surface and surface finish will be reduced substantially.

Now after it comes out of the work piece surface it is being collected and re-circulated same way as shown by the arrows over here, these 2 ways abrasive flow finishing process I have already explained upper cylinder, lower cylinder and here is the medium and here is the work piece and medium is moving up and down with the help of the hydraulic unit. Hydraulic unit is being used here also in the one-way as well as two-way as well as orbital AFF. You have to use it for the moment of the medium.

Now in some cases you cannot use either one way or two-way AFF process and then they developed what is known as orbital abrasive flow finishing process this is interesting and simple, you can see this is the tooling which is just the replica of the work piece surface shown over here.

Now here is the medium and this is the piston 1, piston 2 this pushes the medium in both directions and when it is being pushed and the work piece is or this piston which is holding the tool is rotated then what happening this turbulence takes place in the medium and it removes the surface peaks from the work piece. As a result of that surface roughness value is improved or surface roughness value goes down and you have the metal surface finish. So you can see here the kind of the component that are finished by each type of the AFF setup, this is one way, this is for two-way because it is a through holes or through cavities over there and this is again the blind cavities which is using orbital abrasive flow finishing process.

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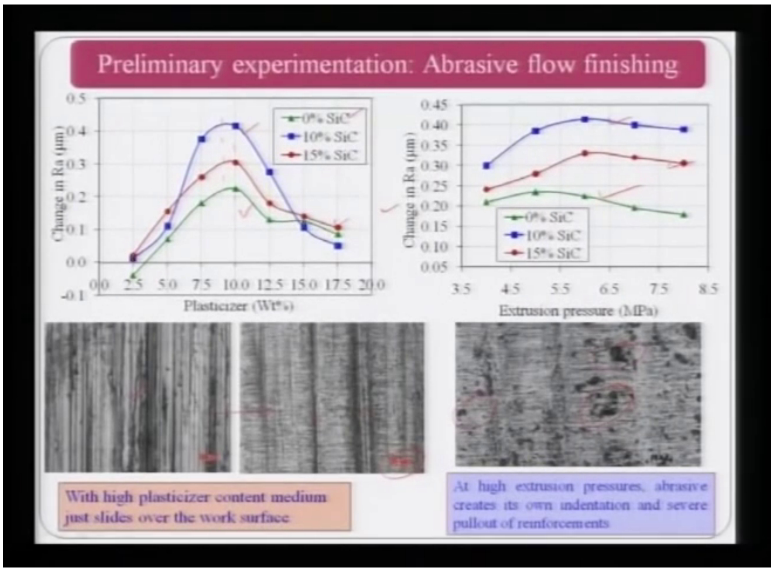

Let us see the parametric analyses of abrasive flow finishing processes, some experiments are conducted at IIT Kanpur and you can see here that with high plasticiser content medium just slides over the work piece surface this is the original surface obtained by grinding process and then after finishing for certain number of cycles you can clearly see the qualitative difference between the 2 surfaces and here is the scale that is shown over here which will give you, now you can see the distance between the 2 valleys as substantially increased that means finishing has taken place substantially while it is different in case of ground surface.

This same thing has been shown over here on the top picture that is the relationship between the plasticiser with percent contained and changes in Ra value that is initial Ra value minus final Ra value that gives you the change in Ra value. Now you can see that up to a certain percentage over of the plasticiser around 10 percent of plasticiser up to that particular point the surf change in Ra value is increasing and beyond that it is start decreasing.

And you can see here 0 percent silicon that means pure aluminium alloy is there, 10 percent this is the metal matrix composite with 10 percent silicon Carbide, in red colour is again metal matrix composite with 15 percent silicon Carbide. So there is optimum value of plasticiser beyond which or less then which if you use that it is not going to give you the best performance.

Then there is some effect of high extrusion pressure abrasive creates its own indentation hence severe pullout of reinforcement may take place. Now when you're using the extrusion which is very high then what can happen? That as we saw in the earlier slides also that the pullout of the abrasive sorry reinforcement may take place and a pullout takes then cavity is created on the finish surface and it may lead to the rejection. Similar kinds of the things can be seen over here which I have shown to you in a better way in the earlier slides.

Now here you can see that not much difference is that as long as extrusion pressure effect on the Ra value, a change in Ra value is concerned some effect is there now you can see this is the aluminium alloy with 0 percent silicon Carbide and this is the 10 percent silicon Carbide and this is the 15 percent silicon Carbide and you can see initially some improvement is there as long as change in Ra is concerned but then after that it more or less stabilises. So one can see that there is some effect of extrusion pressure but not substantial.

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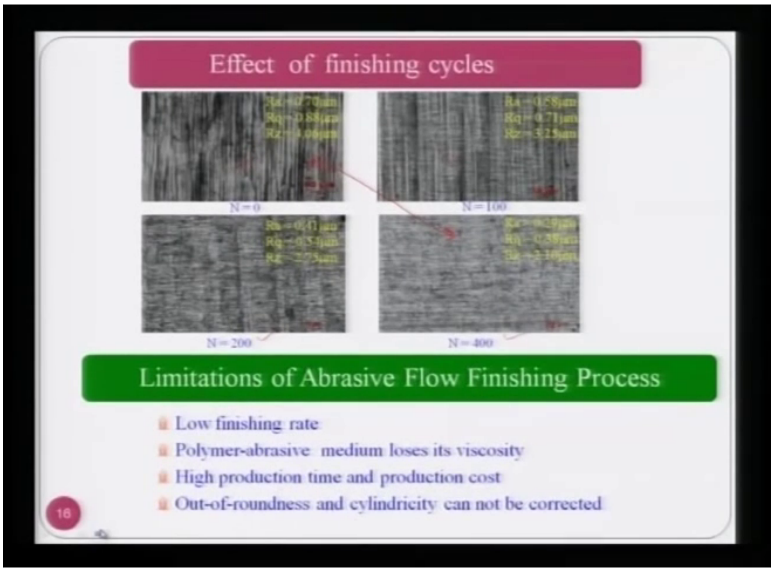

Effect of finishing cycles, now clearly shows the effect of finishing cycle over here, this is the initial surface after grinding then hundred cycles it was finished and you can see that from 0.70 micro-meter Ra value to 0.58 micro-meter surface finishes has been achieved. Now if you further continue then after 200 cycles you get 0.41 micro-meter as Ra value and after 400 cycles you get much better surface and as you can compare here with the these 2 initial and the final and surface roughness value goes down to 0.29 micro-meter.

So definitely there is an improvement as long as you keep engaging the finishing cycle but there is always a limit beyond which you cannot improve the surface finish and that value of surface finish is known as critical surface roughness values which are explained in some other lectures already.

Now there are certain limitations of abrasive flow finishing process. First thing is it has low finishing rate. Second is Polymer abrasive medium loses its viscosity, as you keep finishing the rheological properties of the medium keeps changing or rather deteriorating. So you after a certain period of its use you have to replace it by the fresh one and its high production time and cost of production cost of finishing is also high because medium which is supplied by earlier extruded hone now (())(26:20) metal is quite expensive. So a lot of research has gone into it at IIT Kanpur to develop new type of abrasive flow finishing medium and out of roundness and cylindricity cannot be corrected to a large extent.

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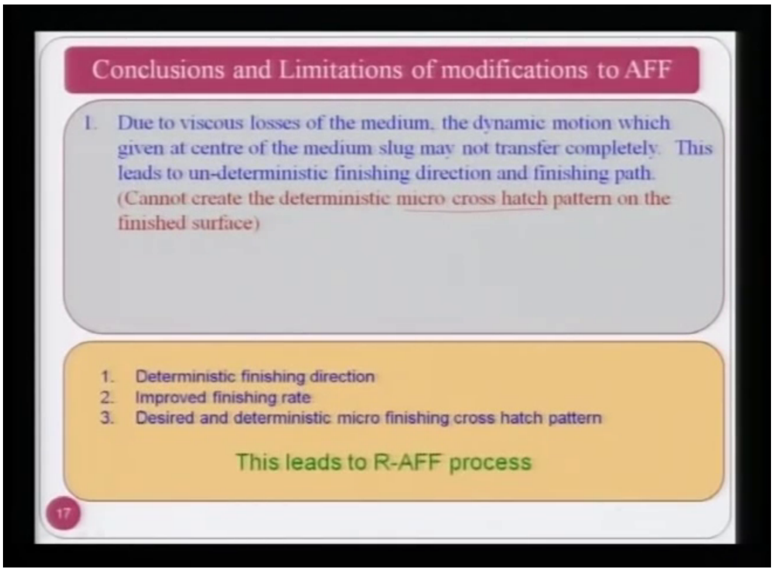

Conclusions and limitations of modifications to abrasive flow finishing. Due to viscous losses of the medium that is change in the viscosity the dynamic motion which given at centre of the medium slug may not transfer completely to the abrasive particles which are in contact with the work surface this leads to a deterministic finishing direction and finishing path. Cannot create the deterministic micro cross hatch pattern on the finish surface, this micro-crosshatch pattern is the main characteristic of the honing process which we normally get.

Deterministic finishing direction, improved finishing rate, desired and deterministic micro finishing hatch pattern these are some of the things which we are attempting to achieve and for this purpose and attempt was made at IIT Kanpur and that process was named as rotational abrasive flow finishing process.

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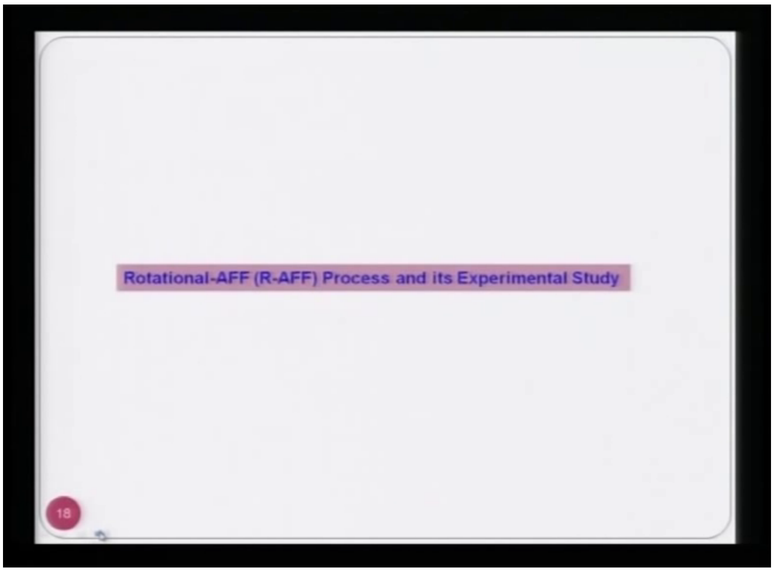

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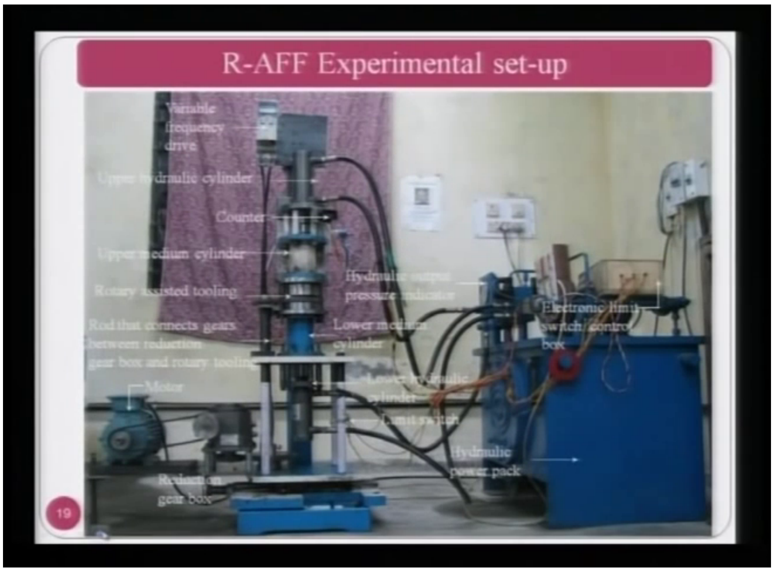

I will discuss this rotational abrasive flow finishing process and its some experimental study. Now this setup was very similar to what I had shown to you in the very first slide after content of this particular talk. Now the basic difference in this particular a that here you have a device over here, this device is capable to rotate the work piece internally and once the work piece is rotating then there will be 2 motions, one is the axial motion due to the medium piston, upper medium piston and lower medium piston and the same abrasive will also be rotating to do the rotating motion of the work because work piece is rotating, so there will be rotary motion of the abrasive particle with respect to the work piece and giving that particular rotary motion so many other arrangements are there which we will explain to you little later.

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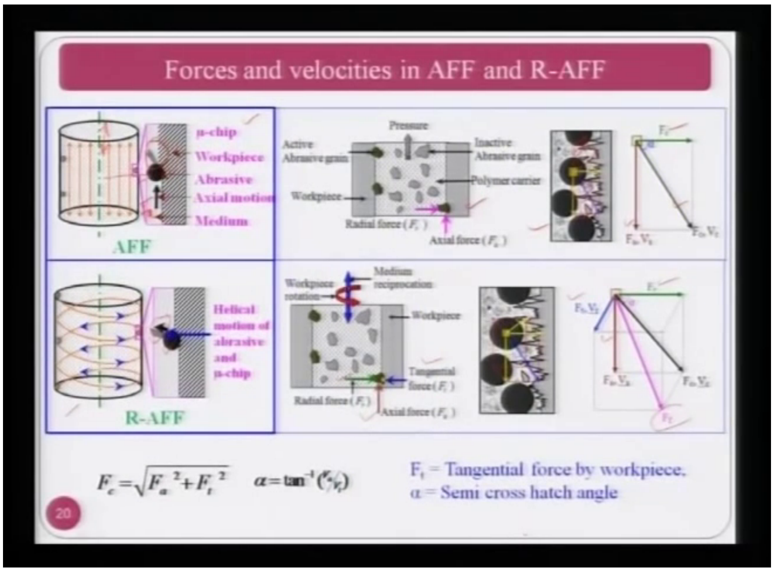

Now this tells you clearly the difference between abrasive flow finishing process and rotary abrasive flow finishing process, this we have already seen abrasive flow finishing process where medium is moving up and down due to the upper medium cylinder and lower medium cylinder and you can see here, here is the abrasive particle which is penetrating to do the radial force Fr and it removes the material in the form of microchip shown over here due to the axial force that is Fa and this is clearly shown over in this particular figure in the middle Fr is the radial force and Fa is the axial force.

Now how it is shearing the peaks that is shown over here in the last one figure and you can see smaller pieces that are removed in the form of the microchips by the abrasive particles and last figure on the right-hand side it shows radial force that is acting on the abrasive particles and axial force that is acting on the same abrasive particle and here is the cutting force our resultant force Fc over there.

Now, one can clearly see that since abrasive particles is moving to and fro the total length from which it is removing the piece of the work piece surface are in the straight line. If you want to improve the performance then definitely abrasive particles has to interact more in the single stroke and for that purpose what has been done in this, if you see the bottom figure the abrasive particle along with the axial motion is also having rotary motion.

As a result of that it gets helical motion, as shown over here in the figure as you can see this particle is moving in the helical motion throughout. As a result of that total length of the travel of an abrasive particle along the work piece surface increases substantially compared to abrasive flow finishing process. As a result of this it is shearing more number of piece from the work piece surface or you can say finishing rate is improving compared to abrasive flow finishing this is the gist of the whole of this rotary abrasive flow finishing process.

Abrasive particle and material is removed in the form of the microchip. Now in this particular case you can see here it is the radial force that is acting due to the elastic behaviour of the medium length there is a tangential component Ft which is due to the rotary motion of the work piece with respect to the abrasive particle or vice versa, axial force I have already explained.

So if you see here on the last figure there is the radial force acting over there, there is tangential force acting over the work piece surface and here is the axial force. So as a result of that you get the final finishing force which is the resultant of all these forces and we have found that the finishing rate has improved compared to abrasive flow finishing as well as the final surface roughness value has gone down compared to what one achieves in case of abrasive flow finishing process.

Now here also show cutting force is the resultant of Fa square plus Ft square and Ft is the tangential force by work piece and alpha is the semi-crosshatch pattern or semi-crosshatch angle, sorry.

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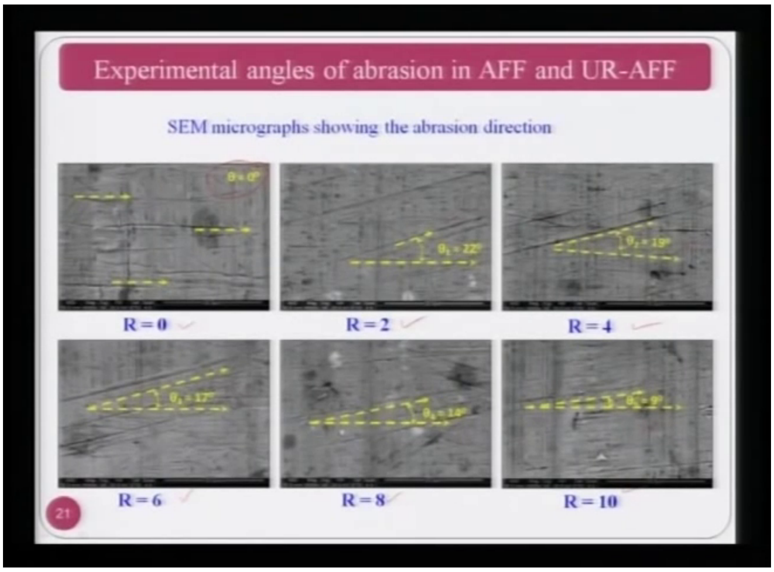

Experimental angles of abrasion in abrasive flow finishing and universal rotary abrasive flow finishing as a spinning electron microscope micrograph showing the abrasion direction. We have tried to take some of the pictorial views of the finish surface just to find out what is the angle at which abrasive is removing the material from the work piece in case of abrasive flow finishing process and rotary abrasive flow finishing process.

Now you can see here the material is being removed at 0 degree and that means it is very close to or really it is a abrasive flow finishing process while in this following figures Theta 1 is 20 degrees in the another case 19 degrees then 17 degrees, 14 degrees and 9 degree. Now as this angle is decreasing RPM of the work piece or the rotational speed of the work piece is increasing.

So you can see here initially it is 0 rpm, 2 rpm, 4 rpm, 6 rpm, 8 rpm and 10 rpm that means the crosshatch pattern angle is also changing as is very clearly visible from the photographs taken of the finished surface.

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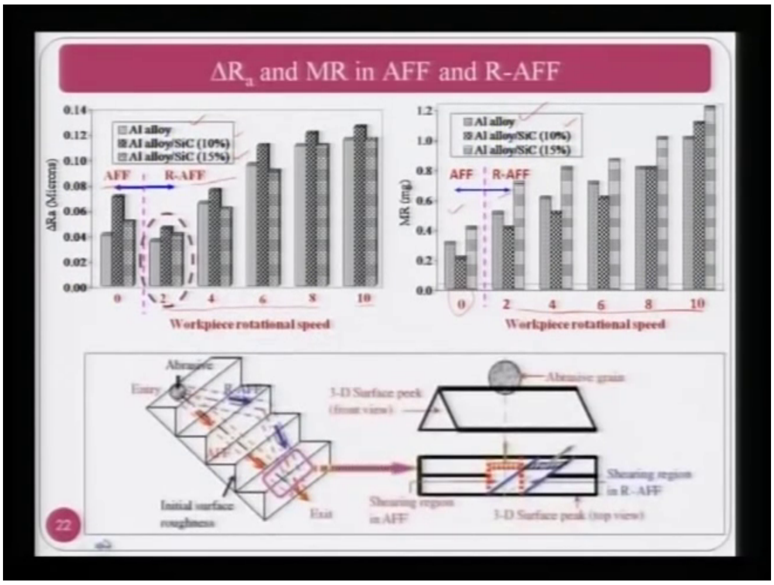

Now if you see here again the comparison of change in Ra value and material removal in case of abrasive flow finishing and rotary abrasive flow finishing, you just see here change in Ra value that is Delta Ra on the left side of this, this is in abrasive flow finishing, on the right side it is in rotary abrasive flow finishing. Now you can see as the rpm or rotational speed of the work piece is increasing, Delta Ra change in surface roughness value is continuously increasing in all the 3 cases of aluminium alloy, metal matrix composite with 10 percent silicon Carbide, metal matrix composite with 15 percent silicon Carbide.

So it clearly indicates that yes rotary motion given to the work piece is changing or improving the performance of finishing of the AFF setup and then it only it is known as RAFF. Now same thing is true for material removal in case of abrasive flow finishing process and rotary abrasive flow finishing process with different rpm. Now at 0 rpm that is AFF process the material removed in the given number of cycle is a small as compared to RAFF, as the rpm is increasing the material removed in all the 3 cases if aluminium alloy, aluminium alloy which silicon Carbide 10 percent, silicon Carbide 15 percent is all the 3 cases the material removed is increasing.

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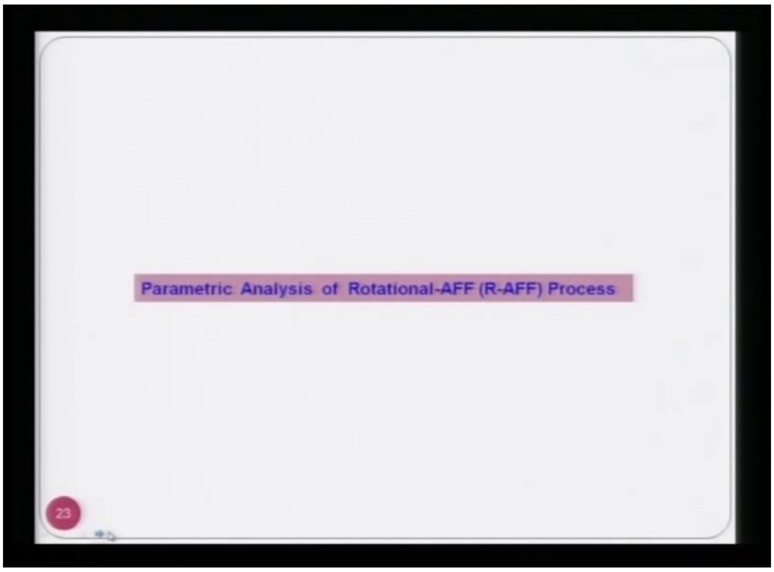

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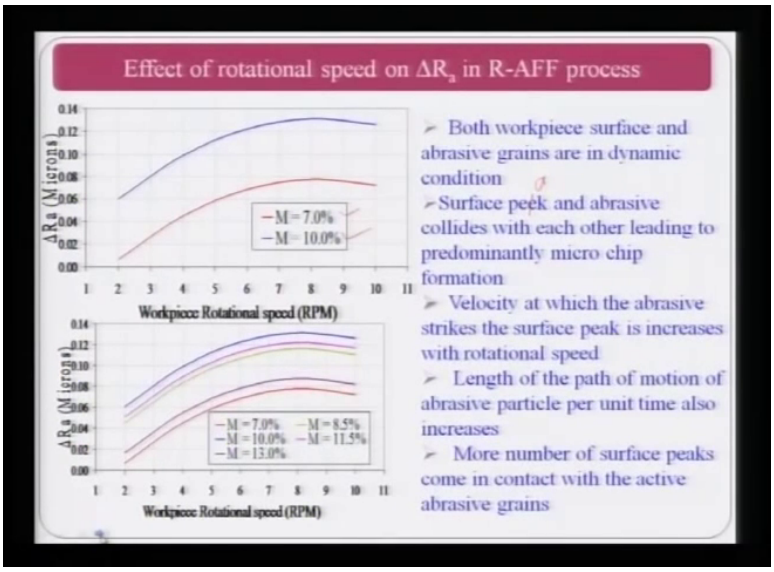

Parametric analyses of rotational abrasive flow finishing process. I will give you some results related to rotational abrasive flow finishing process. Let us see the effect of rotational speed on Delta Ra that is the change in Ra value in RAFF process. You can see here the (()) (35:57) work piece rotational speed rpm and on the ordinate you have Delta Ra that is the change in value in micro-meter and in true cases we have 7 percent plasticiser and 10 percent plasticiser, in both cases initially as RPM is increasing Delta Ra is increasing beyond a certain value of rpm it slightly starts decreasing or become more or less stable.

So there is an optimum RPM of the work piece act which you get maximum delta Ra value. Here again you can see for different cases that work piece speed is there then rotational speed is there. Here on the first graph if you see both work piece surface and abrasive grains are in dynamic condition. Surface Peak this is P E A K peak and abrasive collides with each other leading to the predominantly microchip.

Velocity at which the abrasive strikes the surface Peak increases with rotational speed definitely length of the path of motion of the abrasive particle per unit time also increases which I have shown to you that in place of axial motion there is the helical motion. More number of surface peaks comes in contact with the active abrasive grains in case of RAFF as compared to AFF.

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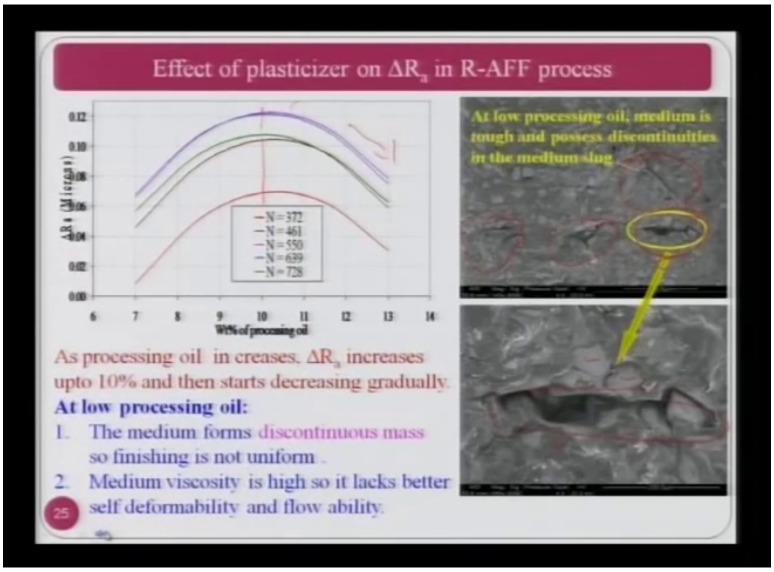

Now let us discuss the effect of plasticiser on change in surface roughness value that is delta Ra in rotary abrasive flow finishing process. As you will see here on the (())(37:48) weight percent of processing oil that is plasticiser is given and on the ordinate you have the change in Ra value in terms of the micron and again you will find that at a certain optimum value you are having the maximum change in delta Ra on either side of this it starts decreasing. So definitely for the given set of machining conditions and work piece surface you can choose this particular optimum value of (())(38:21) percent of processing oil.

At low processing oil medium stuff and processed discontinuities in the medium slug, as you can see here this is the picture of the medium and these are the discontinuities at the low percent oil and they do not give enough strength to the medium. This is the enlarged view of the discontinuity of the medium. Here are the abrasive particles, this is the base medium that is the Polymer and in between you can see these kinds of the discontinuities are obtained and they are not good for the performance of the medium.

As processing oil increases delta Ra increases up to 10 percent and then start decreasing as I have already explained that 10 percent beyond 10 percent it starts decreasing. And at low processing oil the medium forms discontinues mass as shown over on the right-hand side, so finishing is not uniform. Medium viscosity is high, so it lacks better self deformability and flow ability.

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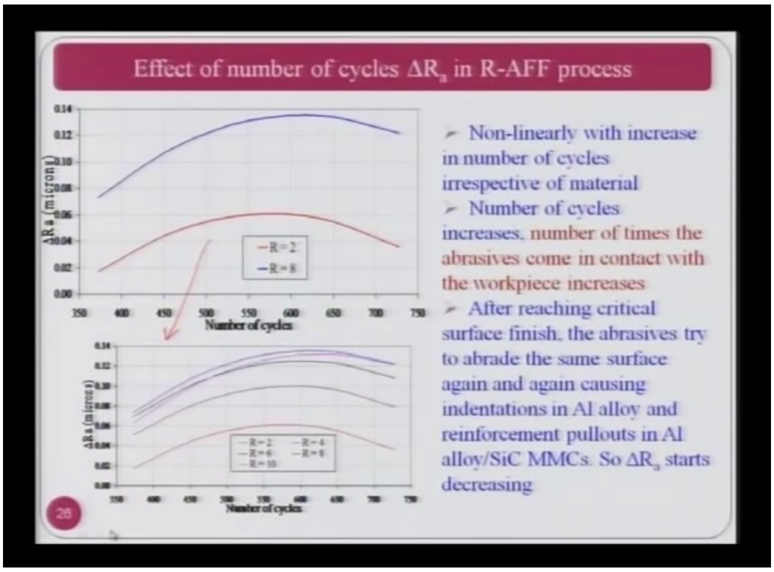

Effect of number of cycles as you see here as number of cycles is increasing again the delta Ra keeps increasing but it attains the maximum value and beyond which this starts decreasing, so definitely we should select the optimum number of cycles where you get maximum value of Delta Ra and it comes out around 600 number of cycles. Now you can see here that it is the case of rotary AFF abrasive flow finishing and you can see large number of RPMs are given over here 2, 4, 6, 8, 10 and similar behaviour is seen in those particular in all the cases also other than the 2 and the 8,

This is the same as this except that here more number of rpm results is shown over there. So you find nonlinearity with increasing number of cycles irrespective of material that you are using. Number of cycle’s increases, number of times the abrasives come in contact with the work piece increases therefore you get higher value of delta Ra. After reaching critical surface finish the abrasives try to abrade the same surface again and again causing indentation in aluminium alloy and reinforcement pullouts in aluminium alloy, silicon Carbide material matrix composite. So delta Ra starts decreasing as you can clearly see in both these figures.

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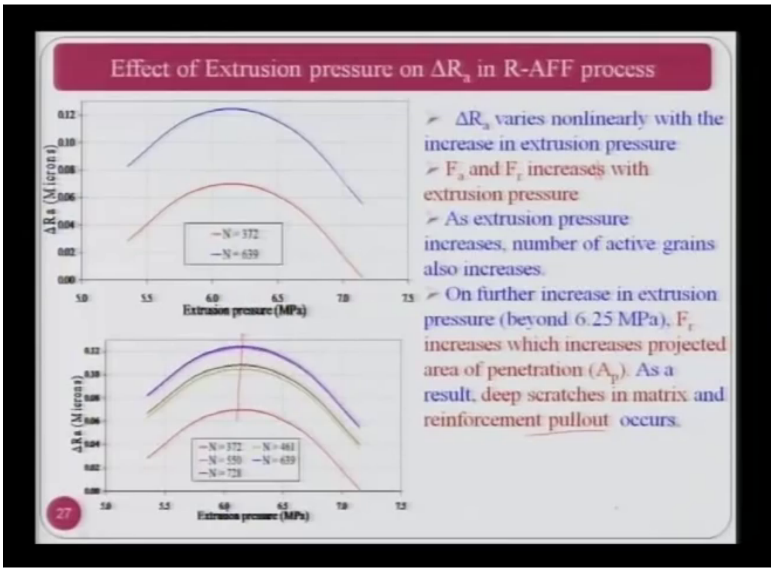

Effect of extrusion pressure, you can see delta Ra again is affected by the extrusion pressure and again there is the optimum value of extrusion pressure beyond which if it increase then it starts decreasing and the reason I have explained earlier also that deep indentation leads to the lower improvement in surface finish and sometimes it may lead to even deterioration of the surface finish, a very high extrusion pressure is used.

Now here you can see the number of cycles these are the 320, 372, 461, 550, 639 728 and in all cases you will find that they are attaining a certain value which is giving you maximum or optimum delta Ra value, so we should use that particular extrusion pressure which is giving the maximum value of delta Ra for the given set up and finishing conditions. Definitely it will be different for different work piece material also and this number will be different for different setups also under certain conditions and what are the finishing conditions? What is a medium? That also will change the optimum value to some extent.

Delta Ra varies nonlinearly with the increase in the extrusion pressure as is cleared from both the figures, Fa and Fr increase with extrusion pressure and as extrusion pressure increases number of active grains also increases and that simply means finishing rate will also increase. On further increase in extrusion pressure that is beyond 6.25 mega-Pascal, Fr increases which increases a projected area of penetration Ap. As a result deep scratches in matrix and reinforcement pullout occur and as I have already mentioned that if deep scratches are there or pullout is there then delta Ra is going to decrease.

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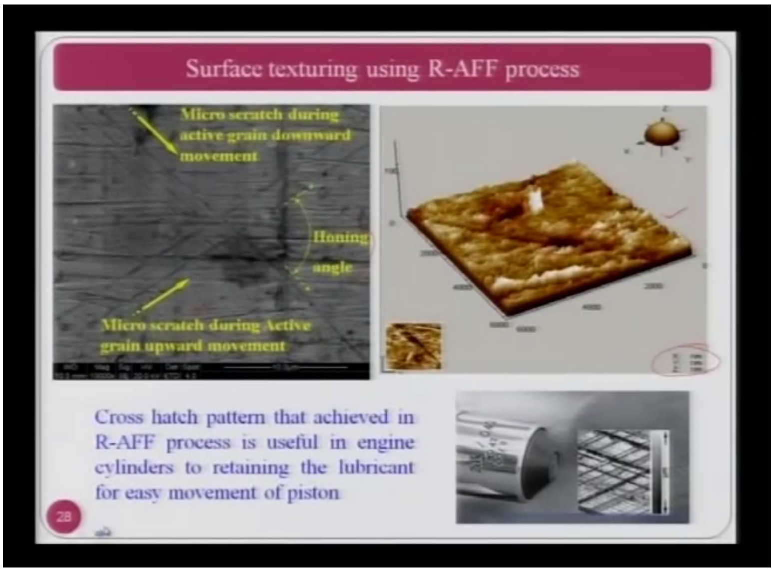

Now surface texturing using RAFF process, this clearly indicates surface texturing using RAFF process Micro scratch during active grain downward motion is in this particular direction and Micro scratch during active grain upward motion is given over there and you can see here the angle of the crosshatch pattern is also given a honing angle. Now this is an interesting picture you can clearly see the kind of the surface finish you can obtain and all these numbers are given in nanometres not in micro-meters, so very fine surface is obtained after RAFF.

However this surface still have some problematic areas as you can see here which I have in circle where slightly deeper scratches are there by the abrasive particles and they may not be very good for the performance of the final product. Now those kinds of scratches are shown over here also. So crosshatch pattern that is achieved in RAFF process is useful in engine cylinders for retaining the lubricant for easy movement of the piston because in certain applications we want that the lubricant should be retained at the interface of the 2 moving bodies say a piston and cylinder.

In those cases a piston and cylinder they are finished by RAFF process because RAFF process can be used for finishing internal as well as external surfaces if they are finished by such kind of the processes then they will be able to retain the lubricant and that lubricant will reduce the friction during the operation and that is a good feature of any finished piston and cylinder.

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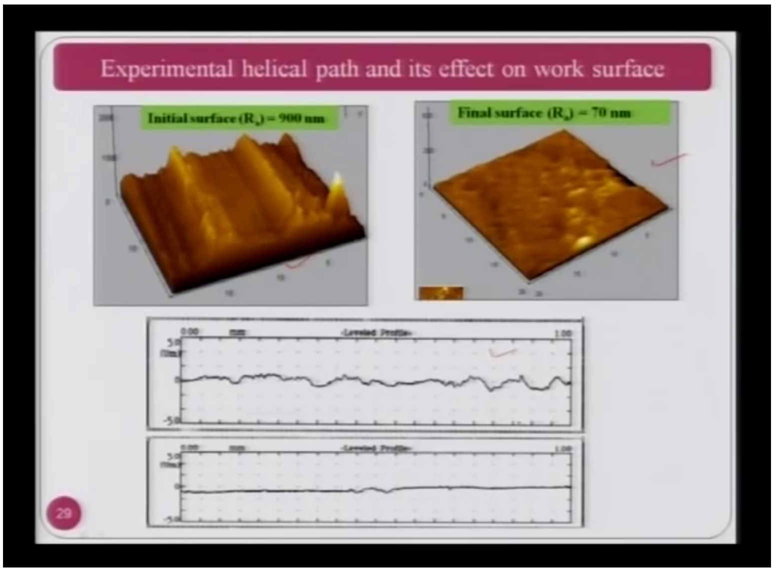

Experimental helical path and its effect on work piece surface. Now you can see here this is the initial surface roughness that is 900 nanometre on the ground surface and after finishing with RAFF one is able to obtain 70 nanometre and you can clearly see the difference in the surface texture and surface quality after RAFF. Now these are the self analyser plots this is for first one that is without finishing and this is for the finished part and you can clearly see the qualitative difference as well as quantitative difference in 2 surfaces.

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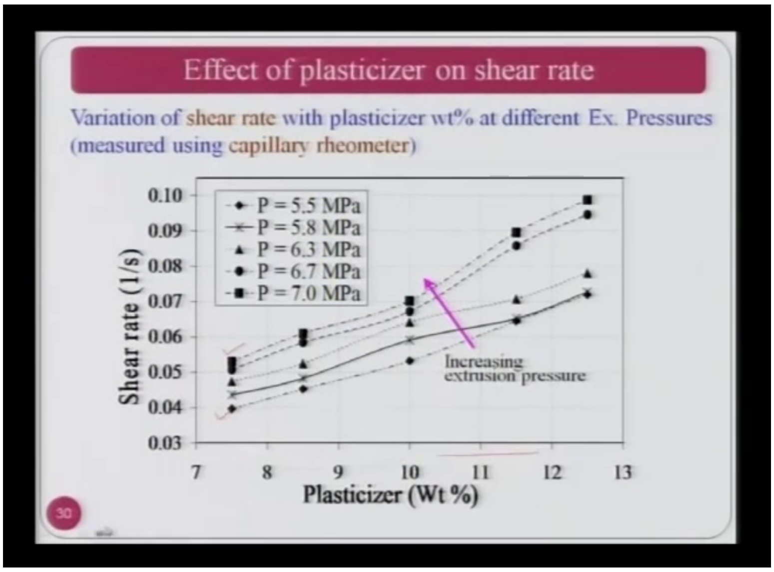

Now effect of plasticiser on shear rate, variation of shear rate with plasticiser weight percent at different experimental pressures measured using capillary Rheometer. You can clearly see that as weight percent of the plasticiser is increasing shear rate is increasing and this is the arrow indicates the increasing extrusion pressure. So you can see that as plasticiser content increases shear rate is increasing, it is easy to flow hence shear rate is increasing and as pressure is increasing the nature of the relationship between plasticiser and shear rate remains the same except that shear rate is higher for higher pressure and lower for lower extrusion pressure. As you can see this is for 5.5 mega-Pascal and top one curve is for 7 mega-Pascal.

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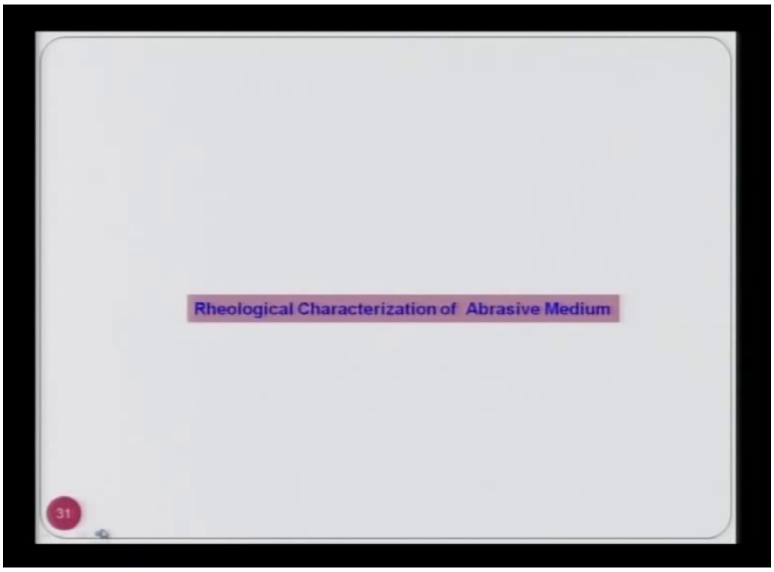

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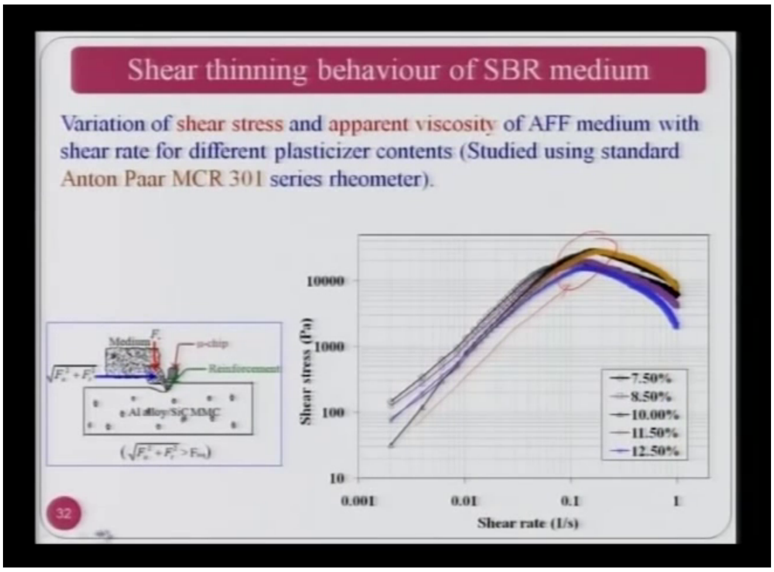

Rheological characterization of the abrasive medium. Shear thinning, this is a very interesting feature, here I will show you that variation of shear stress and apparent viscosity of abrasive flow finishing medium with shear rate for different plasticiser contents they were studied using standard and Anton paar MCR 301 series rheometer at IIT Kanpur and you can see here that very interesting phenomena that as shear rate is increasing, shear stress of the medium or the capability or the shear strength of the medium is increasing.

But when shear rate increases up to a certain value that is shown over here then it's shear stress or shear capability of the medium starts decreasing and this phenomena when it starts decreasing is known as shear thinning phenomena and this is really able to explain many of the results which have not been explained so far as long as abrasive flow finishing or rotary abrasive flow finishing process is concerned and from that point of view this curve is very interesting.

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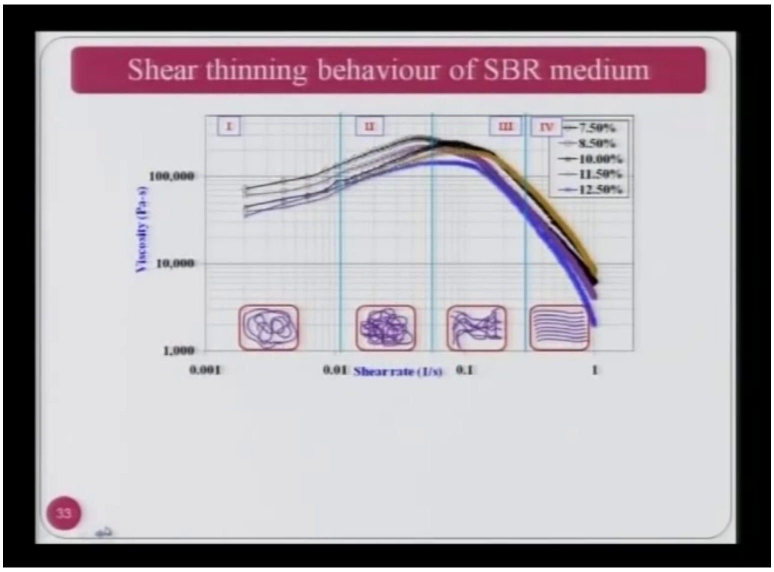

Shear thinning behaviour of SBR medium was evaluated as I showed to you in the earlier figure. Now here is the shear rate, now as shear rate is increasing, viscosity of the medium is slightly increasing, not slightly to a large extent it is increasing because it is all on the logarithmic scale, both x axis as well as y axis are on the logarithmic scale and you can see that the increase of the shear rate increases the viscosity but beyond a certain value of the shear rate it starts decreasing that means shear thinning behaviour starts taking place in this particular region and this is able to explain many experimental results obtained in case of abrasive flow finishing as well as rotary abrasive flow finishing.

Now really what is happening in the polymer that is shown over here, you can see the chains are there, Polymer chains are entangling over there and once this high shear rate starts further increasing then they start breaking and shear thinning takes place, so these figures are also interesting and important to explain the shear thinning behaviour, this is the further one which shows the various behaviour of the SBR medium at different shear rates.

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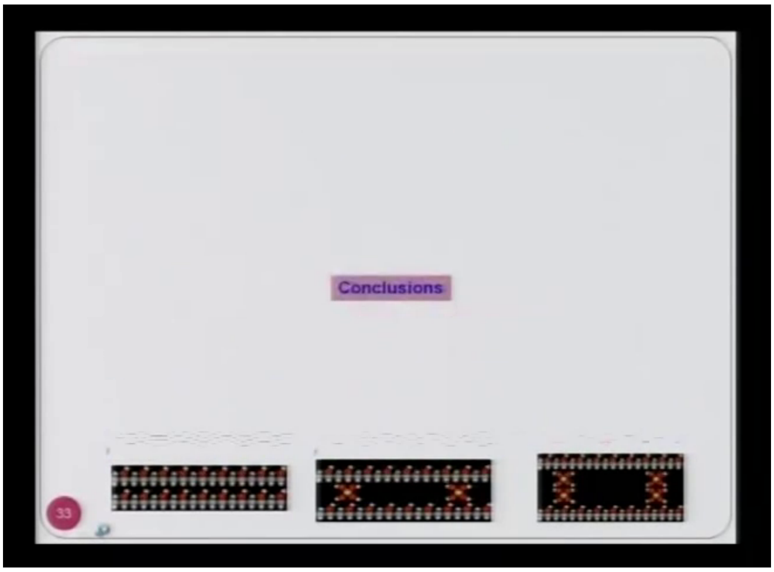

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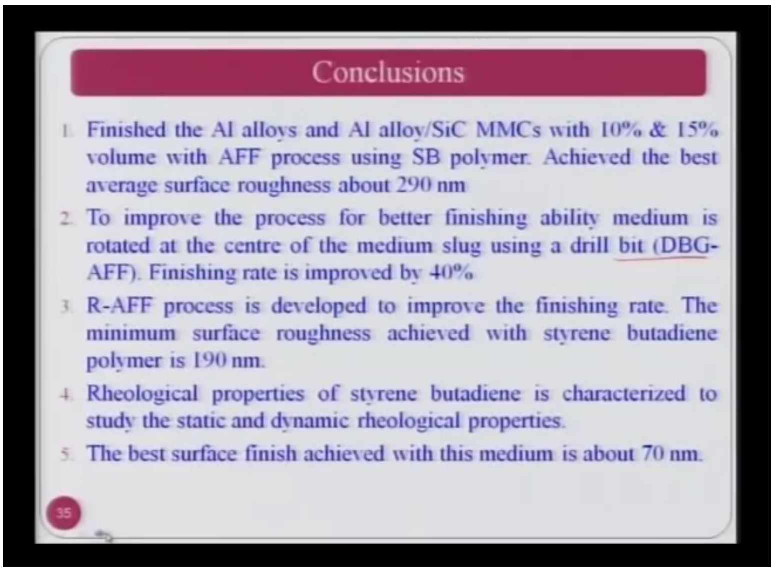

Conclusions, finished aluminium alloys and aluminium alloy silicon Carbide metal matrix composite with 10 percent and 15 percent volume with AFF process using SB polymer the results have been presented in this particular talk and achieve the best average surface roughness value as 290 nanometre because is very important to note that to achieve a very low surface roughness value in case of metal matrix composite is very difficult because this abrasive reinforcement they are either projecting outside or they are due to the pullout they are creating the valleys.

So really what you can obtain? A very good surface finish in case of alloys, for other materials you cannot achieve similar kind of the surface roughness value in case of composites especially metal matrix composites. To improve the process for better finishing ability medium is rotated at the centre of the medium slug using a drill bit DBG- AFF which I have not explained but this is one of the techniques which were used to improve the performance of the abrasive flow finishing process at IIT Kanpur and finishing great improved by about 40 percent.

In case of rotary abrasive flow finishing process is developed to improve finishing rate further the minimum surface roughness value achieved with styrene butadiene polymerase 190 nanometre that is 0.190 micro-meters. Now this is the final surface roughness value that you’re going to get will depend upon many parameter that I have already explained. Rheological properties of styrene butadiene are characterized to study the static and dynamic rheological properties. The best surface finish achieved with this medium is 70 nanometres that is 0.07 micron.

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Thank you very much, now Mr. Ravishankar Ph.D. scholar of mechanical engineering Department IIT Kanpur is taking you to the manufacturing science lab of mechanical engineering Department and he will explain you the abrasive flow finishing setup, rotary abrasive flow finishing setup and some of the results and all details of the set up, thank you very much.

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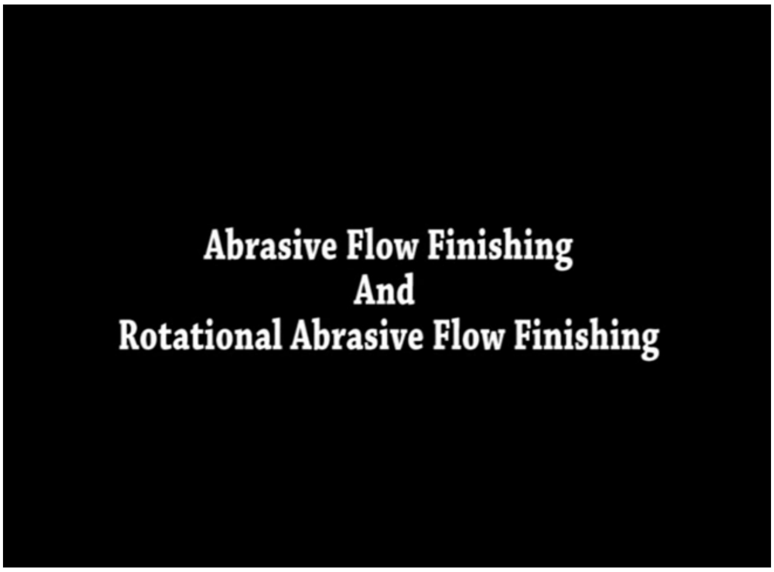

I am Mamile Ravi Shankar working under Professor Vijay Kumar Jain and Professor J Ramkumar, I'm doing my Ph.D. program in the Department of mechanical engineering IIT Kanpur. Now I'm going to explain you about the abrasive flow finishing process. This abrasive flow finishing was invented in 1950s by extrude hone company in US at the time this process is used majorly further deburring process.

This process at the time because of machining process it is called as abrasive flow machining process. Nowadays the same machine we are using for the finishing process even we are also using for the Nano finishing process thus this process is renamed as abrasive flow finishing process.

In the present the experimental setup you can see the abrasive flow finishing process and universal abrasive flow finishing process and rotational abrasive flow finishing process, these are the advanced versions of the existing abrasive flow machining process that is developed by extrude hone.

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You are seeing here is the advanced version of abrasive flow finishing process. Basically abrasive flow finishing process has 3 elements. One is machine, second is tooling another one is medium. So coming to the abrasive flow machine it is a double acting abrasive flow finishing process you have an upper hydraulic cylinder and lower hydraulic cylinder and lower medium cylinder and upper medium cylinder and these 2 hydraulics top and bottom hydraulics are controlled by a hydraulic power pack.

This is a hydraulic power pack and where you can set the extrusion pressure. Here you can see the extrusion pressure; you can go maximum extrusion pressure about 140 bar that means 14 mega-Pascal. This is apparent medium cylinder and this is lower medium cylinder we place the medium in the lower medium cylinder and we try to reciprocate. Now you will see how the machine will reciprocate.

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Now you can see the piston movement, this piston movement is given by the hydraulic power pack and this bottom stroke and top stroke is controlled by an electronic controlling box, this is an electronic controlling box which controls the electronics of the limit switches. Now you can see the reciprocation motion of the piston, this is the piston and this is the cylinder wherein we place the medium. Now you can see the medium motion, we have given a small reciprocation motion by controlling the limit switches to demonstrate, how the medium reciprocates top and bottom?

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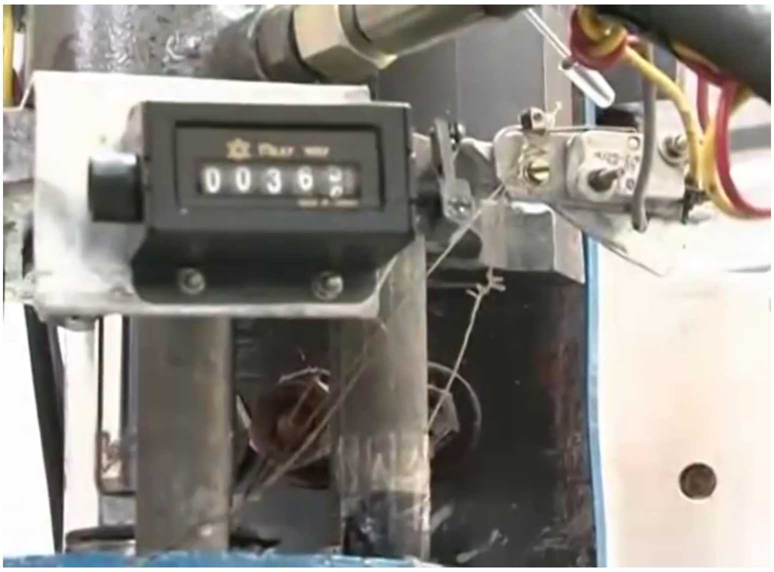

This is the limit switch that controls the stroke length of the piston, this limits which is controlled by a polymeric wire to the piston, this is the piston and this stroke is controlled by the limit switch and for every complete up and down stroke you can see the variation in the mechanical counter, this will count the number of cycles of 1 abrasive flow finishing process.

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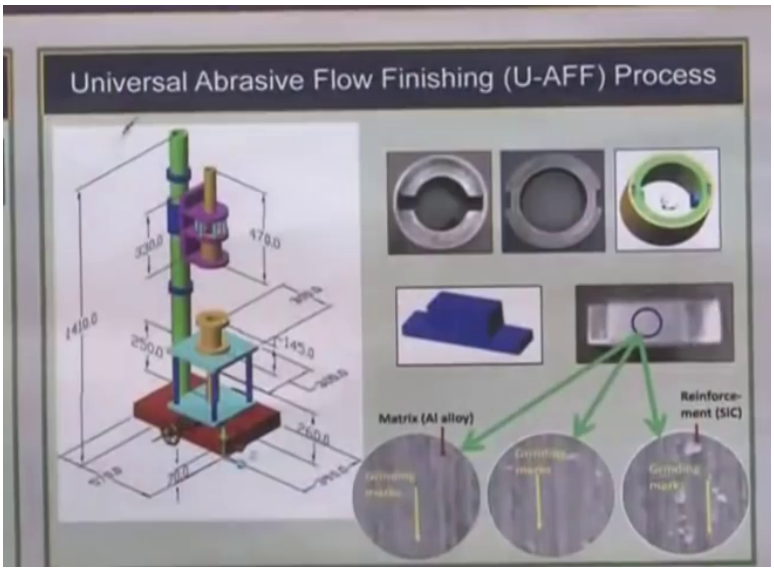

The machine which you saw is an advanced version of the abrasive flow finishing process. The schematic three-dimensional view of that machine is this one and this is called as universal abrasive flow finishing process, this has various motions in the x direction, y direction and z direction.

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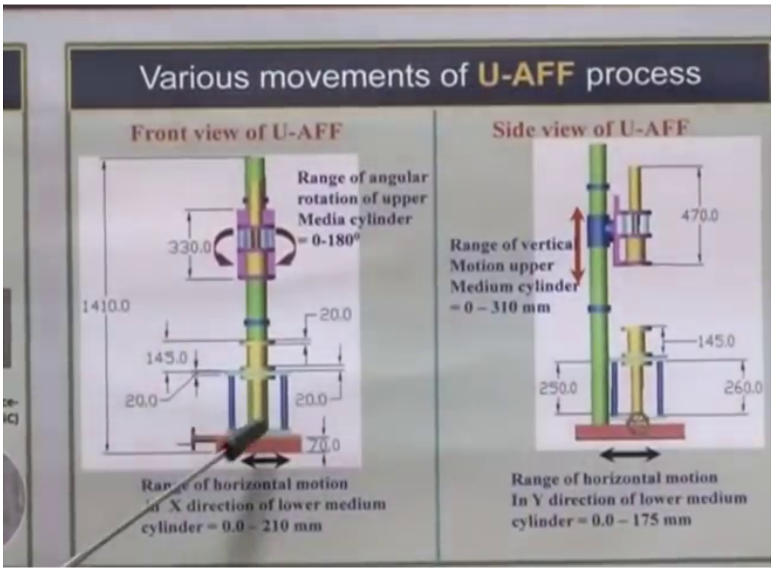

Now you can see it has x direction from 0 to 210 MM. You can move the bottom hydraulics cylinder in the x axis up to 210 millimetres and you have a rotational motion of the top cylinder, hydraulic and medium cylinder about 0 to 180 degrees at the same time you can have a top to bottom motion that is the vertical motion about a maximum of 310mm and you have y direction that is perpendicular to the x axis about 175 meters.

These all motions are incorporated in the existing abrasive flow finishing process in order to make the machine as a universal abrasive flow finishing process. This process has ability to finish complex surfaces and this is the advantage compared to the existing abrasive flow finishing processes.

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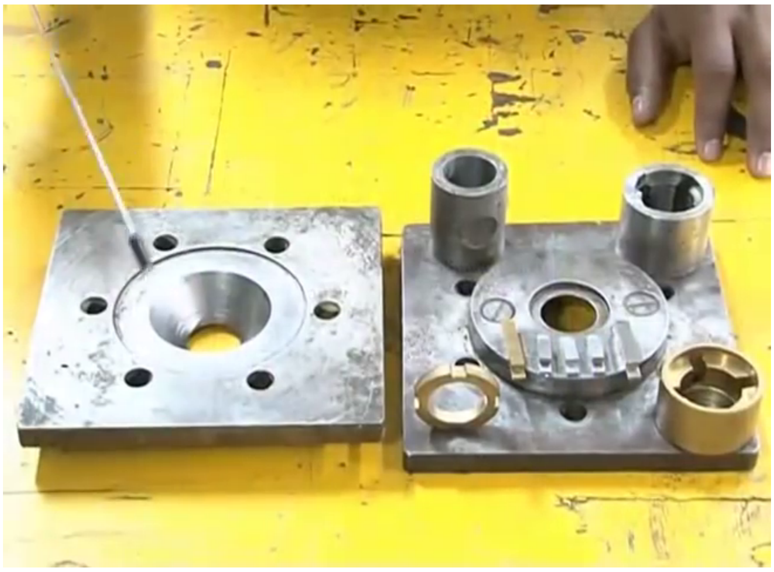

The second major element in the abrasive flow finishing process is tooling. Tooling, it controls the flow of the medium in the place where it is required. So this is the bottom plate and this is the top plate and this diameter size is equal into the lower medium cylinders size and we have a taper portion to control the medium gradually into the working region.

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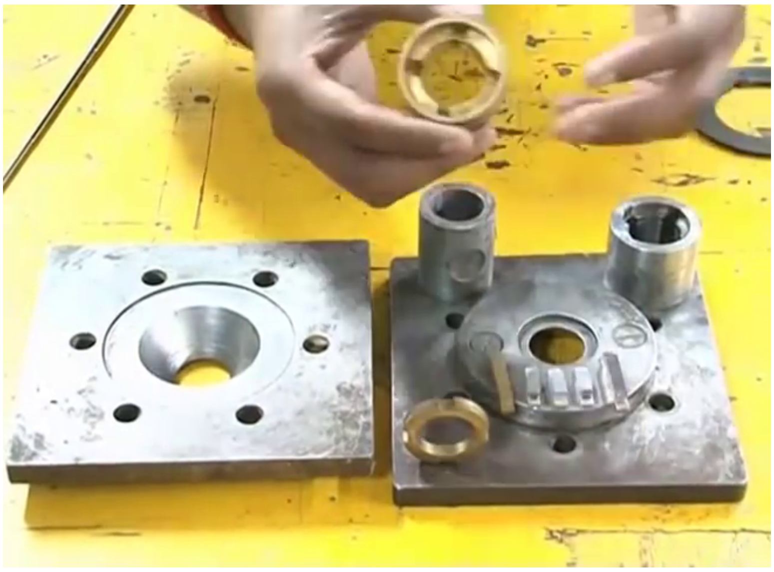

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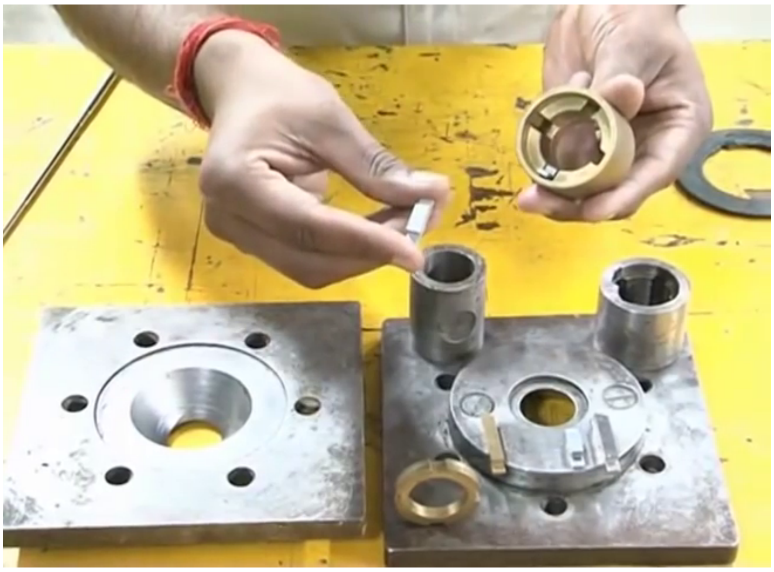

And this is the work fixtures where you can fix the work pieces. You can fix the work pieces and these are the work pieces and you can fix these work pieces like this and similarly all these are the aluminium alloy and silicon Carbide metal matrix composites and we have also finished the brass work pieces as well as stainless steel work pieces, for this you required the special work fiction that is this one and we have also finished the cylindrical work pieces and we have also measured the online surface finish measurement using acoustic emission sensor.

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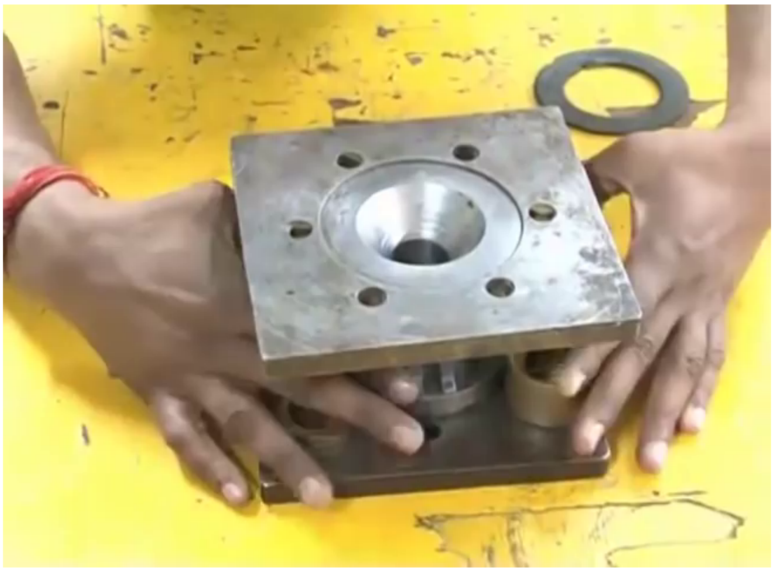

If placed this work piece like this and you will place the bottom plate like this and this completes the tooling and now the medium flows from bottom cylinder to the top cylinder gradually to the this tapered portion this is a assembly of abrasive flow finishing process where in this is the bottom fixture plate and this is the top fixture plate and this is the work piece that we are finishing and we can sense the acoustic sent signal from this hole, this is the place where we place the acoustic emission sensor for measuring the acoustic signal while the finishing process is going on to control online surface finish measurement and you can see this tapered portion this whole size is equivalent to the bottom medium cylinder hole and this medium when comes here it is gradually flows through a tapered portion and it enters into the work piece region and comes out from a again a tapered position.

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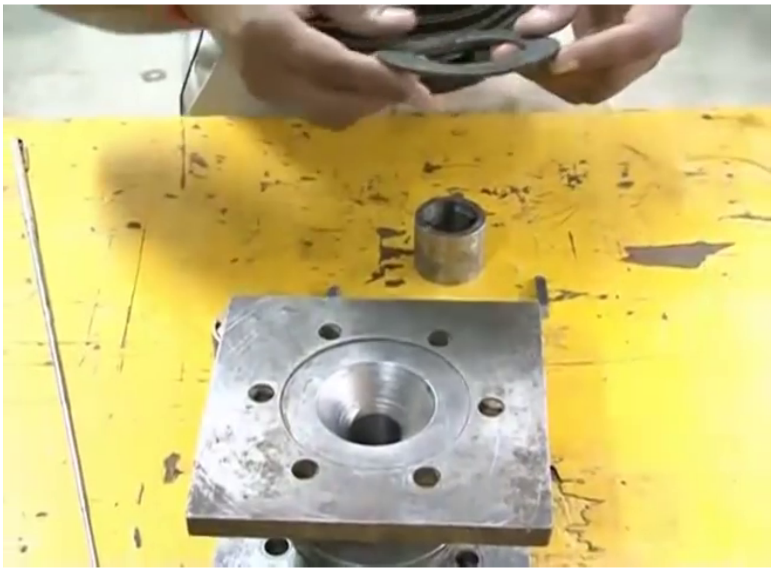

This again equivalent to the top medium cylinder size and it goes into the top medium cylinder. Similarly every cycle will take place and additionally we have a washer to control the leak.

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Third major element in abrasive flow finishing process is Polymer rheological abrasive medium, this is the polymer rheological abrasive medium and we have placed this spherical ball on the surface it has 3 major properties that is self deformability, better flow ability and better abrasive ability, you can see if we place a spherical ball after sometime it deforms itself into a flat surface if we place on a flat surface.

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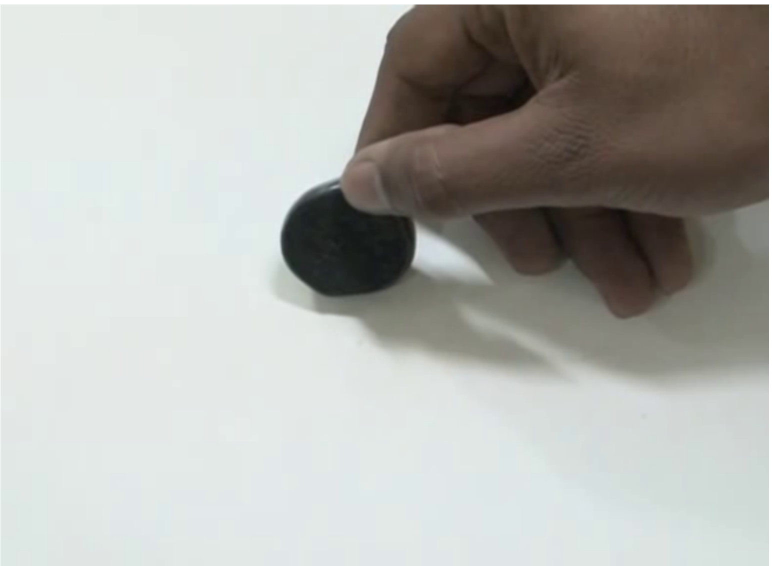

Now you can see the medium self deforms itself into a flat surface you can see the bottom it is completely flat, this is called its self deformability because of this gravitational forces, it is deforming itself into a flat surface.

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The main ingredients in the polymer rheological abrasive medium are the first one is polymer carrier; this is the base polymer Carrier. In the base polymer carrier we have specially made styrene polymer and we have Silicon polymers. In the Silicon polymers we have 2 types, one is Silicon and another one is silly putty, the basic aim of using these polymer carriers is to hold the abrasive particle between the polymer chains flexibly.

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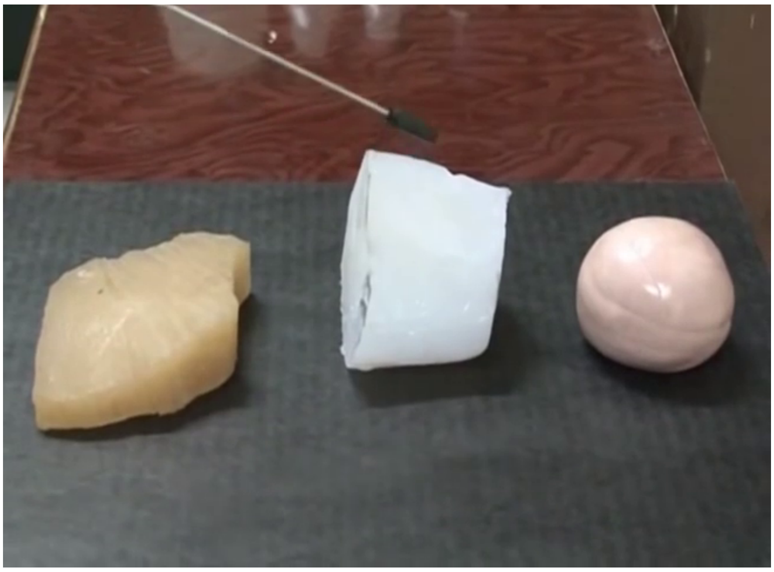

The second major ingredients in the polymer rheological medium are rheological additives. In the rheological additives we have the plasticisers, these are all the plasticisers with varying viscosities, this is the first plasticiser that is paraffinic oil and these are the second plasticisers is a silicon oil of different different viscosities. You can see the 350 centipoises, thousand centipoises and 5000 centipoises, this is the high viscous silicone oil and this is the low viscous silicon oil, these are the plasticisers in the present process of making the medium.

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The third major element in the medium making is the softeners. In the present condition we are using the stearate this will change the viscosity of the polymer medium by assisting to the plasticisers. These plasticisers and the softeners combinely change the medium viscosity and thus decide the flexibility of active abrasive grain in the finishing zone. Once these plasticisers and the softeners embedded in the polymer chains this will spread apart and goes and sits in between the polymer chains and the polymer chains spread apart. So that it will provide the flexibility to the active abrasive grain.

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The other element in the medium making is the abrasive particles. The abrasive particles are the main elements that try to shear the surface peaks of the work piece with the help of polymer rheological medium as well as the plasticisers.

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This is the 2 roll mill where we fabricate the polymer rheological abrasive medium by mixing with 2 roll. In this one roller is the supporting roller and one roller is the grabbing roller when you are processing the medium, one the medium will stick to the one roll and another roll supports in rolling. The gap between 2 roles is called as nip and this is a variable. You can vary the gap.

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Now you can see the variation in the gap, depend on how much you want the gap you can set the gap. Now you can see the motion of the rollers. Now we are mixing the multiple polymers this is a styrene polymer and this is a Silicon polymer. Basically the styrene polymer has elastic component and low viscous component. Compared to the styrene polymer silicon polymers processes better viscous properties.

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In order to improve the viscous properties further as per requirement we mix the plasticisers. This is the plasticiser you can see the plasticiser, this plasticiser breaks the polymer molecules, this is the softener which we are adding, this is assists the plasticiser. Now we are mixing the abrasive particles that are silicon Carbide abrasive particles. Now you can see the final version of the medium this contains the uniformly distributed abrasive particles.

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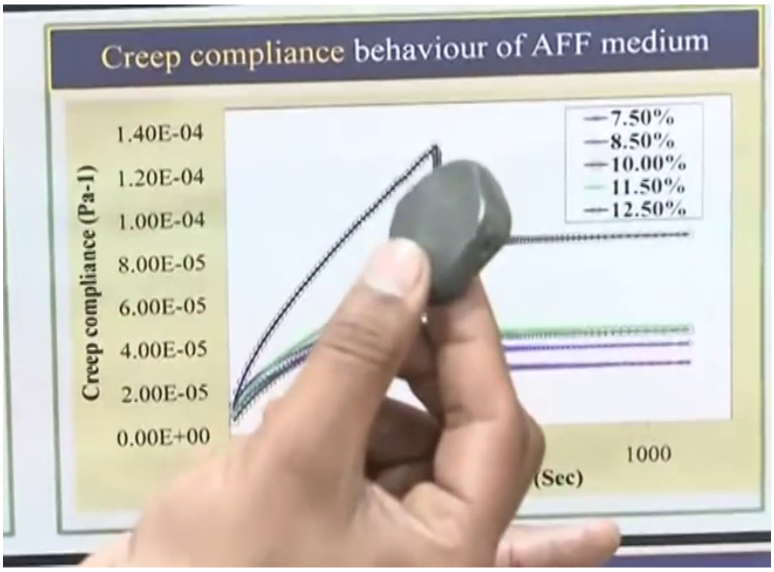

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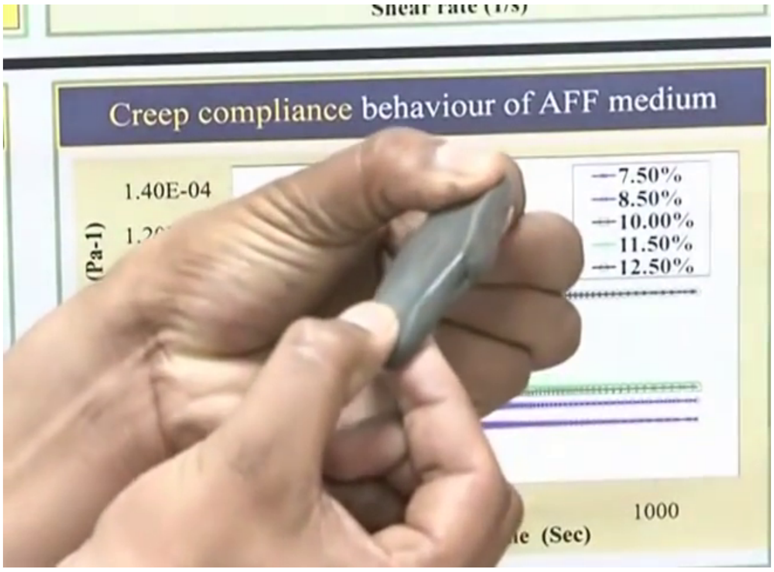

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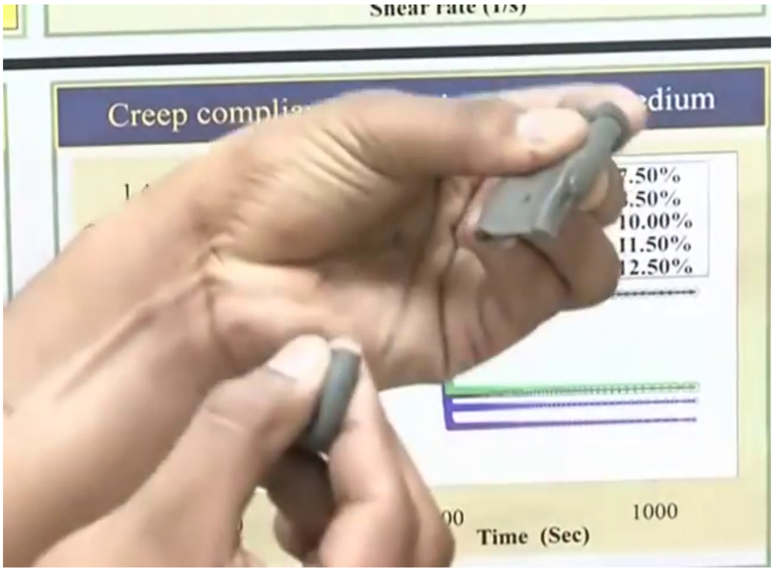

This is the polymer rheological abrasive medium that we have fabricated in-house, this has a special characters if you stretch it, it will continuously stretch if you are pulling suddenly it will break into 2 parts as well as it has a self deformability and better flow ability, all these special character's are important, in order to understand all these special rheological characters we should understand the rheology of this polymer rheological abrasive medium.

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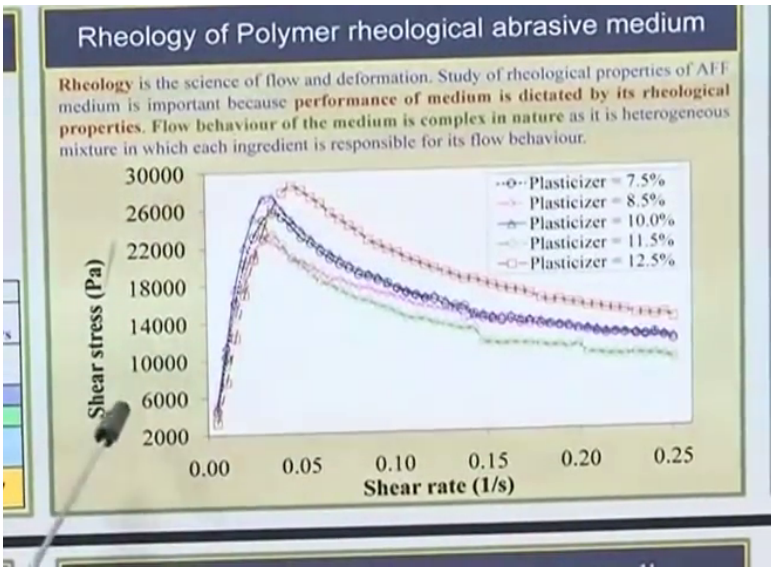

Now you are seeing the rheology of the polymer rheological abrasive medium. The rheology is nothing but the signs of flow and the formation and wherein this is the basic flow test wherein you are seeing the shear rate versus the shear stress, you can see as the shear rate increases the shear stress increases steeply and gradually falls down this is the basic curve of the viscoelastic medium.

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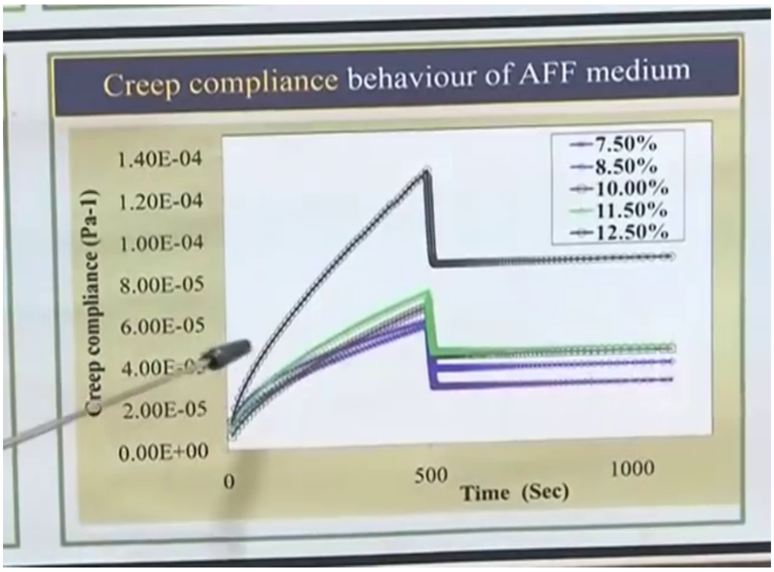

Once we know the medium is a Viscoelastic Polymer it will have both viscous component as well as the elastic component. If you see the creep compliance curve this, from this point to this point it is Viscoelasticity and when you unload this you have the recovery phase this is called elastic recovery and the remaining portion if you draw a parallel line to the x axis the remaining portion from this is the viscous component.

From this creep compliance curve we can understand how much viscous component is there how much elastic component is there in the medium? Because the viscous component tells you the flow ability and elastic component tells you the radial force component from this curve the elastic component tell you the radial force and the viscous component tell you the axial force. These both forces are required in the Viscoelastic medium in order to remove the material in a nano scale.

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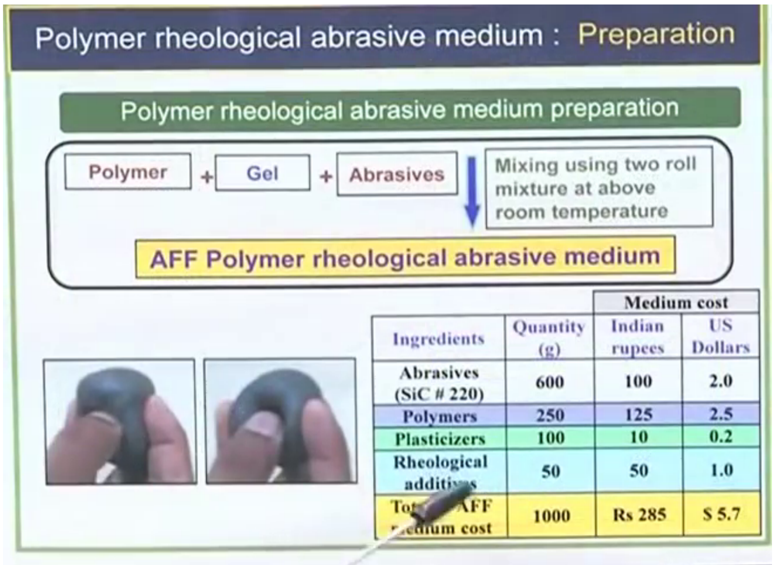

Ingredients	Quantity (g)	Medium cost: Indian rupees	Medium cost: US Dollars
Abrasives (SiC # 220)	600	100	2.0
Polymers	250	125	2.5
Plasticizers	100	10	0.2
Rheological additives	50	50	1.0
Total AFF medium cost	1000	Rs 285	$ 5.7

This is the cost table that we have prepared in-house medium and thus is coming about around approximately 6 dollars wherein the commercially available polymer rheological abrasive medium is 5 lakh rupees and in the present case it is only approximately 300 rupees.

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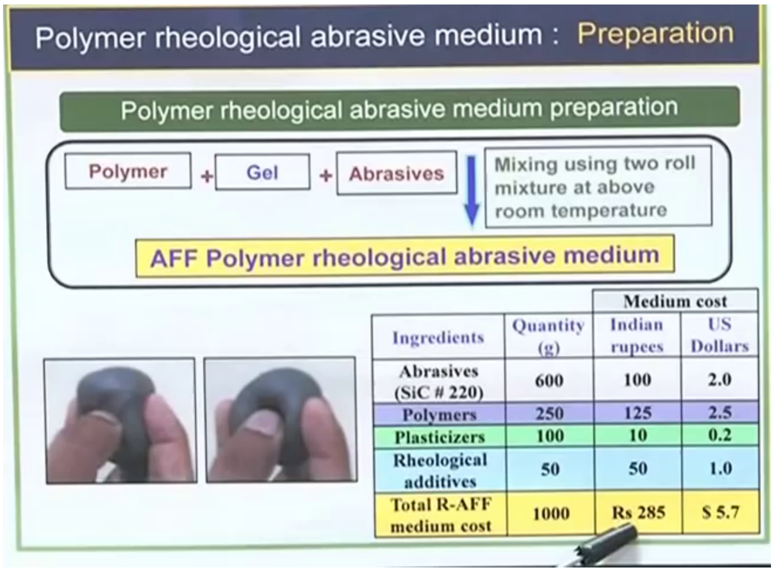

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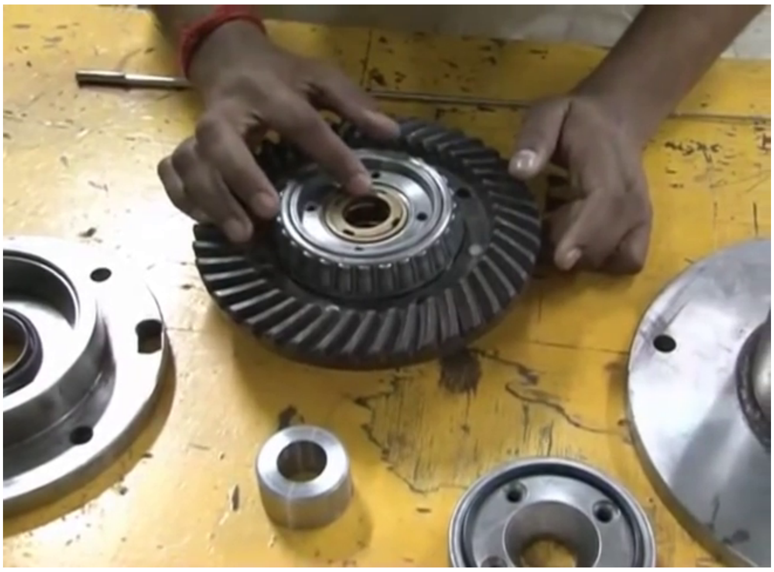

Now you're seeing the rotational tooling that we are using in the reversal rotational abrasive flow finishing process. The inner details of this one is this is a bottom plate wherein we have a curve surface wherein we place the O ring to prevent the leak proof and this is the Crohn that is made especially for the rotational system and this is a work piece holder wherein you have to work pieces and we are placing this work piece holder in the tooling and the motion of this work piece holder is prevented by the locking plate.

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This is the locking plate and we have 4 screws to tighten it and we place this total system in the bottom plate. There are the 2 ball bearings this is one ball bearing and another one is top ball bearing in order to give the free motion to the work piece.

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This is the top plate to cover the complete tooling and this will go and fix like this, this is called complete rotational tooling for the universal rotational abrasive flow finishing process.

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Now we have placed the rotational tooling in the machine setup this is the rotational tooling and we are placing the work fixture in the rotational tooling.

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Any medium leakage is prevented by using an O ring.

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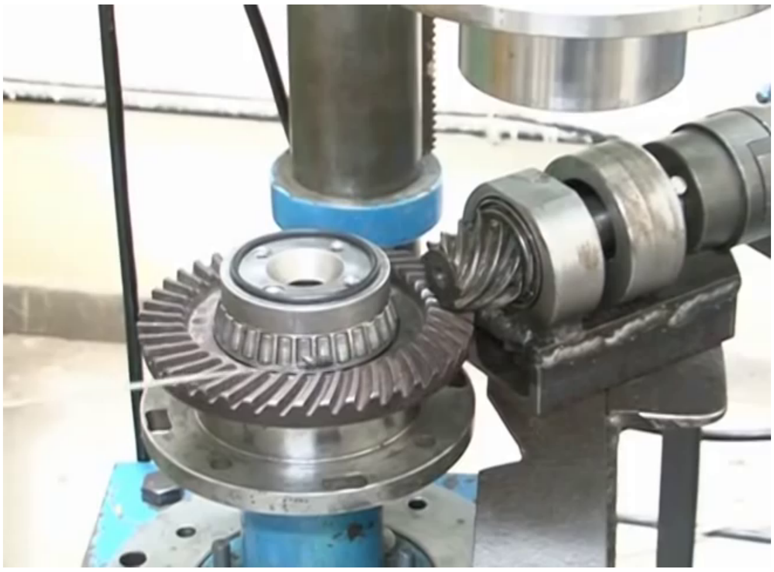

Now you're seeing the advanced version of universal abrasive flow finishing process that is called universal rotational abrasive flow finishing process wherein we have a rotational tooling that is the tooling is externally rotated by the variable frequency drive.

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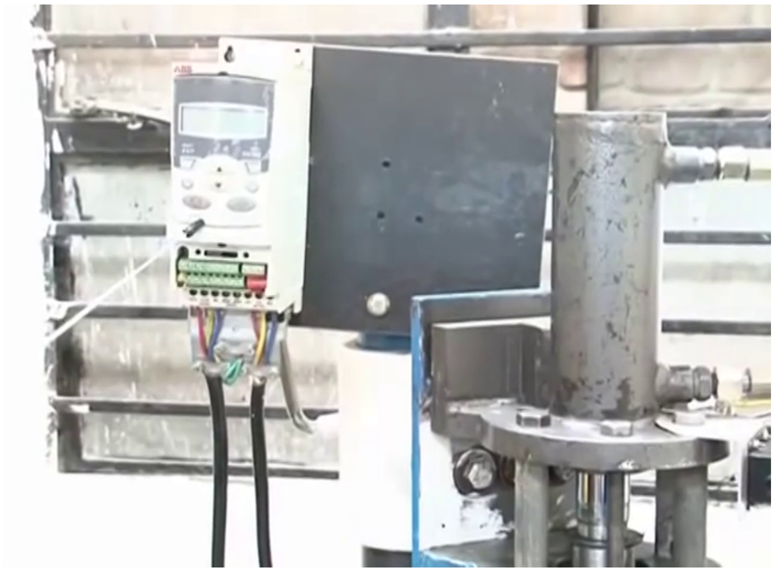

This is variable frequency drive; this gives the motion or the rotational motion to the motor.

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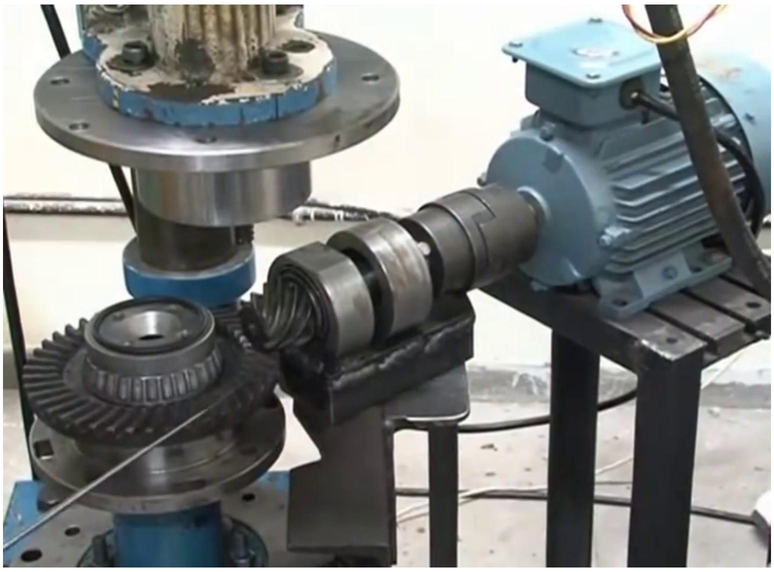

This motor drives the Crohn and pinion gear system, this is called Crohn and this is called pinion. This pinion is driver gear and this Crohn is driven gear wherein we have attached the work piece inside. This pinion gets the motion from the motor through an old ham coupling.

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Now you're seeing the 100 rpm that is visible in the variable frequency drive. This gives hundred rpm to the motor. Motoring turns rotates the pinion, this pinion rotates the Crohn and Crohn internally rotates the work piece in this way we are giving the external rotational motion to the work piece. Now you can also see the reciprocation motion of the hydraulic piston, this piston pushes the medium and this rotational motion gives the rotational motion to the work piece.

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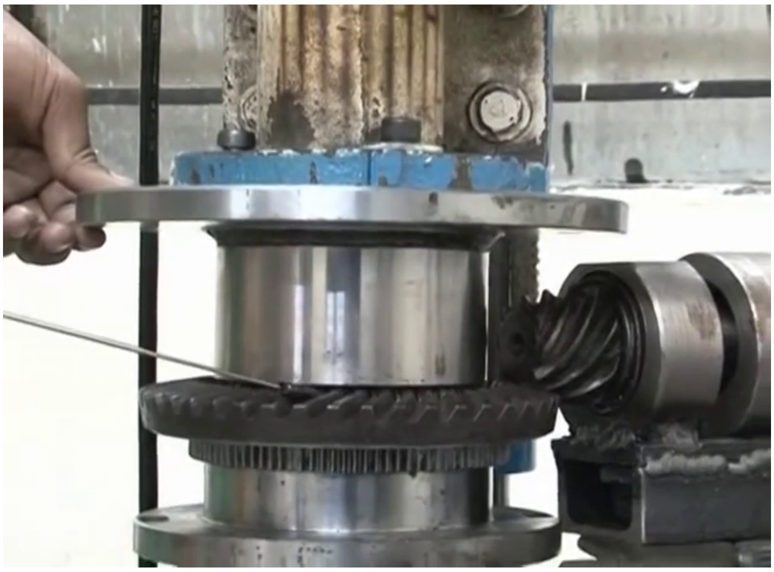

Now you can see the complete tooling that is sitting on the rotational tooling. This is the top plate that covers the external rotational tooling and this is the bottom plate wherein the external tooling is already existing. In this with the complete tooling is mounted. Once both motions are given, reciprocation motion to the medium as well as the rotational motion to the work piece this is how the rotational abrasive flow finishing setup runs.

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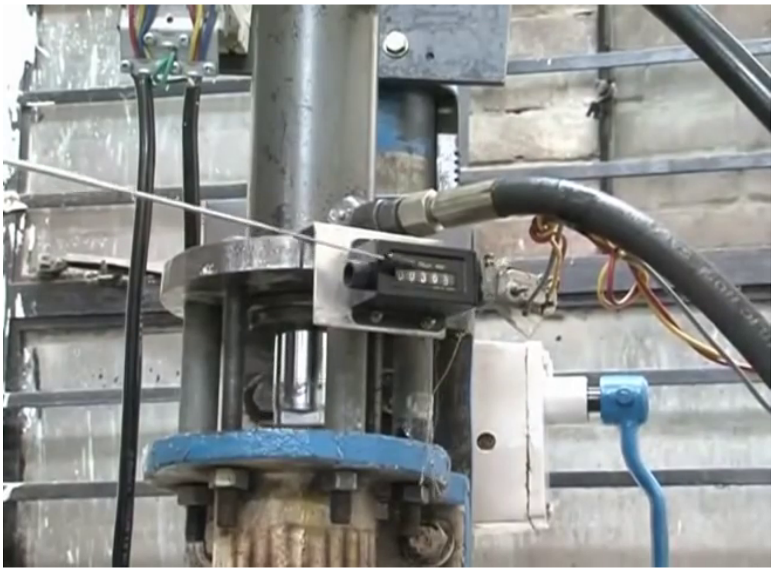

The stroke lengths are controlled by the limit switches and the number of cycles is counted in the mechanical counter.

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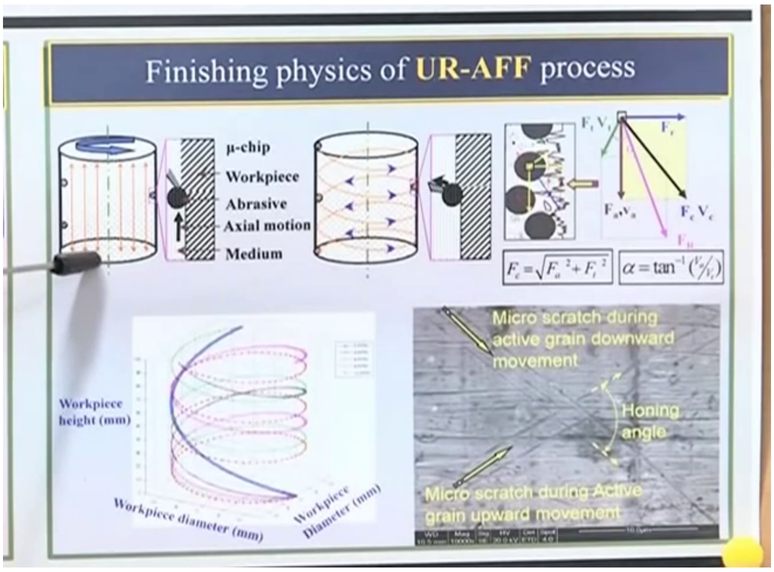

In the abrasive flow finishing process the medium flow from the top medium cylinder to the bottom medium cylinder and bottom medium cylinder to the top medium cylinder. So the medium flow in a shortest straight-line path because of this the number of surface peaks and counters by the abrasive particle per stroke is very less. In the rotation of rotational abrasive flow finishing process the medium is reciprocating as well as the work piece is externally rotated because of this 2 motions the active abrasive particles will follow a helical path.

So the distance travelled per unit time in rotational abrasive flow finishing or universal rotational abrasive flow finishing process is much much higher. So it will encounter higher surface peaks and the finishing rate will be improved because of reciprocational motion and rotational motion of the abrasive the crosshatch patterns you can see on the work piece surfaces.

The additional benefit of this rotational motion is, in the abrasive flow finishing process you have only 2 forces that is axial force as well as the radial force and you have axial velocity but in the in the universal rotational abrasive flow finishing process because of the rotation of the abrasives you have an additional (())(73:59) and velocity that is called tangential force and tangential velocity because of this force and velocity the Shearing of the surface peaks will be much much higher and the surface finish which we get will be better.

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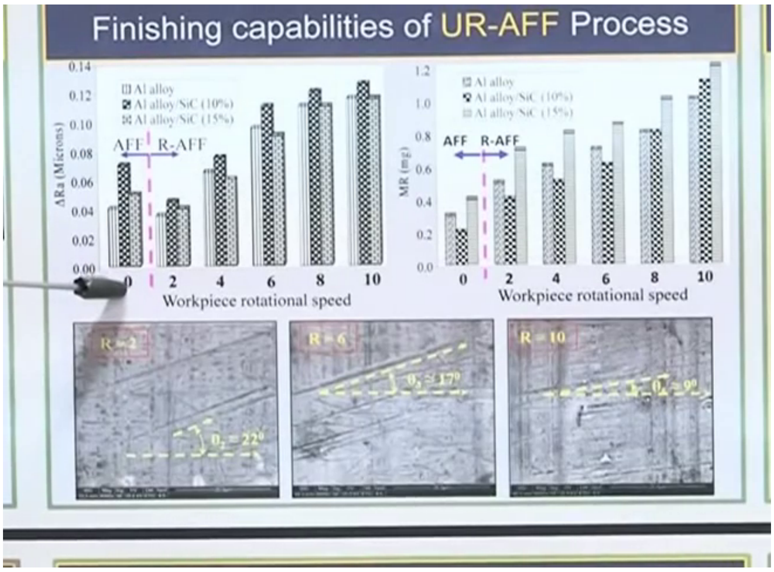

Here you have seen 0 rpm that means it is abrasive flow finishing process and here it is a rotational abrasive flow finishing process you can see in the rotational abrasive flow finishing process as the rotations increases the material removal rate as well as the surface finish that we are achieving will be higher.

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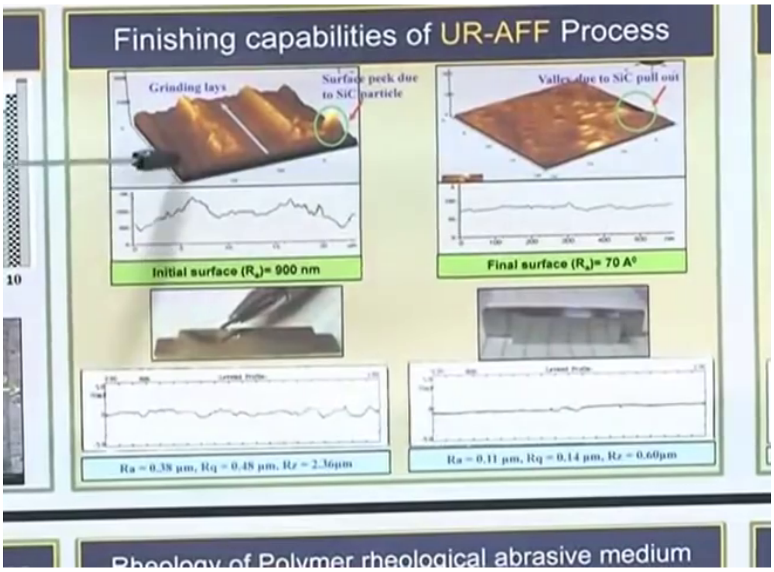

Now you can see the atomic force Micro (())(74:40) of the initial surface as well as the final surface. The initial surface which we try to finish is 900 nanometre and we are finished up to 70 angstrom. You can see the profiles this is the initial surface profile and this is the final surface profile.

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This is the initial work piece made up of stainless steel and wherein the image of the refill tip as well as the refilled blue potion is not visible perfectly.

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After finishing with the rotational abrasive flow finishing process you can see image of the refill as well as its tip, this clear visibility shows the finishing ability of the rotational abrasive flow finishing process.

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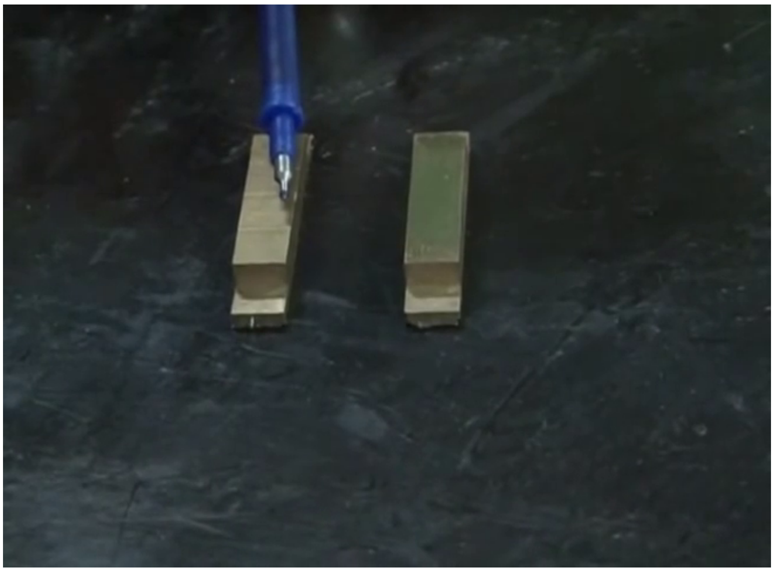

You can see the initial work piece of the brass wherein only you can see the shadow but you cannot see any mirror image.

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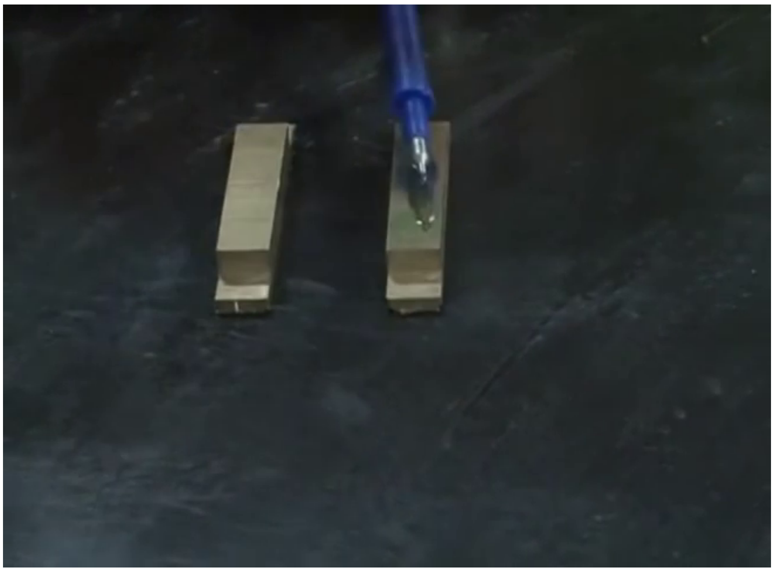

Wherein you can see the clear image or the mirror image in the finish surface by using rotational abrasive flow finishing process or universal rotational abrasive flow finishing process.

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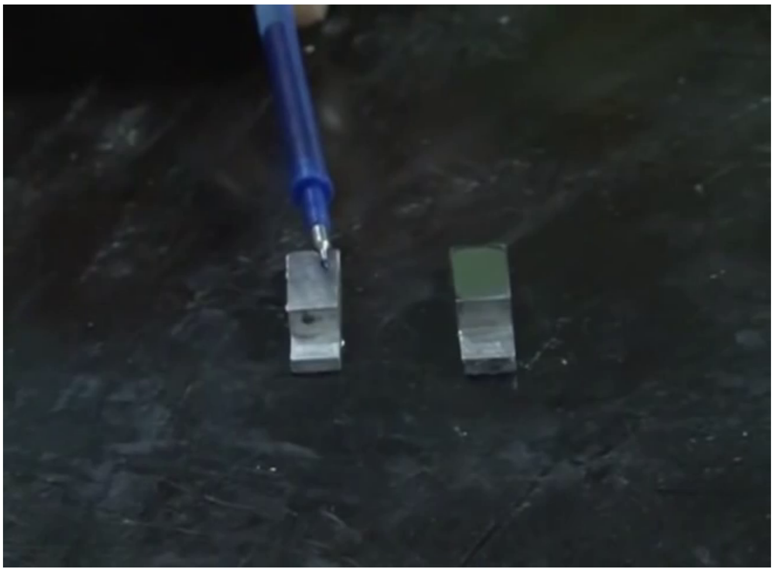

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You can see the aluminium metal matrix composites wherein you can find only the shadow but after finishing you can see the mirror image clearly, this is the micron size surface roughness and this is the nano surface finish wherein we have achieved the best surface finish about 70 nanometres.

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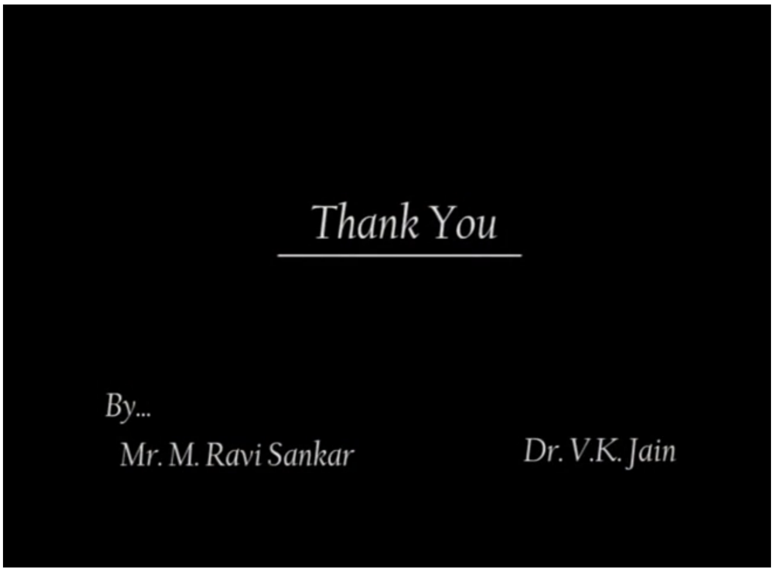

Now you have seen the working of abrasive flow finishing process or universal abrasive flow finishing process as well as the universal rotational abrasive flow finishing process that we have developed in manufacturing science lab of IIT Kanpur, I'm very thankful for your kind attention, thank you.