Advanced Manufacturing Processes
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Module - 3
Advanced Machining Processes
Lecture - 2
Mechanism of Material Removal in AFM and Variant processes in AFM

Welcome to this session on abrasive flow machining under the course advanced manufacturing processes. In the previous session on abrasive flow machining processes we have discussed different advanced manufacturing processes and their classification according to the mode of energy used. In that classification we have seen under the mechanical processes advanced manufacturing process, the abrasive flow machining is one of the advanced manufacturing processes. In this present session, let us see the material removal mechanisms in abrasive flow machining process and hybridization of abrasive flow machining process.

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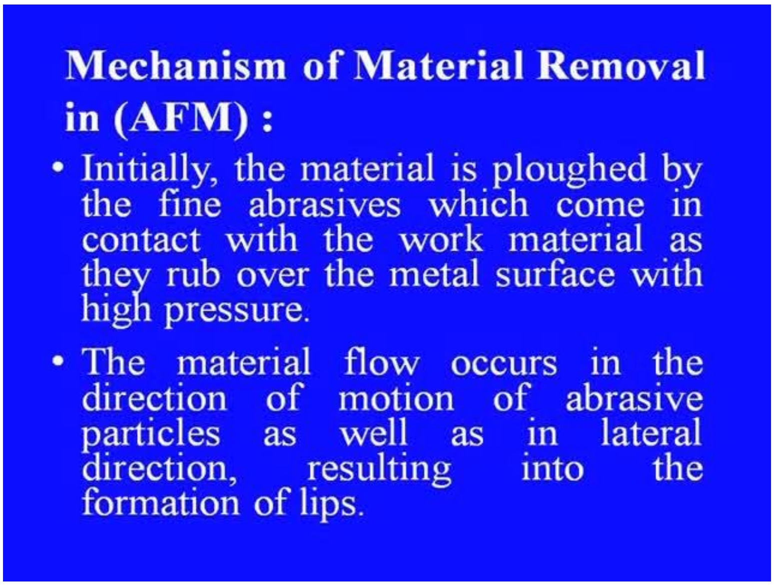

Let us start with mechanism of material removal in abrasive flow machining. In this process generally there are two different modes of material removal are prevalent. These two are ploughing and then abrasion. The material is initially ploughed by fine abrasives which come in contact with the work material as they rub over the metal surface with high pressure. The material flow occurs in the direction of motion of abrasive particles as well as in lateral direction.

This results in formation of leaps and leaps work hardening is noticed due to rubbing action of the continuous flowing abrasive particles which are also responsible for intense plastic flow with considerable stress concentration. The further flow of abrasive particles causes continued work hardening which results in embattlement and fragmentation of the lips into micro chips. This can be also seen in this way.

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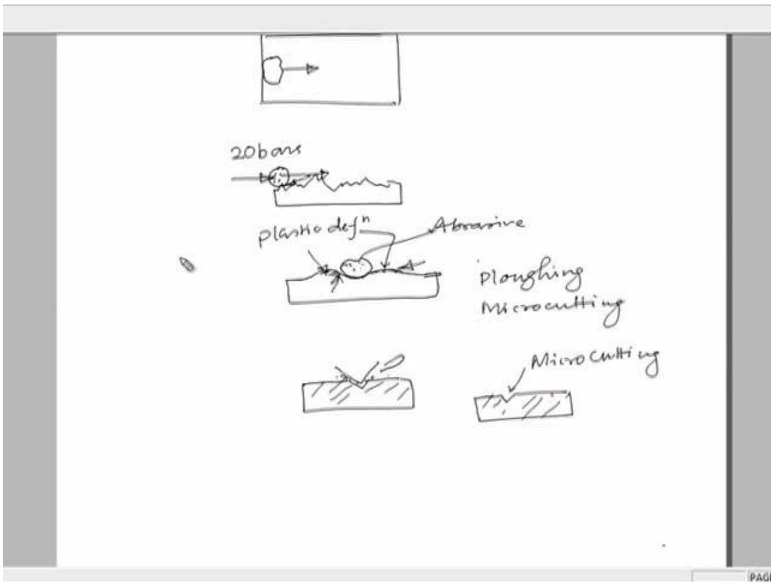

If this is the work piece in which one abrasive particle say this is the abrasive particle which is flowing through this surface and the surface contains some asperities like this then this abrasive particles as we have seen in the last session also, will either remove this this peaks on its way while pushed in the form of media under some pressure something like 20 bars or so. Then in some cases in some cases if you see the other view of this, the abrasives will impinge on this and it will cause plastic flow of the materials nearby to this abrasive particle.

So, this is the abrasive particle, abrasive particle and this is the work piece surface and there are plastic deformation, plastic deformations in the side ways of this abrasive part. So, this is called ploughing ploughing of the abrasive particles on the work piece surface which also causes these leaps leap formation on this material and on subsequent progression of this abrasive abrasive materials through this work piece surface causes the work hardening on these leaps, work hardening on this and then subsequently this leaps are removed in the form of micro chips. This is one mechanism prevalent in this and this is called ploughing action.

And the another is micro cutting which is also prevalent in this mechanism of abrasive flow machining process. In this case in micro cutting case the abrasives coming in contact with the surface physically removes the material in the form of small shapes without causing much side flow towards the both sides of this abrasive material as in the case of ploughing.

So, here in this case this cutting is taking place and it is in the form of micro groups on the work, work piece surface. If this is the work piece then this will be the result of micro micro cutting. This will be in the dimension of few micro meters or the fraction of micro meters and repeated cutting off in this fashion of the work surface causes smoothening of the surface.

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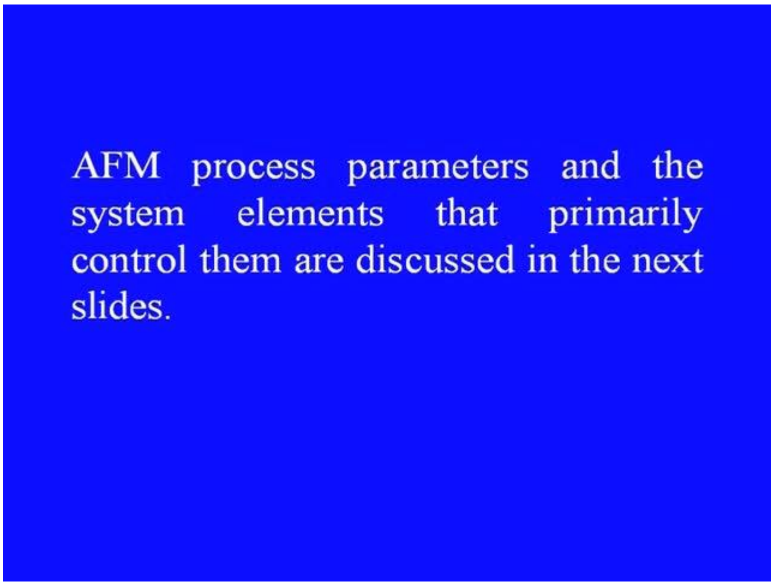

Now, let us see the process parameters and the system elements that control the process performance.

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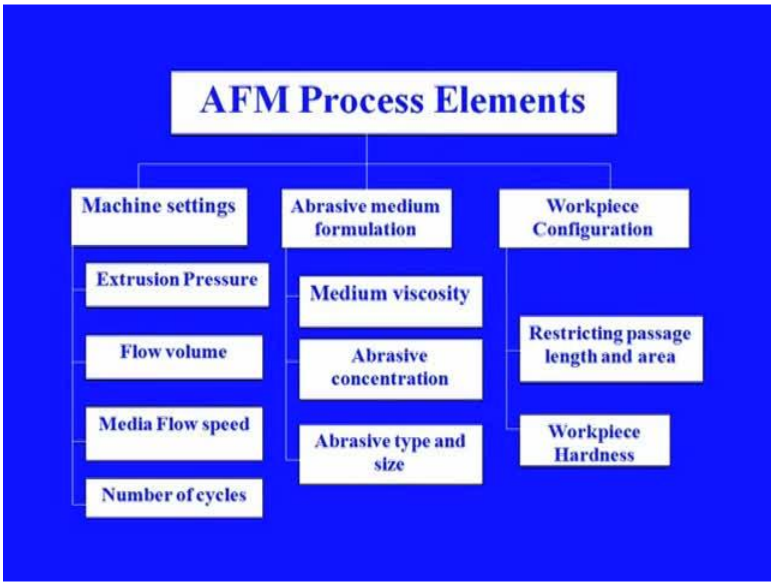

So, the different process parameters or process elements are on the screen now. These process elements, parameters are broadly classified into three categories. One is machine based parameters or depending on the machine settings, the other one is abrasive medium based parameters which we can control through abrasive medium formulation and the other one is work piece related. In machine based parameters extrusion pressure, flow volume, media flow speed and number of cycles are some of the parameters which we can set during machining.

On the other hand abrasive media based parameters include medium viscosity, then abrasive concentration in that carrier and then abrasive type and size in that media. Then on work piece based parameters include the passage length and area, and then work piece hardness etcetera.

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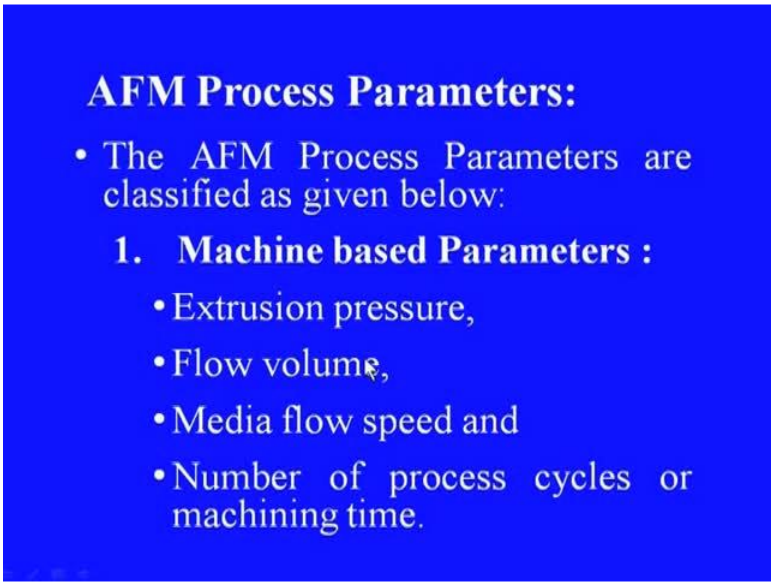

This machine based parameters in which the following parameters are included extrusion pressure, flow volume, media flow speed and number of process cycles or machining time. In most of the published literature it is found the number of process cycles have been reported. However, this can be equated with machining time which is not being used so far so frequently.

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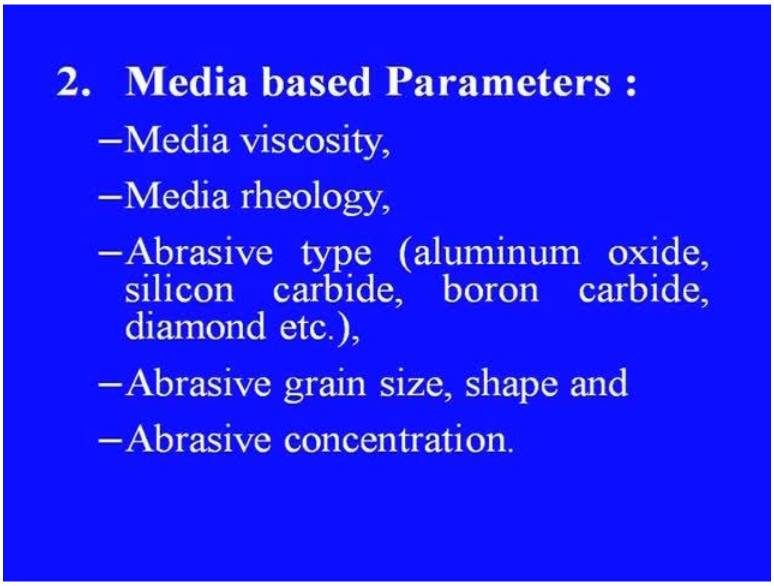

Then very prime factors in media related parameters are media viscosity, media rheology, then abrasive type for example whether it is aluminum oxide, silicon carbide, boron carbide, diamond etcetera, then abrasive grain size and shape. Of course, not much investigations have been carried out regarding the affect of abrasive shapes on the affect of the quality of the machined surface.

However, abrasive grains size is found to be a prime parameter in case of the product quality that is the surfaces finished and of course, abrasive concentration is another important factor which affects the machining quality significantly. In general higher the content of abrasive abrasives in that mix higher will be the material removal weight.

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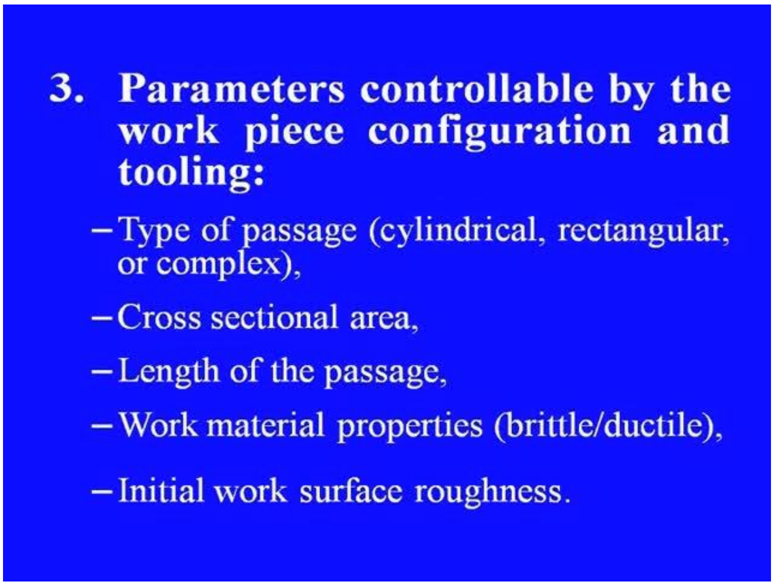

Then the parameters those can be controlled by work piece configuration and tooling include the type of passage whether it is cylindrical, rectangular or some complex shapes. Then cross sectional area, then length of the passage, then work material properties whether they are the ductile material or brittle material depending on that material removal will be affected, then initial work surface roughness, that also matters because the work piece we would be using in this process will be only for finishing.

Therefore, the previous process whether it is turning or rough turning or finish turning or whether it is milling or grinding or reamed surface that might cause some affect on the final surface that will be achieved or otherwise we may need to process the surface for a longer time depending on the initial surface roughness received. Now, let us see the influence of these process parameters in the form of Ishikawa cause and effect diagram.

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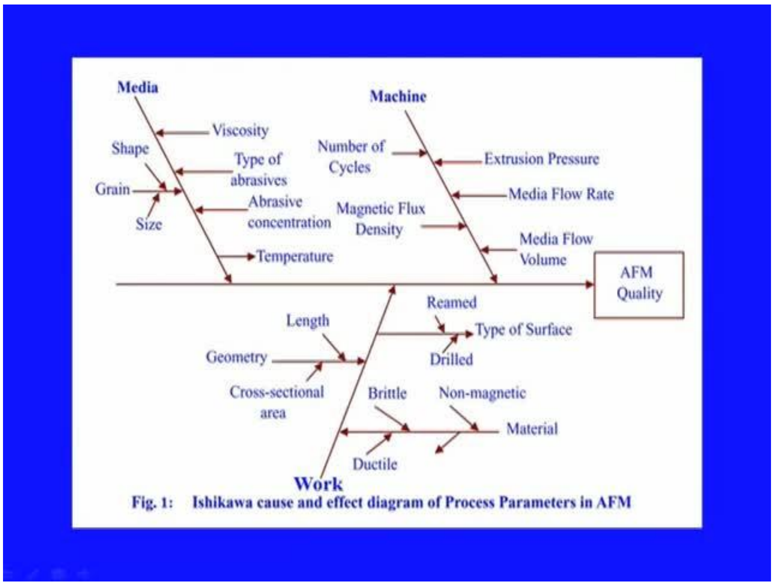

Here, here is the diagram in the screen. Here, the all three categories of process parameters based on media, then based on the machine and based on the work piece are been shown. The work piece so many other parameters are there like material whether the material is brittle and ductile, then the geometry of the work piece, then the length on the work piece, cross sectional area of the work piece, then whether the work piece is reamed or drilled, this type of information. All this will affect the final quality of the surface that is being produced in the AFM.

Similarly, the machine based parameters already we have discussed; these are number of cycles, then extrusion pressure, media flow rate and so on. A brief description of some of the important process parameters are like this, media flow volume and extrusion pressure. What is the affect of these two parameters on the quality of the surface produced by AFM? These two parameters are the dominant process parameters that controls the amount of abrasion by a specific media composition, with all other factors constant a greater volume of media will cause more abrasion. If two passages of different cross sectional areas are given the same volume of flow the smaller passage will therefore, be abraded more than the larger passage.

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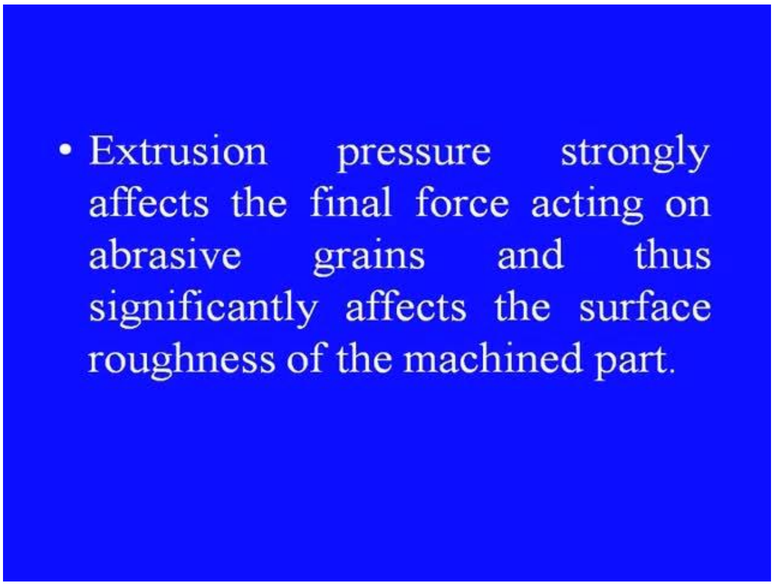

Extrusion pressure strongly affects the final force acting on abrasive grains and thus significantly affects the surface roughness of the machine part. It was found that extrusion pressure affects up to a critical pressure point beyond which even if the extrusion pressure increases the surface quality does not get any better. Therefore, the importance of optimizing these process parameters is much more in getting a desired surface quality.

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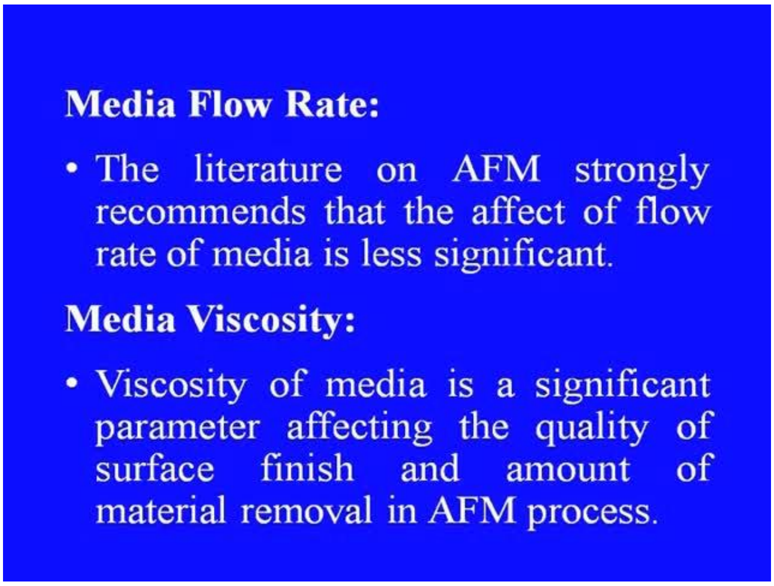

Media flow rate, literature on abrasive flow machining strongly recommends that the affect of flow rate of media is less significant. Then as far as the media viscosity is concerned viscosity is a significant parameter affecting the quality of surface finish and amount of material removal in abrasive flow machining process. Media viscosity is affected by the type of abrasives, its concentration and size of grains. It is also strongly affected by the working temperature as we know as temperature increases the viscosity of material decreases. Therefore, while working with AFM one should always concentrate on keeping as far as possible the temperature constant. So, that in between while working with the fluid the media viscosity do not get affected and there by the work piece that is being processed is not affected.

In general increase in temperature causes appreciable decrease in media viscosity which may result in settling of the grains thereby influencing the flow parameters, and over all abrasion process. (( )) one gives some general guidelines to select viscosity of media for various passage size which two is to one length to width ratio.

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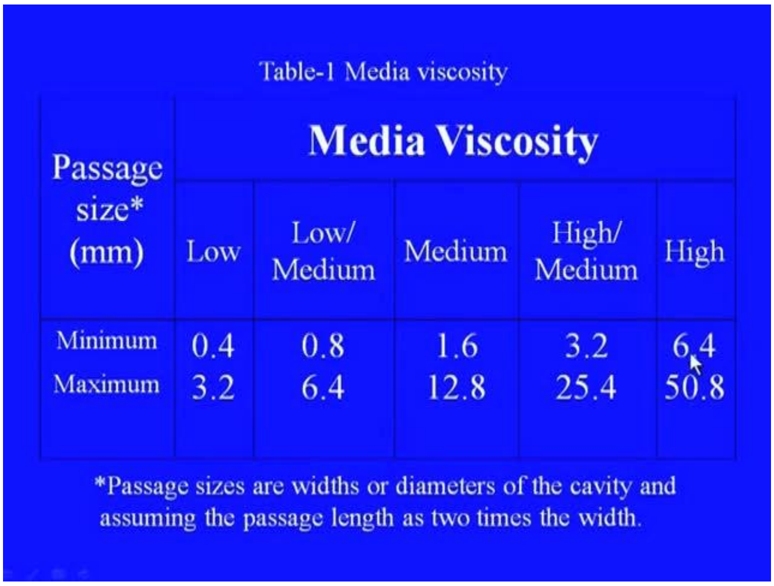

Table-1 Media viscosity

Passage size* (mm)	Media Viscosity				
	Low	Low/ Medium	Medium	High/ Medium	High
Minimum	0.4	0.8	1.6	3.2	6.4
Maximum	3.2	6.4	12.8	25.4	50.8

*Passage sizes are widths or diameters of the cavity and assuming the passage length as two times the width.

This is this is some guidelines given here, according to the passage size is given here and then how the viscosity should be selected whether it should be low viscosity, medium or high or high medium and so on. The number of cycles, the travel of media from one cylinder to other cylinder and then back to the first cylinder is termed as a cycle. Several cycles are generally required to achieve a particular amount of material removal and final surface finish on a component.

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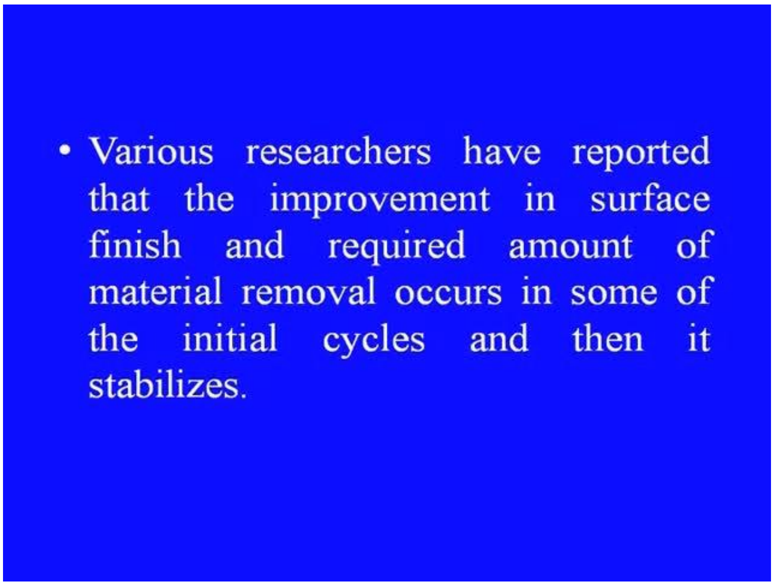

Various researches have reported that improvement in surface finish and required amount of material removal occurs in some of the initial cycles and then it stabilizes. This means even if we go on working repeatedly on a finished surface the improvement in surface finish may not be significant after some optimum value. However, during the initial few cycles material removal will be much faster.

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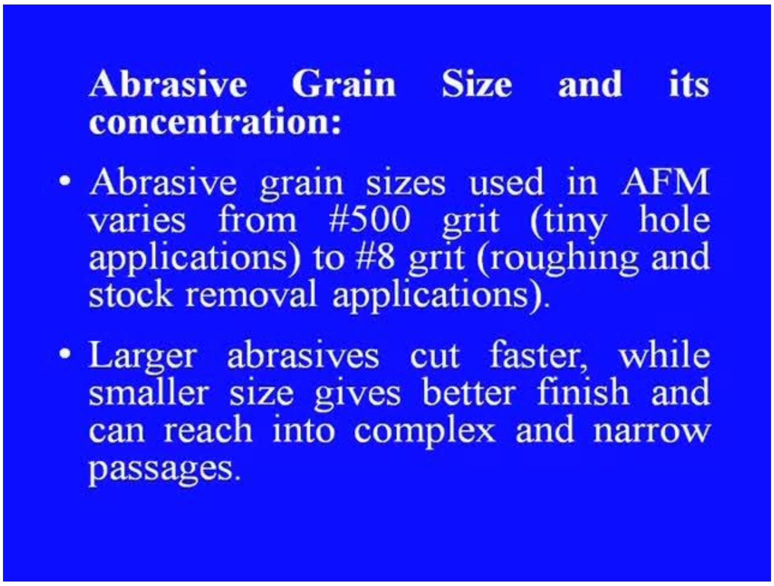

Abrasive grain size and its concentration, abrasive grain sizes used in AFM varies from 500 number 500 grit which represents tiny hole applications to number 8 grit which is used for roughing and stock removal applications. Larger abrasives cut faster as in always with the abrasive machining processes while smaller size gives better finish and can reach into complex and narrow passages. Generally, for final finishes we would use finer abrasive materials without bothering about the material removal. Now, let us look into the capabilities of the abrasive flow machining process.

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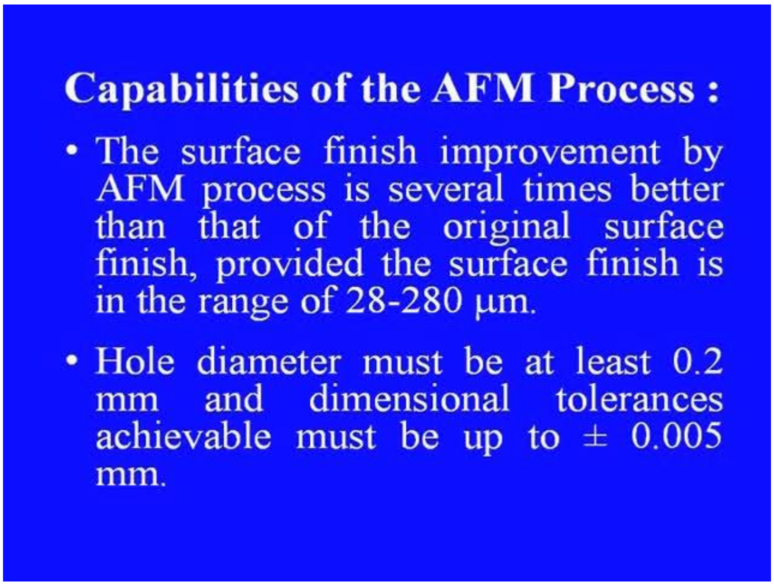

The surface finish improvement by this process is several times better than that of the original surface finish provided the surface finish is in the range of 28 to 280 micro meter. Even better surfaces have been reported with this process. Hole diameter must be at least 0.2 millimeter and dimensional tolerances achievable must be up to 0.005 millimeter. Very fine holes will not get better finish because the restriction of the hole will not permit the free flow of the abrasives into these narrow zones, thereby we may not get expected results in case of very, very tiny holes.

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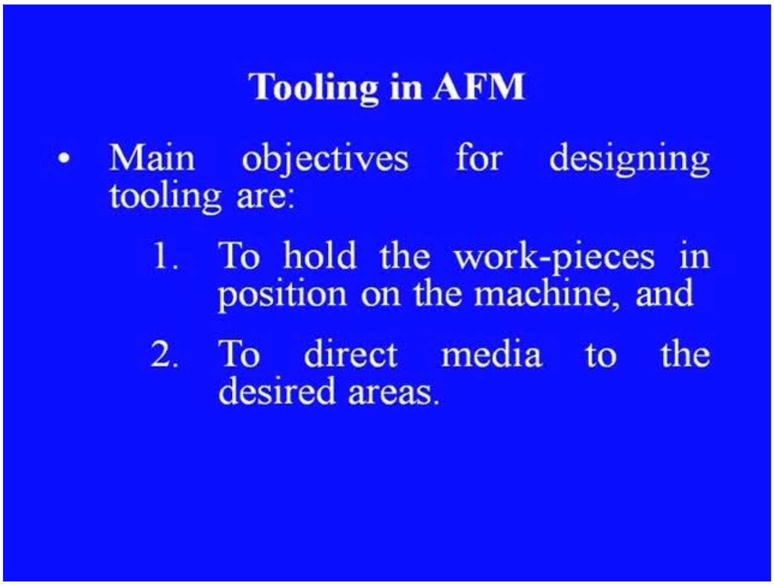

Now, let us see the toolings in AFM. The main objectives for designing tooling in this AFM process are to hold the work piece in position on the machine and then to direct the media to the desired areas. Generally, two three different materials are there, popular materials are there for tooling, number one it steel which has got very good strength and durability. Therefore, it can be reused for several hours of working, then another one is (( )) this material is very useful for complex shapes and then aluminum and nylon, they can also be used for tooling purposes as they can be easily machined and they are very light in weight.

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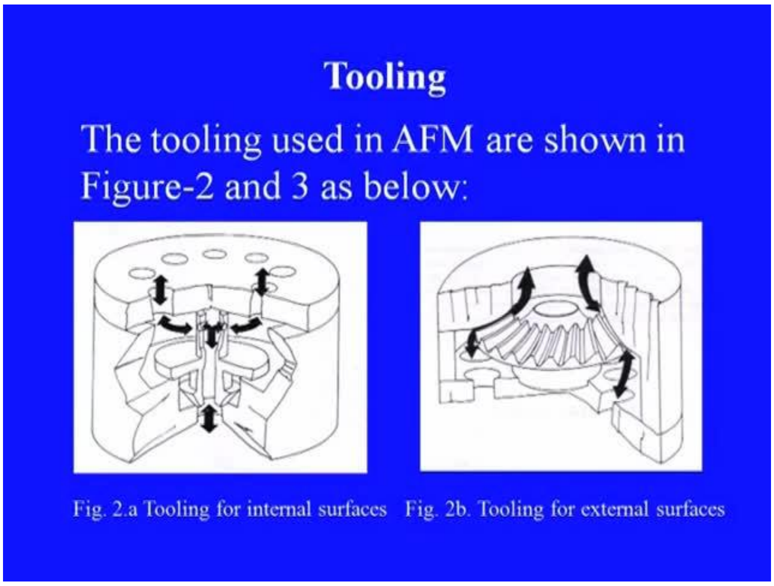

Here are the some schematics of tooling. So, this is how a tooling is designed of course, this is, this one is for internal part finishing and this one is for external finishing of the parts. This is the part to be finished, these are the surfaces to be finished and this is the media flow which contains the abrasive materials and while passing through this, this causes abrasion on these surfaces and thereby improves the finish of these surfaces. So, is the case with this this internal surfaces.

So, media is is directed through different passages in this solid tooling and media is allowed to flow through this work piece and while flowing through it comes in contact with the internal surfaces of this work piece, and the abrasives causes the abrasion on the surface, box surface and thereby causing improvement in the surface finish.

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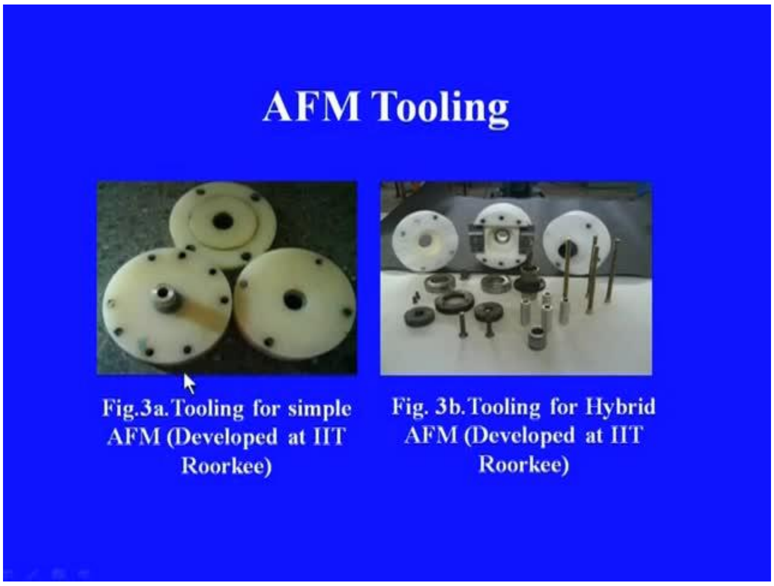

These are some of the tooling which were being prepared in IIT Roorkee, this is with nylon material which is easily machinable and also light in weight. This can be designed or fabricated to accommodate different kind of work pieces. So, here it is shown for cylindrical type of work pieces. However, this can be modified for holding different work pieces as well. With this now let us move on to hybridization in abrasive flow machining. First of all why do we need hybridization?

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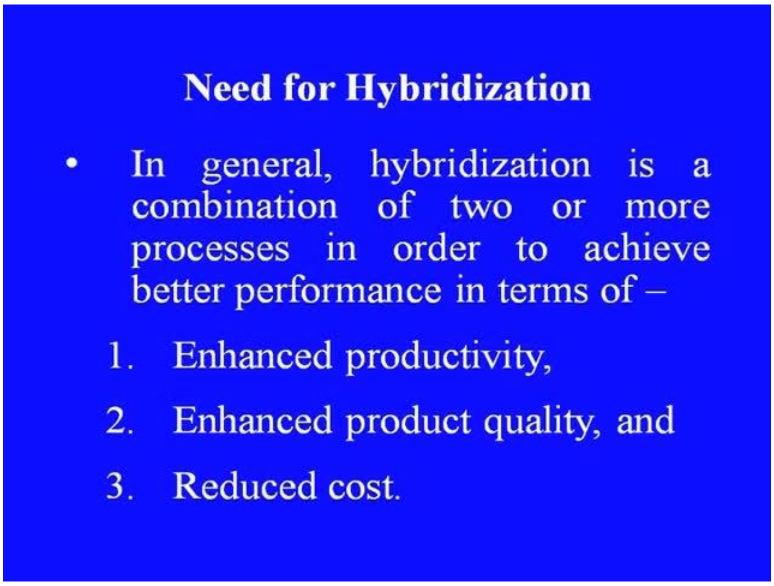

In general hybridization is a combination of two or more processes in order to achieve better performance in terms of enhanced productivity, enhanced product quality and reduced cost.

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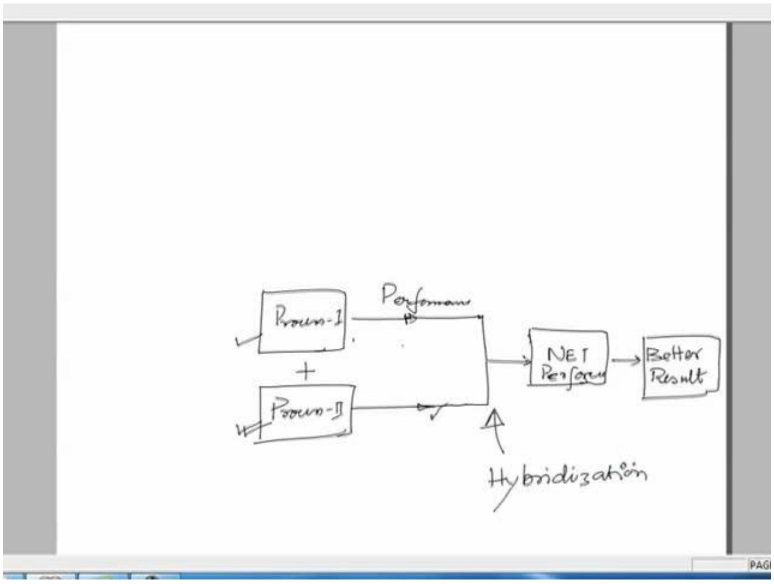

If there is a process 1, process 1 and it has got some performance. This performance is along with its the process an inherent limitations, then if we add one more process in this say process 2 which is being added to this and then what we can have is the combined effect of these two and we can get the net performance of both the processes and this gives naturally a better result.

However, we should be very, very careful while choosing this process 1 and process 2 because simply adding two processes will not give rise to the net performance enhancement of this process. We have to be very careful about how these, the limitations of process 1 or either process 2 can be nullified by each other and as a result we can get better performance in the end. So, this causes, this calls for the term hybridization which nowadays is very popular among the machining process, different machining processes. This is not only true with abrasive flow machining processes, but also with other advanced manufacturing processes, this hybridization is nowadays very very popular.

Now, let us see how this hybridization in abrasive flow machining can improve the performance of this process. As we have discussed in the last session itself abrasive flow machining is basically a low MRR process, low material removal process. Therefore, hybridization in abrasive flow machining is directed to improving the efficiency of the process in terms of higher MRR and to obtain better surface quality.

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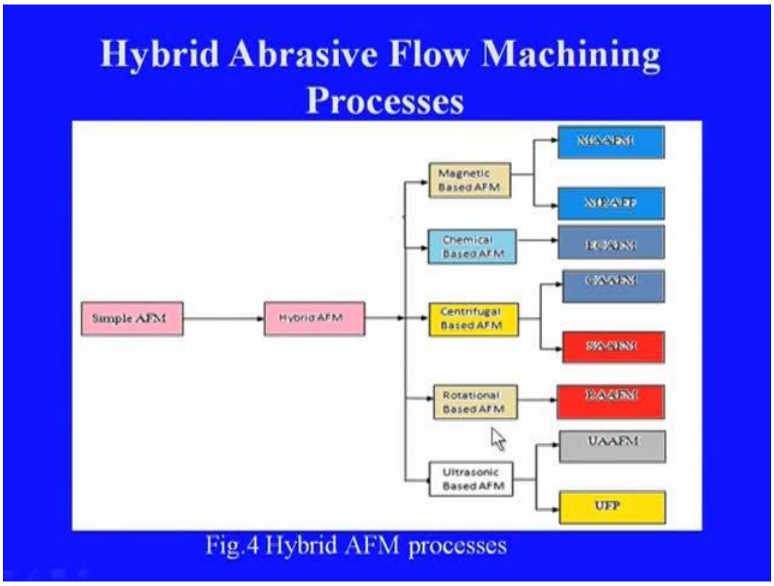

Now, here are some the hybrid, hybrid AFM processes. So, here the first one is the simple AFM process and then added to this is some affect in that, in the form of hybridization or in some other material removal affect. And then this this gives some enhanced affect in terms of either material removal or in terms of better surface finish. Some of these processes are like magnetic based AFM in which the actual process is magnetically assisted abrasive flow machining or magneto realistically assisted abrasive flow finishing, then chemical based AFM where electro chemical assisted abrasive flow machining is one of the hybridized processes.

Then centrifugal based abrasive flow machining, in this centrifugal assisted abrasive flow machining and spiral assisted abrasive flow machining, these two have been developed and it was found that they are working well as far as the enhancement of the process performance is concerned. Then another hybridization is rotational based AFM where rotation assisted abrasive flow machining is one of the hybridizations. Then ultrasonic based AFM in which ultrasonic affect is being added to enhance the performance of the normal abrasive flow machining process.

The two variants are ultrasonic flow polishing and ultrasonic assisted abrasive flow machining. Let us see how this ultrasonic flow polishing works. In ultrasonic flow polishing the combination of AFM and USM principles are used. In this process the abrasive polymer mix is pumped down the center of the ultrasonically energized tool. The concept is explained like this.

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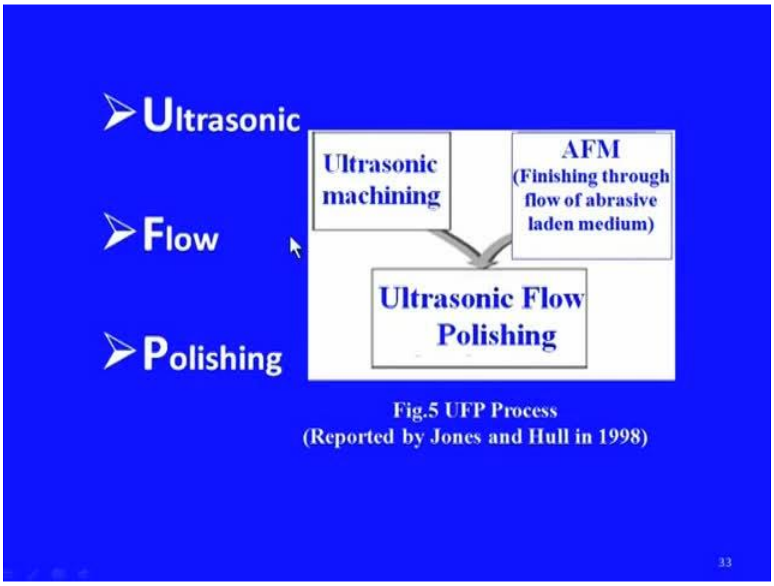

Ultrasonic machining, then the abrasive flow machining and this gives ultrasonic flow polishing. This can also be seen like this.

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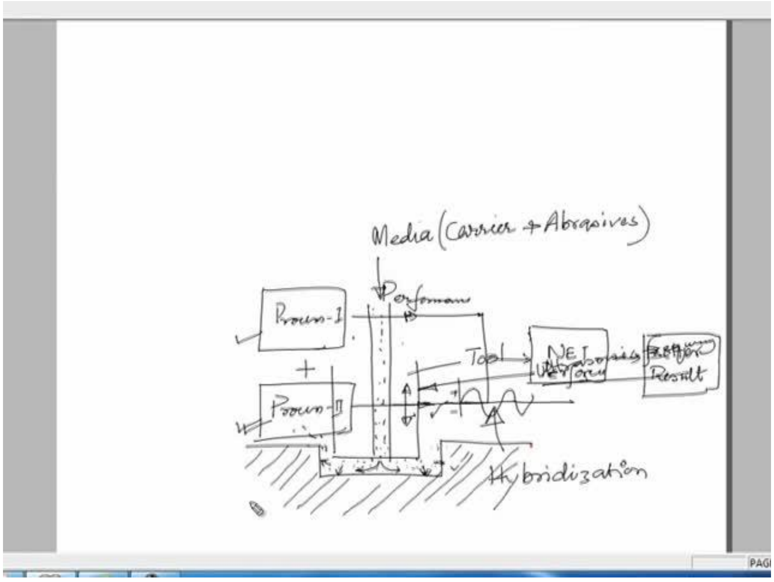

If this is the tool and this is the work piece which needs to be polished then the media is passed, can be passed through this, through this hollow tool or special arrangement of this tool. So, this can be the media. This media means carrier as we have already seen carrier plus abrasives abrasives and then this media after coming out through this. So, it will flow like this, take the path like this and this tool can be made to oscillate in a particular fashion and this can be given an ultrasonic ultrasonic movement that is ultra sonic frequency, it can be moved and therefore what will, the net affect will be along with this tool this will impart motions, ultrasonic motions to this media in turn the abrasive particles embedded on this media will get a motion, additional motion that is in the form of ultrasonic frequency.

And which will get energized then and hit this work piece surface like this, at much more velocity, much higher velocity than it would have been with normal AFM process and now as a result of this enhanced velocity this will abrade this work piece material at a faster rate and therefore, the material removal on this work piece surface is expected to be much higher.

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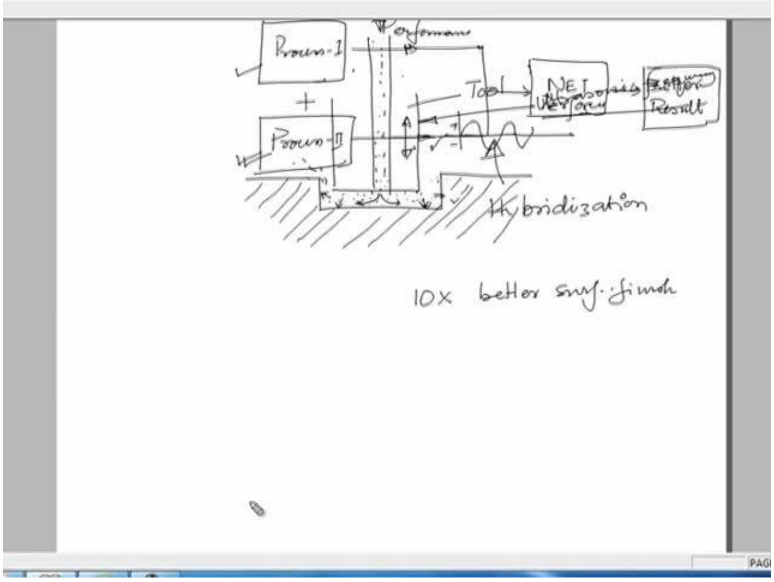

And also 10 times, 10 times better surface finish have also been reported. The vibrating tool ultrasonically energizes this mix as I have already told and it causes, the important thing is it cause minimal deterioration to the work profile or dimensional accuracy. The surface finish improvements up to 10 times have been reported by this process and the process has special application for machining blind cavities which are difficult to be polished by conventional AFM.

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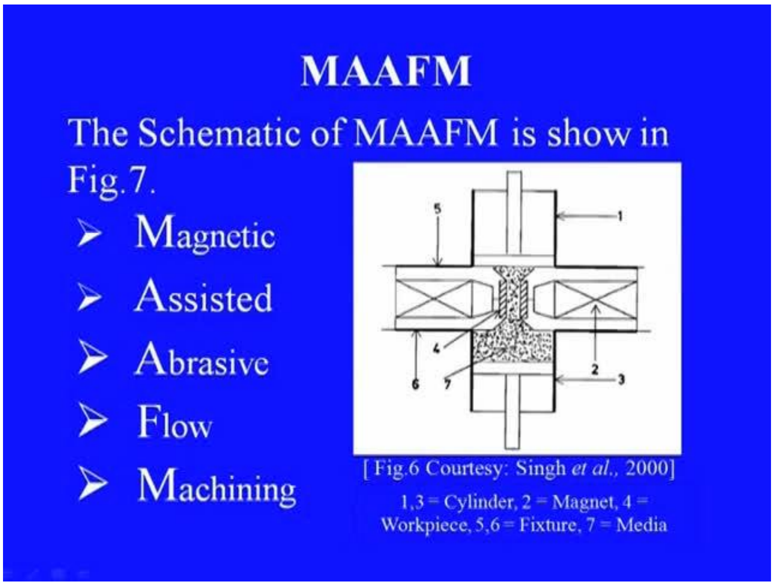

Then let us come to a new process that is magnetic assisted abrasive flow machining. In this the process principle is almost remaining same as in the case of normal AFM in which two cylinders are there, media cylinders, in which the media will be abrasive laden media will be there, it will be pushed through the work piece. This is where the work piece work piece is and the media from one cylinder to the other cylinder will be pushed from this side and then from the opposite side, but the difference here is the abrasives used in this case will be some faro magnetic particles and while processing a strong magnetic field will be applied, as can be seen here.

These two are the magnets and as soon as the magnetic field is applied this faro magnetic particles they will get attracted towards this magnetic poles in between however the work piece surfaces are there, and thereby this will cause abrasion with a better impact on this work piece surface which will result in enhanced material removal as well as enhanced surface finish. The magnetic field increased the resultant cutting force on this surface, because of the change in the incidence angle with which the particles impinge upon the surface.

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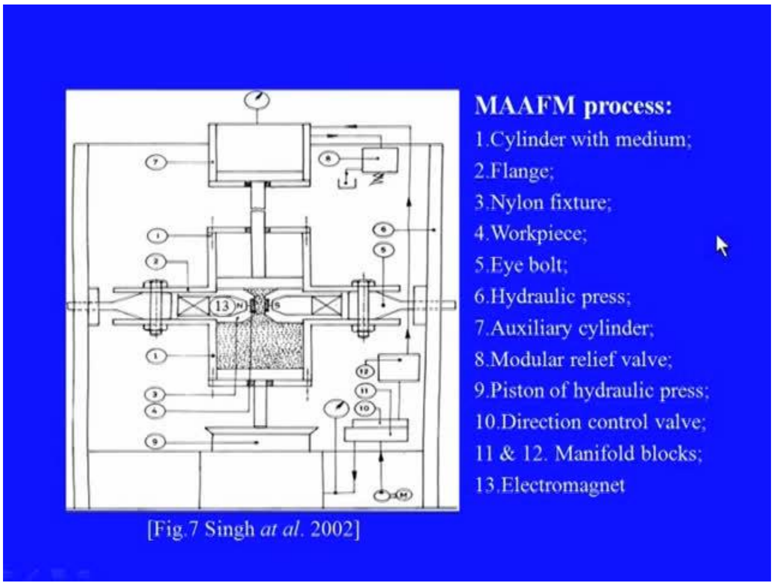

So, this is the complete setup of this process with hydraulic diagrams and different other components for measurement of different parameters like flow parameters, pressures and so on. This has been incidentally developed in IIT Roorkee again. This was first developed by Singh at al and they have reported that substantial improvements in surface roughness and material removal weight were observed. They studied extensively on materials like brass, aluminum, mild steel etcetera and they continued research on understanding the mechanism of material removal and ware behavior of materials by this process.

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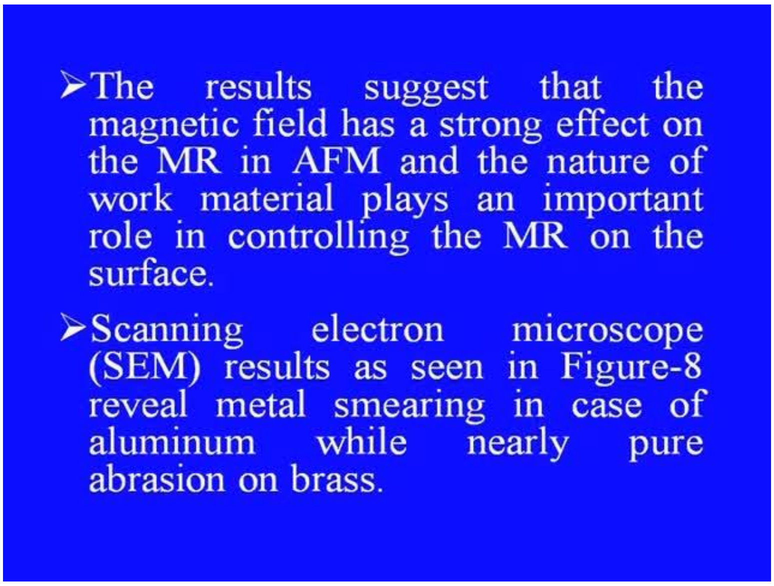

The results suggest that the magnetic field has a strong affect on the material removal and the nature of what material plays an important role in controlling the material removal on the surface. Scanning electron microscope results as shown in the next figure reveals metals smearing in case of aluminum while nearly pure abrasion on brass, this we can see.

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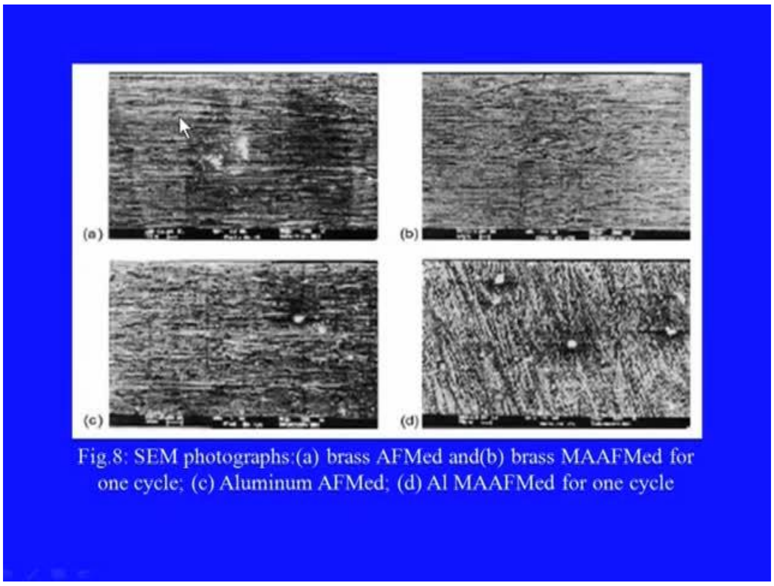

So, this is aluminum this is in case of sorry this is in case of brass and this in case of aluminum and this is prior to the magnetically assisted AFM, this is conventional AFM and this is magnetically assisted AFM surface which we can see undoubtedly much better than what is obtained with conventional AFM process. This is in through in both the cases like in aluminum as well as in brass.

Magneto rheological abrasive flow finishing this is another hybridization in this abrasive flow machining family. In this process a magnetically stiffen plough of magneto rheological fluid is extruded back and forth through the across the passage formed by work piece and fixture.

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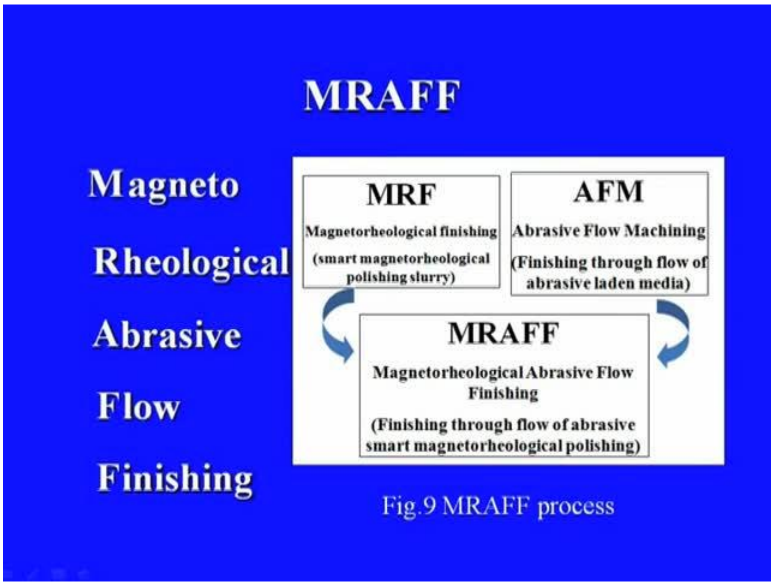

This we can see in the, this particular figure where magneto rheological finishing and abrasive flow machining both are combined that gives to magneto rheological abrasive flow finishing process. In this process rheological properties of an abrasive laden medium also called smart magneto rheological fluid is controlled using an internal magnetic field. It imparts better control of the process behavior due to better control over abrading mediums rheological behavior.

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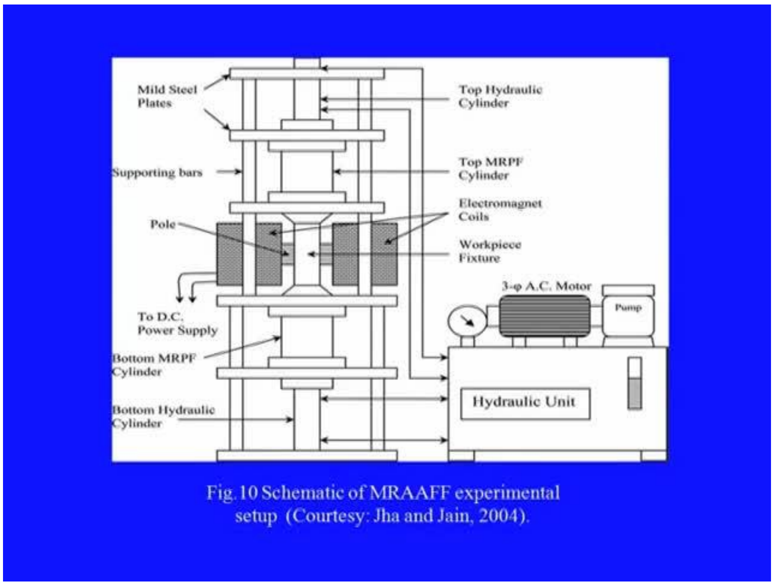

This this is the schematic of this process. This is where the magnetic poles are there and this is the work piece fixture and these are cylinder in which magneto rheological fluid is stored and this will be pushed from the one end to the other cylinder where the magnetic rheological fluid will be collected and then process will continue. The other controls and necessary measurement devices are also shown. In this process rheological behavior of the fluid changes from nearly Newtonian to Bingham plastic and vice versa upon entry and exit of the finishing zone respectively. This process was first reported by the researchers in the IIT Kanpur named Jha and Jain in the year 2004.

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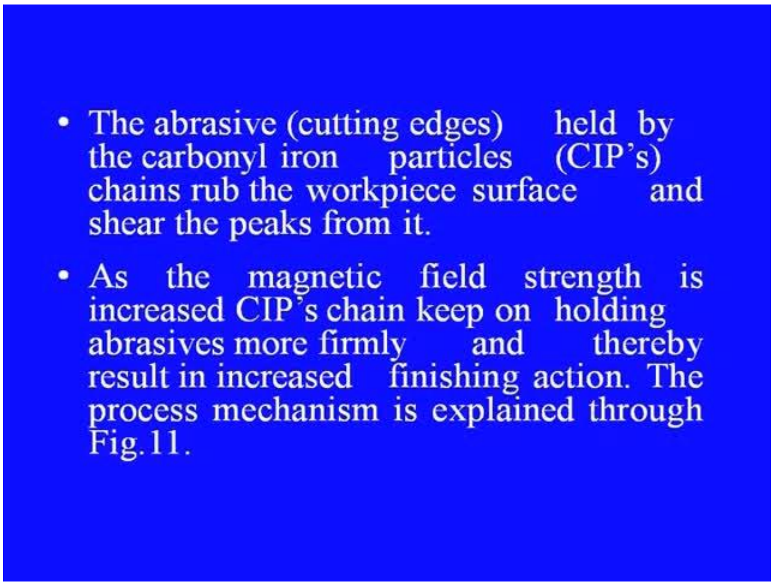

The abrasive cutting edges are held by the carbonyl iron iron particles which forms some chains and this rubs the work piece surface and shear the peaks from the work piece surface. As the magnetic field strength is increased carbonyl iron particles chain keep on holding the abrasives more firmly and thereby results in increased finishing action. The process mechanism is explained in this.

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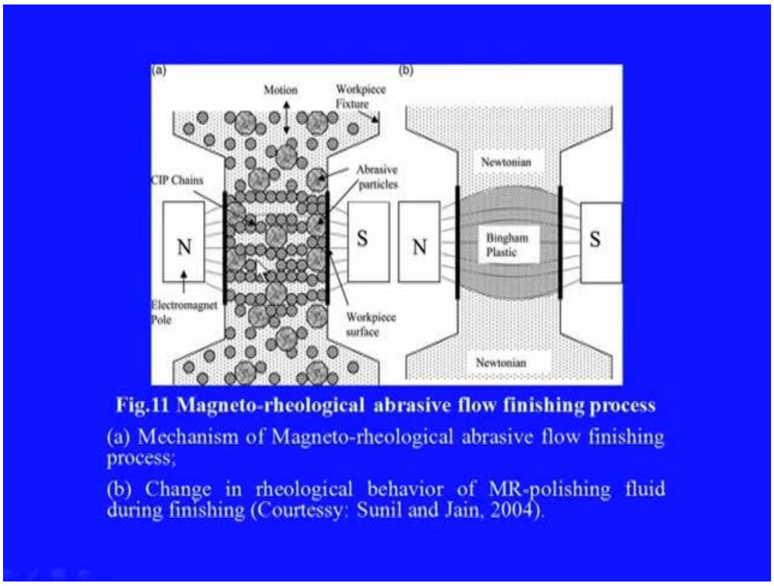

Fig.11 Magneto-rheological abrasive flow finishing process

(a) Mechanism of Magneto-rheological abrasive flow finishing process;

(b) Change in rheological behavior of MR-polishing fluid during finishing (Courtessy: Sunil and Jain, 2004).

These are the carbonyl irons, these are the abrasives. Under the action of this magnetic field this carbonyl irons they form some sort of (( )) like this, chains like this which embraces the abrasive particles and make them to abrade more with more forces on this work piece surface. This causes better surface finish on this, on this box surface. Now, let us discuss another form of hybridized abrasive flow machining process that is called centrifugal force assisted abrasive flow machining.

In this process the abrasive particles in the media upgrade the contacting surface of work piece with an additional force that is centrifugal force during processing. This is achieved by providing a centrifugal force generating rod in the AFM setup. This rod centrifugal force generating rod helps the media to simultaneously rotate at a speed while being axially post, the rotation of the rod causes a centrifugal force to act on the media which in turn increases the media contact quality. This is the schematic of this process.

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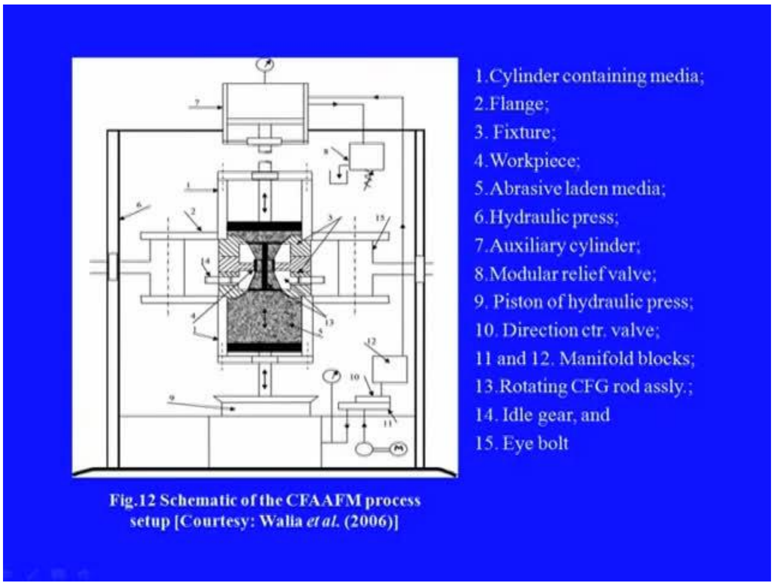

Fig.12 Schematic of the CFAAFM process setup [Courtesy: Walia *et al.* (2006)]

This is again the basic AFM setup as we have been seeing associated with different other processes in which this is cylinder one and this is cylinder two with media filled in this. And the media will be pushed from this side and will be collected this side and it will continue to be pushed on the either side. In between the work piece will be held here through this fixture arrangement and this is the black feature is nothing but the centrifugal force generating rod assembly. So, this is kept on rotating with some devices with gear devices which is connected through this tooling arrangement and the speed of this rod can be adjusted according to the requirement.

Now, because of the introduction of this rod the pressure inside this will be enhanced, the restriction will be more and therefore, the affect of this particles on this finishing of this work pieces will be much more, moreover as this rod will be kept on rotating at a particular speed this will exert a centrifugal force on the abrasive particles on this media. Therefore, these abrasive particles will hit this work piece surface with some additional forces which will cause better material removal as well as better surface finish.

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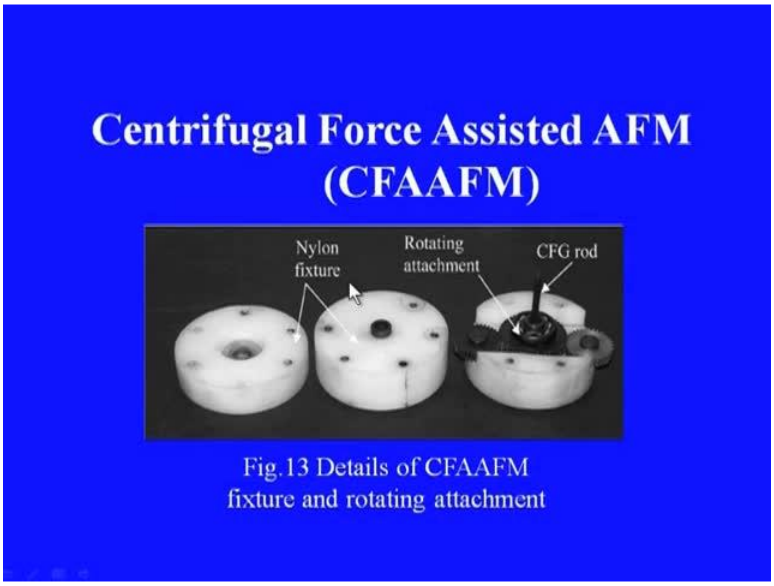

So, this is a fixture or tooling arrangement with the gear etcetera and the CFG rod centrifugal force generating rod. So, this rod will be kept on rotating with this gear enhancement at different speed during the process.

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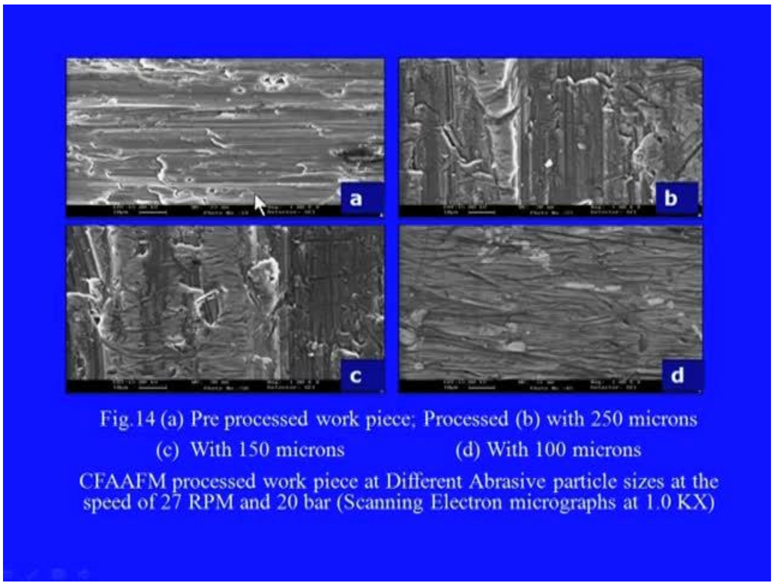

These are some of the results obtained through this centrifugal force assisted abrasive flow machining. So, here this is preprocessed. The work piece as we obtained and then this is with processed with 250 micron abrasive materials, abrasive grits, this is still finer grits that is 150 microns and this surface is machined with 100 micron grit.

Therefore, what we have seen from these figures is that as the abrasive grit size gets smaller the quality of the surface gets better.

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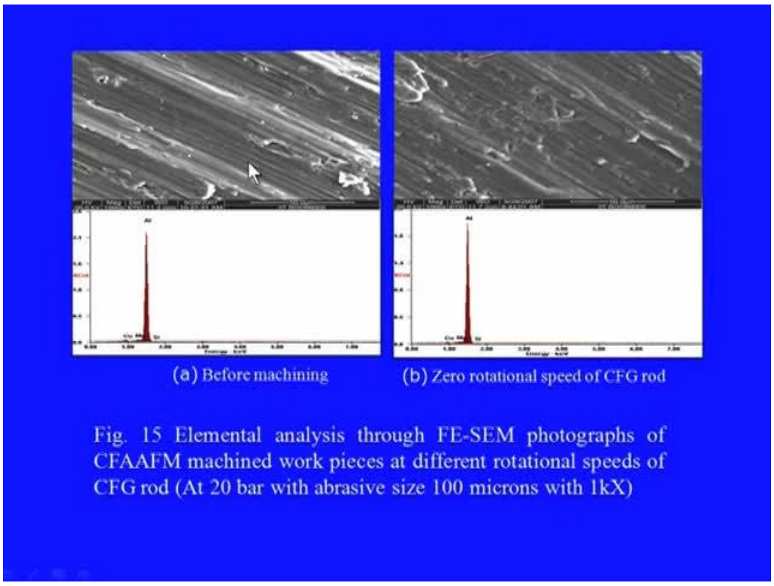

Similarly, so these are also two different surfaces. This is with abrasive flow machining, simple abrasive flow machining machined and this is with with CFG rod inside this. However, this CFG rod was not given any rotation, also this CFG rod was stationary even in the quality of the surface was better. This is another development in hybridization of AFM process.

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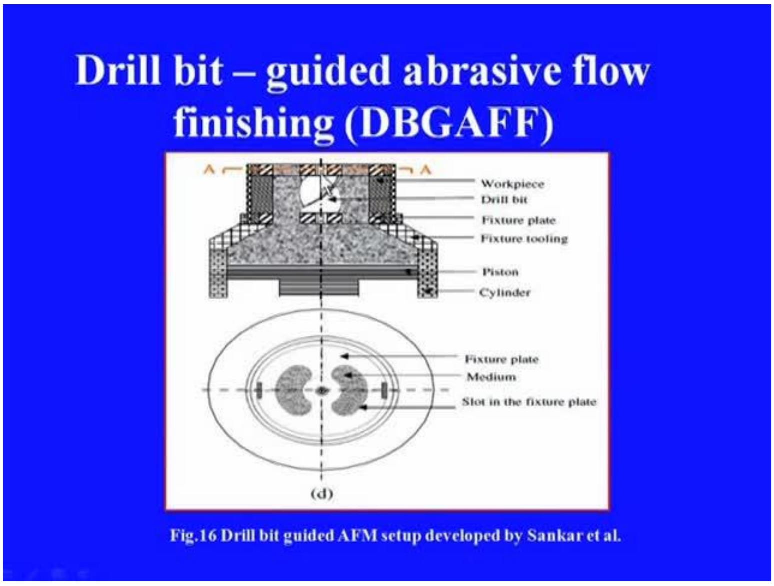

This is drill bit guided abrasive flow machining process in which the drill bit is inside this work piece which will be kept on rotating and that causes the rotation to this abrasive media and the principle is similar to that of centrifugal assisted abrasive flow machining process.

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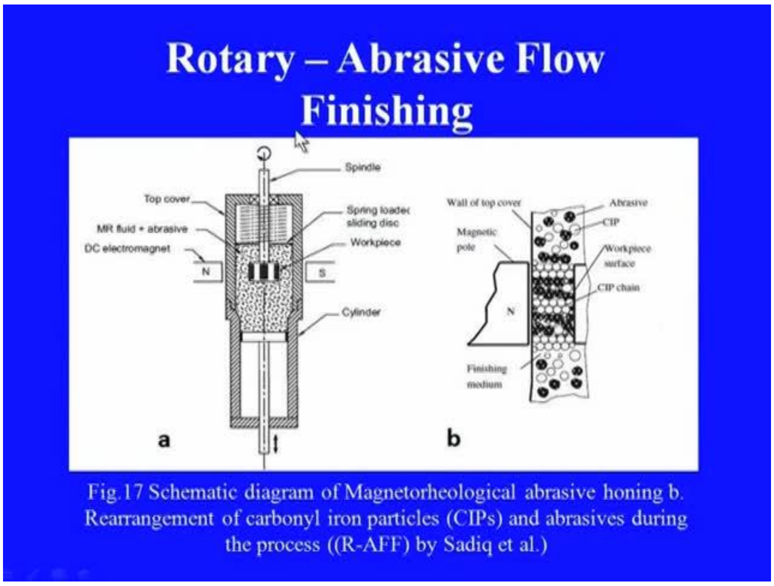

Fig.17 Schematic diagram of Magnetorheological abrasive honing b. Rearrangement of carbonyl iron particles (CIPs) and abrasives during the process ((R-AFF) by Sadiq et al.)

This is rotary abrasive flow machining process in which the principle is almost similar to what we have seen earlier. Just difference is here the media will be kept on rotating with this rotating device.

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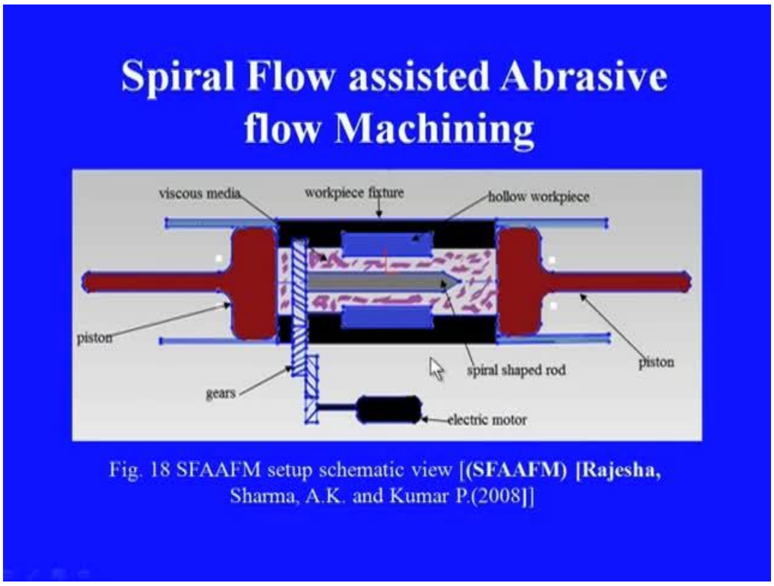

Fig. 18 SFAAFM setup schematic view [(SFAAFM) [Rajesha, Sharma, A.K. and Kumar P.(2008)]

This is another new development in this hybridization of abrasive flow machining in which ultrasonic affect is being introduced onto the work piece and this is the work piece in which in which the spiral rod is one spiral rod is used and this spiral rod is given the rotation with this motor assembly. And this media with abrasives will be will be traveling along this along this work piece surface causing more abrasion on this work piece and giving better result on the work piece surface.

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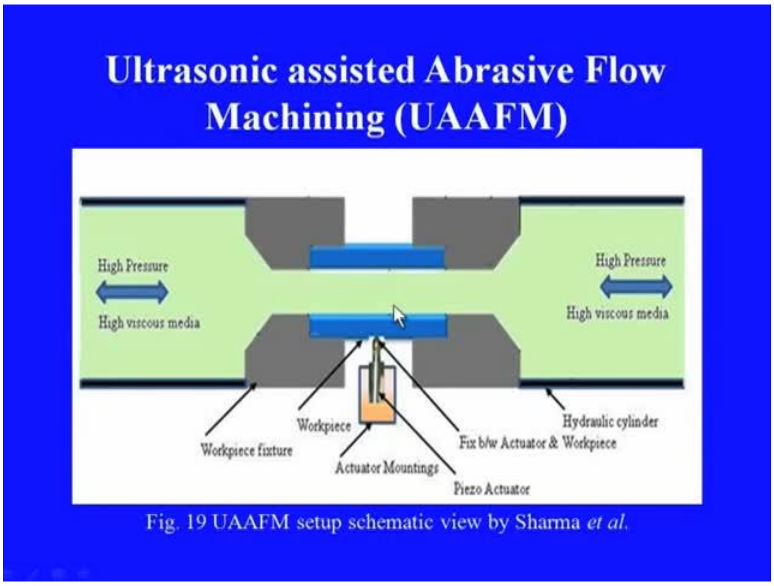

This is another new development in this area of hybridization in ultrasonic ultrasonic assisted abrasive flow machining process in which this work piece is given an additional ultrasonic vibration. And therefore, the abrasive particles will come more frequently in contact with asperities on this work piece surfaces and thereby getting a better surface finish of this work piece. This process was also developed in IIT, Roorkee in the recent years.

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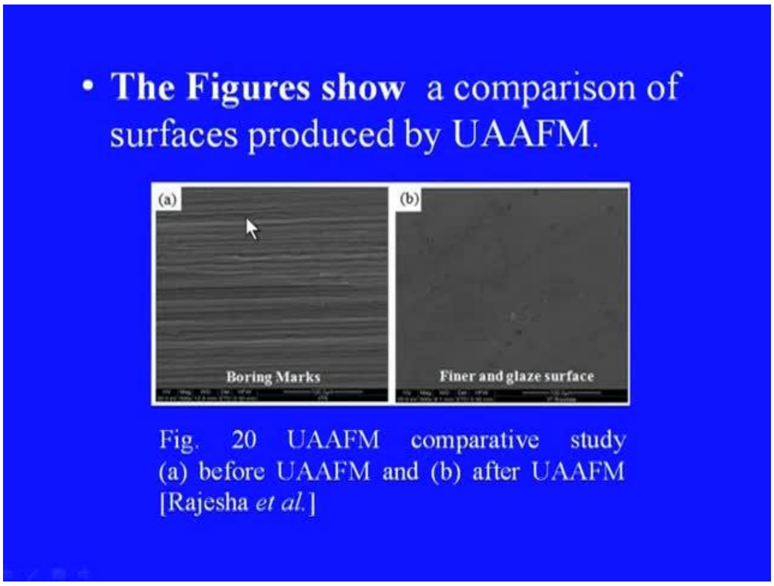

So, here we can see the result of these process like ultrasonic assisted abrasive flow machining machined surface which was prior to this was like this and this improvement in surface finish is nearly fifty times better.

Now, let us summarize what we have discussed in this particular session. In this session we have discussed the process parameters that affects the abrasive flow machining process, the mechanism of material removal that exist in abrasive flow machining process, the toolings used in abrasive flow machining process, new developments in hybridizations in the abrasive flow machining process etcetera. I hope this session was informative and interesting.

Thank you.