Advanced Manufacturing Processes

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Module - 3
Advanced Machining Processes
Lecture - 1
Abrasive Flow Machining

Welcome to this session on advanced manufacturing processes, particularly in advanced material removing processes. In this session, we will discuss some popular advanced material removal processes, earlier today's we have already discussed few advanced casting processes. The casting processes as you know are basically additive processes. In which materials are added, but the processes that we are going to discuss hence forth will be basically processes that involves material removal from the parent work piece. And here some processes that use some advanced techniques, those will be covered in this session.

In this session, we will study about need for advanced material removal processes and then what are the conditions that lead to the development of these processes, like the abrasive flow machining, which is considered to be an advanced machining processes. Then in particular, in this particular session, the AFM which is abrasive flow machining process, its working principle, its advantages, limitations and applications will be discussed.

Before going into the particular abrasive flow machining process, let us quickly refresh about the need for advanced material removal processes. Why do we need these advanced processes, whereas we have number of conventional processes like we know turning, milling, grinding and so many other processes, which are even today very relevant and very widely used. But in spite of having all these processes, we are moving towards some other processes, which are very, very unconventional and are called advance manufacturing processes. Let us see what are the need for these processes, development of these processes.

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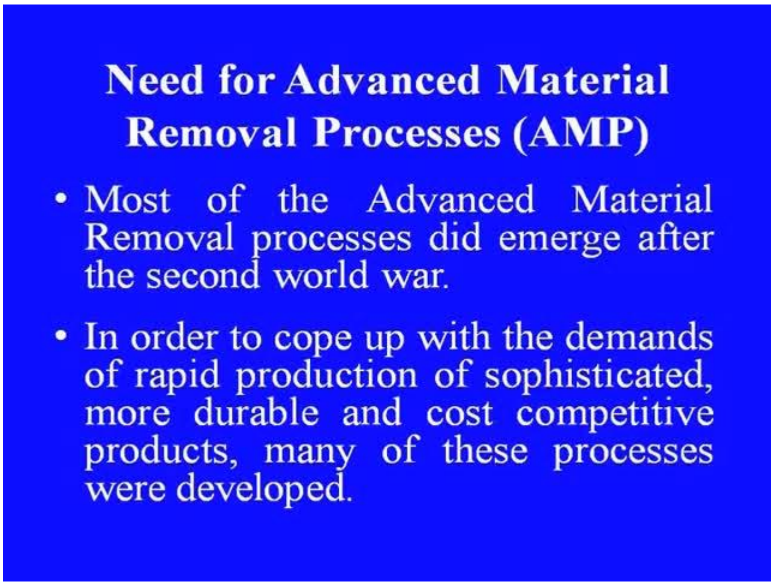

Most of these processes did immerse after the World War 2. During world war the situation was, the manufacturing activities needed to be very, very fast. The products requirements were tremendous and the time for production were very less. Therefore, there was a need that how we can produce the products at a very faster rate.

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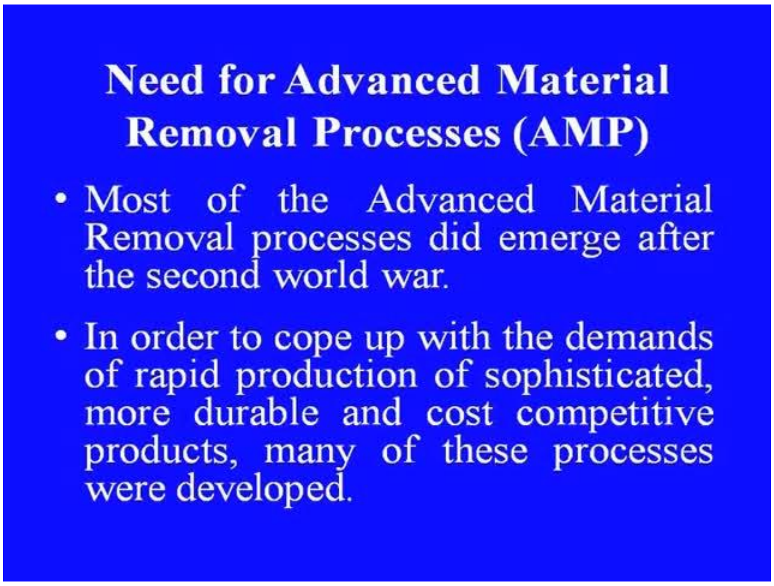

In order to cope up with these demand, increased demand in rapid production of sophisticated and more durable and of course, it has to be cost competitive as well, products some of the new processes were developed. The advent of new materials such as metal matrix composites, which we call or popularly known as MMC's, super alloys, ceramics aluminates and high performance polymers called for development of newer manufacturing processes.

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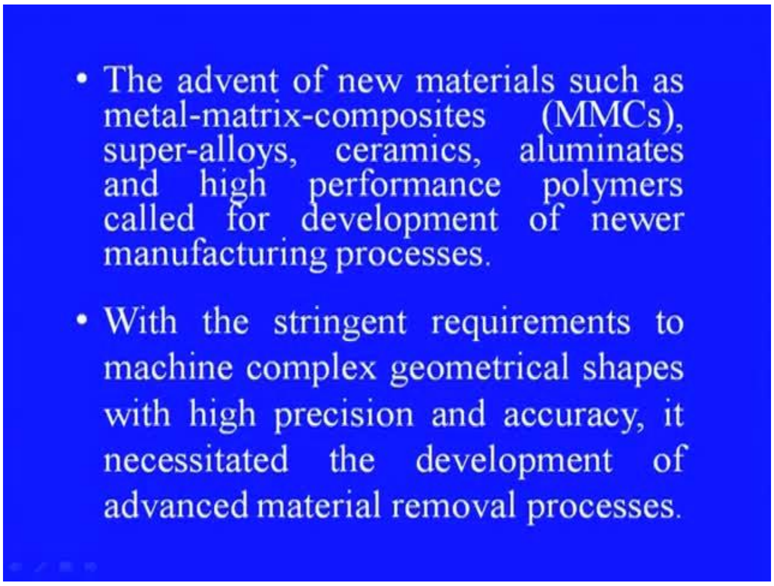

Some of these materials, which we are talking about this MMC's, super alloys; these are mostly nickel based alloys, these are very difficult to machine in the conventional ways. They are very hard; they are heat resistant and very difficult to be processed with the conventional processes like turning and milling etcetera. If at all they can be the cost effectiveness goes down. Therefore, the need arises like how we can bring down the cost to process these materials, which were very, very vital in many applications. Another important issue was the stringent requirement to machine complex geometrical safes, which high precision and accuracy. This also necessitated the development of some of the advanced material removal processes. As we know this milling, turning and all these conventional processes has some limitations, as far as the precision is concerned. The processes in this category differ from conventional processes, in either utilization of energy, in an innovative way or in using forms of energy that were not used for purpose of manufacturing earlier.

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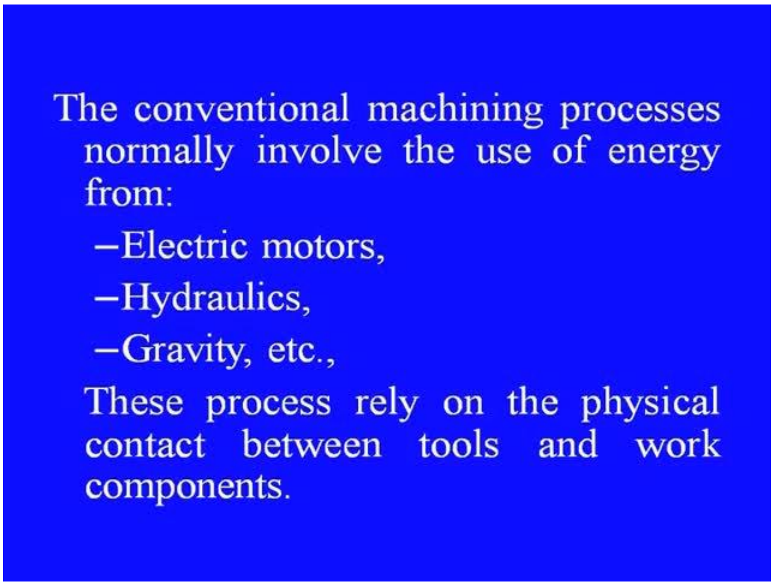

The conventional machining processes normally involved use of energy from electrical motors, hydraulics or gravity etcetera. As we have seen in most of the conventional machines like in lathe machines, we use electrical motors, then in some of the machines like press working machines etcetera. We use hydraulics hydraulic powers etcetera. Then in some of the machines like the stamping etcetera, we can use gravity and so on and these are considered to be pretty conventional methods of producing a part. These processes mostly rely on these physical contacts between tools and the work components. However, the processes, the advanced processes that we are going to discuss are mostly non contact in nature. This is one of the most important issue in this case where there is no physical contact between the so called tool and the work material yet the machining is done very effectively.

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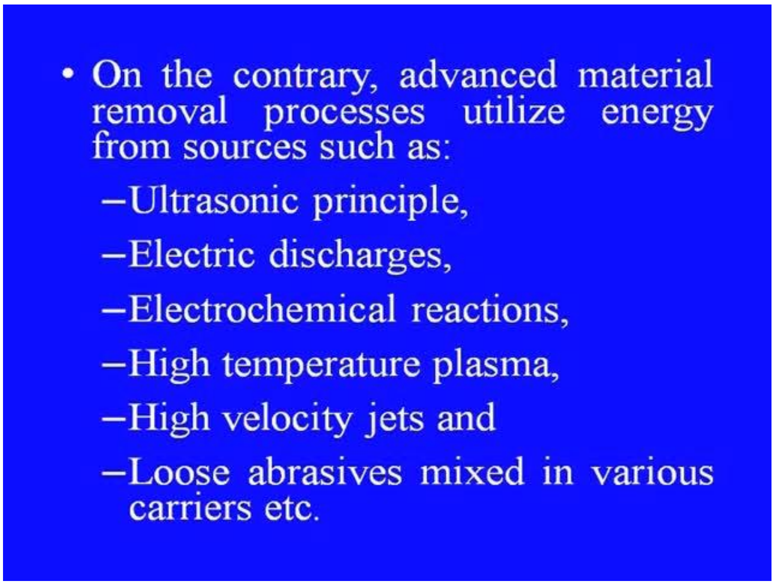

The advanced material removal processes utilize energy from some sources like ultra sonic principle, then electric discharges, electro chemical reactions, then high temperature plasma, high velocity jets, loose abrasives mixed in various carriers then other electromagnetic energies etcetera. Originally these processes were developed to handle unique problems in aerospace industry, for machining very hard and tough alloys. Today a wide range of industries have adopted this technology in numerous manufacturing applications.

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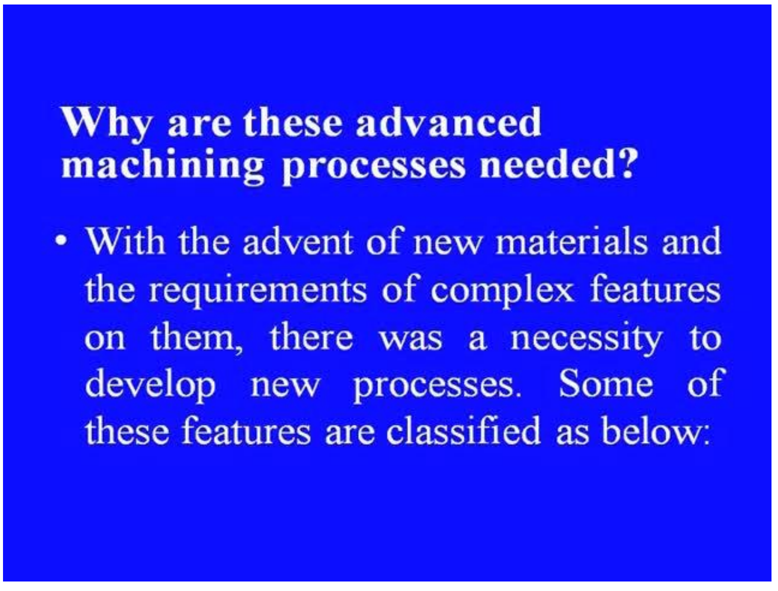

Then let us see why these advanced machining processes are needed. With the advent of new materials and requirements of complex features on them, there was a necessity to develop new processes some of these features are classified like this one issue is related to material properties. The materials I have already mentioned like very high strength materials like in (( )) etcetera, very high hardness material like tungsten, carbide etcetera. Very high strength materials and having high brittleness, these materials need to be effectively machined using some processes, so that we can have a less distorted or you can say a perfect job, as required.

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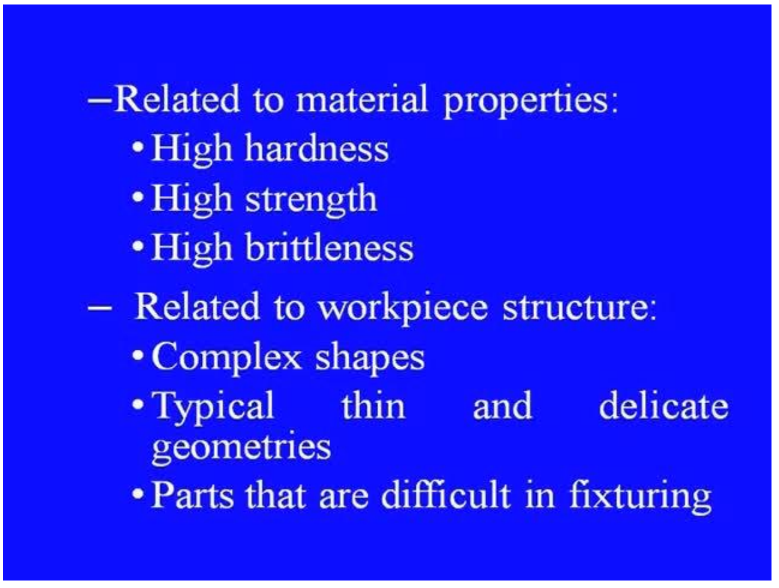

Then related to the work piece structure if the shapes are very complex, then giving these shapes by conventional machining processes is surely time taking. Then typical thin and delicate geometries of the jobs that also takes lot of production time and hence the cost of production gets increased with these conventional processes. Then parts that are difficult in fixturing, this is another important aspect, as we know in case of the machines like lathe, milling, grinding etcetera.

There are some conventional tooling as well in which the work piece is fixed in a particular manner. However if the job is very thin, if the job is very small, if the job to be produced have very complex shapes and geometries then fixing them on a fixture is very difficult. Rather if they can be machined without such fixture then it is convenient as far as the economics of the process is concerned.

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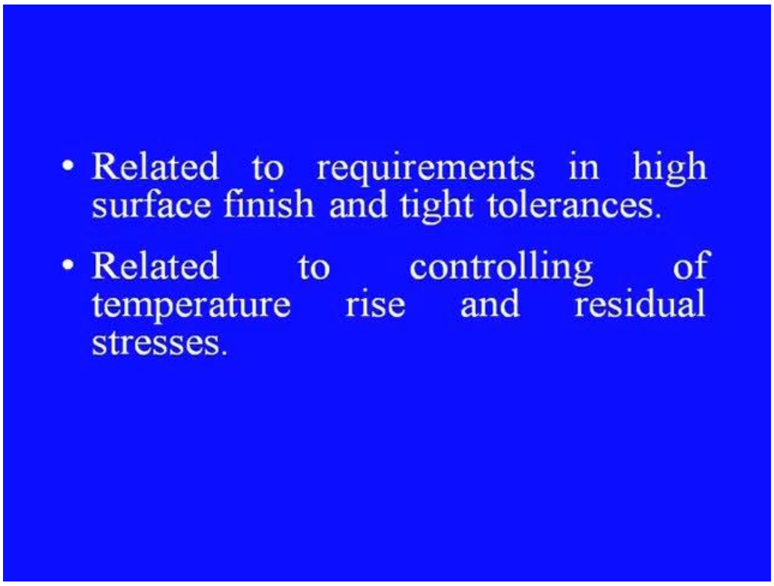

Another point is related to the requirements in high surface finish and high tolerances. Then related to the controlling of temperature rise and residual stresses, these are also considered to be very important issues as if high temperature is developed while machining, it can cause some damage to the part. If the part dimension is relatively very small then there is a possibility that due to this high temperature developed during machining the entire part may get effected, which is at times undesirable. Therefore, we had to look for some processes in which these can be atleast minimized, if not eliminated.

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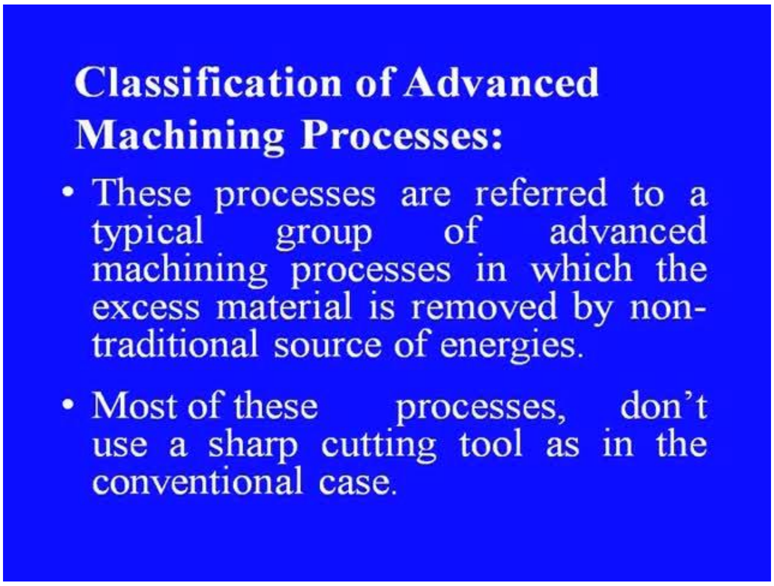

Now, let us see, how do we classify these advanced machining processes. We have already seen the background based on which we have developed or gone for the advanced machining processes. Now, how these processes can be classified. These processes are referred to a typical group of advanced machining processes, in which the excess material is removed by nontraditional source of energies. These sources already I have mentioned, most of these processes do not use a sharp cutting tool as in the conventional cases.

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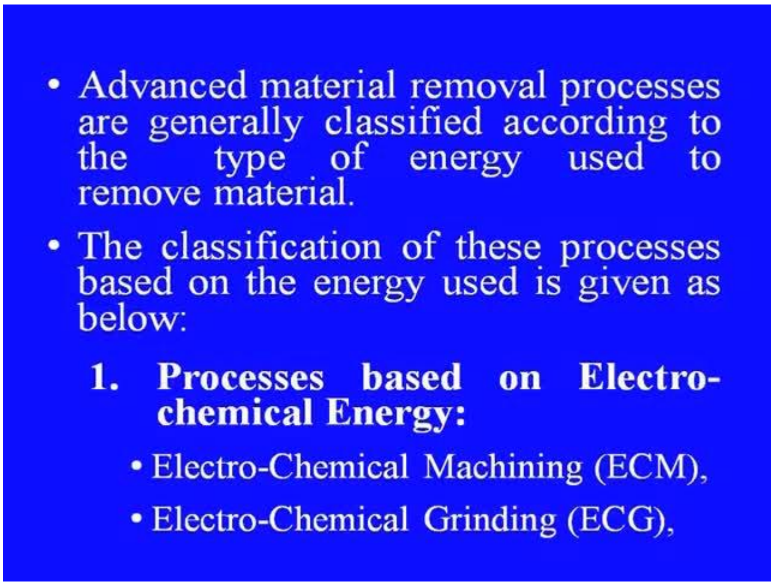

Advanced material removal processes are generally classified according to the type of energy used to remove material, the classification of these processes is based on the energy used, are given like this. Number one processes based on electro chemical energy, these processes include electro chemical machining, in short it is known as ECM very popular as ECM. Then electro chemical grinding, in short it is known as ECG process. Then another category is the processes based on the use of thermal energy these processes include electron discharge machining also known as EDM.

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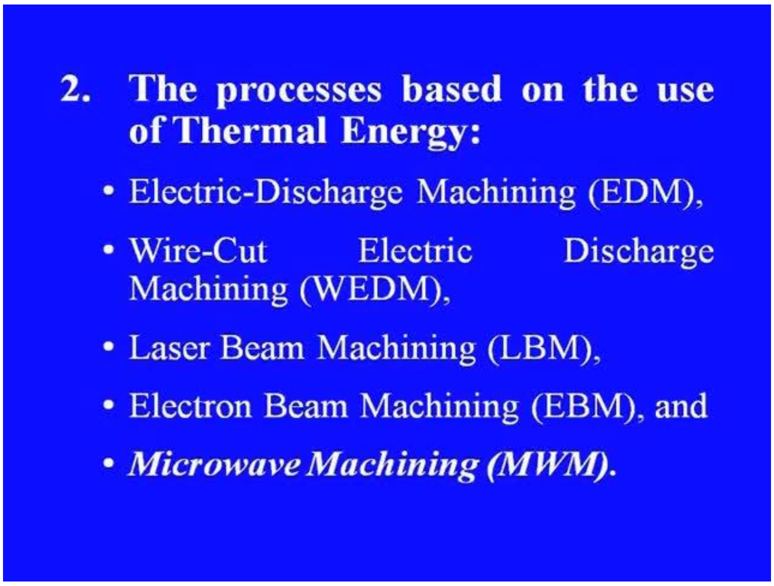

Then wire cut electric discharge machining, also known as WEDM. Then laser beam machining, very popular as LBM. Then electron beam machining known as EBM. This, this LBM and EBM are two processes used for precision machining, very small cut can be achieved with this. Hence very small holes of diameter in microns can be developed using these two processes and I wish to add one more process, which is fast developing, which is considered as micro wave machining MWM. Not much texts are available regarding this new process micro wave machining. However there are some reports one from the researches of (( )) and some research outputs from IIT Roorkee.

These researches have shown that micro waves, which we very frequently use in our kitchen ovens, micro wave ovens, can also be used for machining purposes. Already the researches in IIT Roorkee have shown that the materials like wood, materials like some animal bones, then materials like non metallic materials glass and then even metallic materials like aluminum can be machined by this process. We are sure by further refinement of these process and further developments in these process this micro wave machining process will also establish itself to be placed alongside the precision machining processes like laser beam machining and electron beam machining, ion beam machining and so on.

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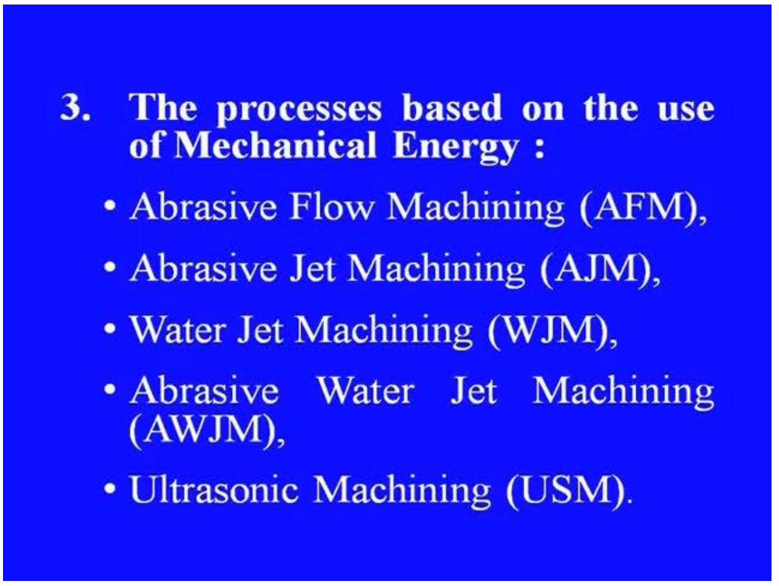

Then third category of these processes are based on the use of mechanical energy. These processes include abrasive flow machining, which is in short known as AFM then abrasive jet machining also known as AJM, water jet machining WJM. Which we can, we can say completely use of mechanical energy, conversion of mechanical energy and then abrasive water jet machining, which can be considered as a hybrid of this water jet machining as well as abrasive jet machining and then ultra sonic machining. Which is by far very, very popular process as far as the machining of brittle materials are concerned. As we know brittle, brittle materials are very difficult to machine with the conventional machining processes.

However this ultra-sonic machining is bound to be very, very effective in machining these materials like glasses etcetera. Now let us see this process, some of these processes one by one in details. First of all let us see the abrasive flow machining process, which is a mechanical material removal process and basically, it is used for finishing purposes and most of these uses of these AFM process is for internal parts, internal surfaces are finished using this part. The requirements in this process can be correlated like this.

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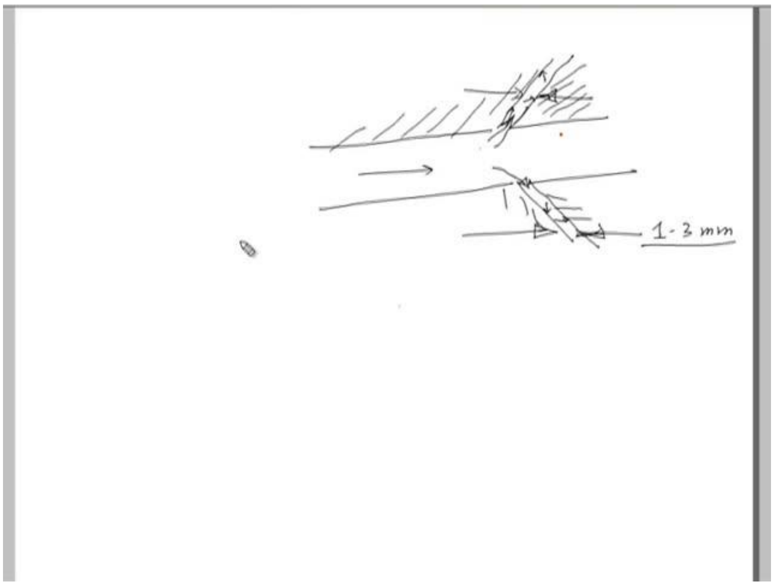

Say for example, if we have a part like this which has got some openings like this and this, this is the part, this has got the opening like this and this opening diameter, here. This diameter is in terms of say 1, 2, 3 milimeter or something like this. Now finishing the walls, these walls, these walls of these channels, we can say this is a channel or sub channel of this main part, this finishing of these walls are really very challenging as far as the conventional machining processes are concerned. For, let us see any finishing processes in the conventional category, the tools will have to be inserted through this openings which is a very, very challenging task in this case. Therefore, these we can consider as one of the limitations of the conventional processes.

However, if we can develop some other process which is capable of reaching these points then perhaps we can call it as a advanced manufacturing process, which is capable of finishing the channels or the openings or in other technical terminology the intricate shapes, very easily.

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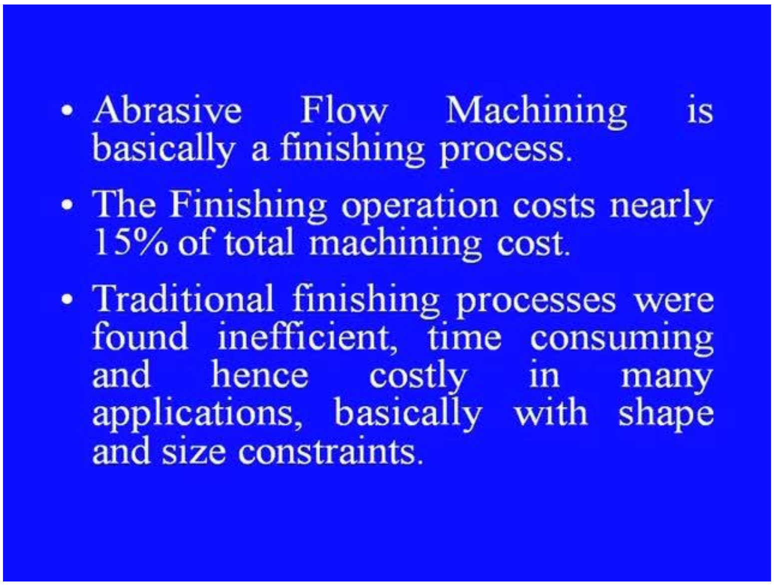

Let us see some of these. This abrasive flow machining process is basically a finishing process, as we know this finishing operation is very important as far as the manufacturing is concerned. Almost a fifteen percent of the total machining cost is for finishing a part only. However these traditional finishing processes were found inefficient as I told just now and the time consuming and hence they are costly as well.

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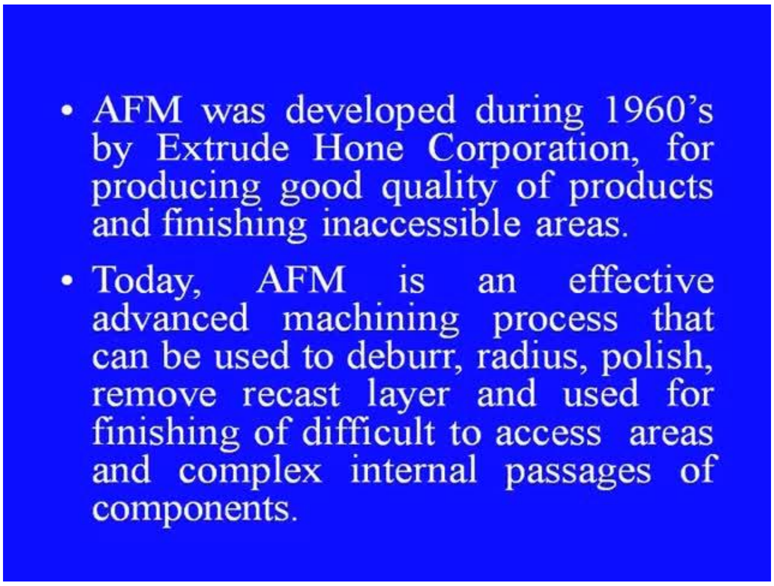

With these problems or limitations of the conventional finishing processes in mind abrasive flow machining was developed during the year 1960s by Extrude Hone

Corporation of the United States of America for producing good quality of products and finishing inaccessible areas. Today this process, abrasive flow machining is an effective advance machining process that can be used to deburr, radius polish, remove recast layers and also can be used for finishing difficult to access areas and complex internal passages of components, which I have just now discussed.

The AFM process is capable of removing the scratching marks produced by other machining processes as we know in most of the conventional machining processes the scratch marks are produced like this, what you call the feed marks.

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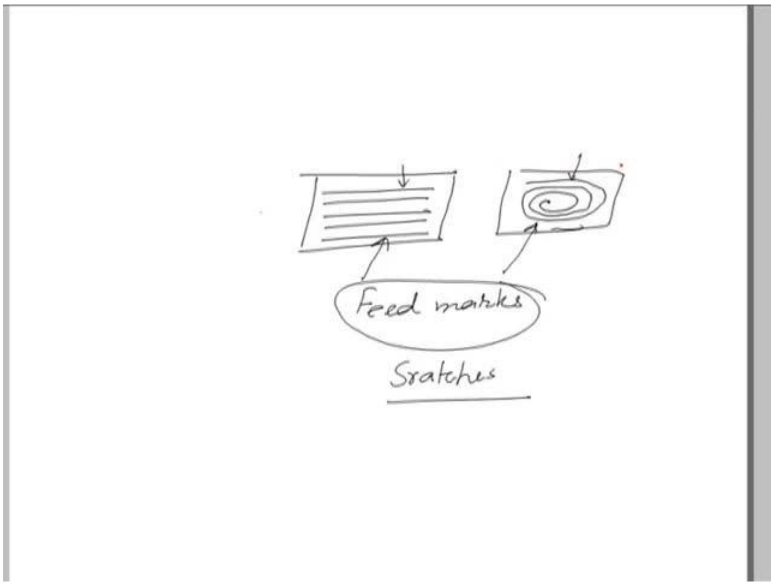

In most of the, if it is, if it is a milling process then the surface will have some kind of the textures, something like this or it can be something like this, depending on the process. However, these kind of these kind of marks that also we call as feed marks. These are results of nothing but some scratches of the conventional tool. However this may not be desirable in most of the products. Therefore, how to remove these feed marks we have to only way is we have to go for some of the finishing processes. Now, here is this process AFM process, which can be effectively used for removing these feed marks or at least to minimize these kind of feed marks to a minimum or acceptable level. Let us see how it goes with the help of subsequent figures etcetera.

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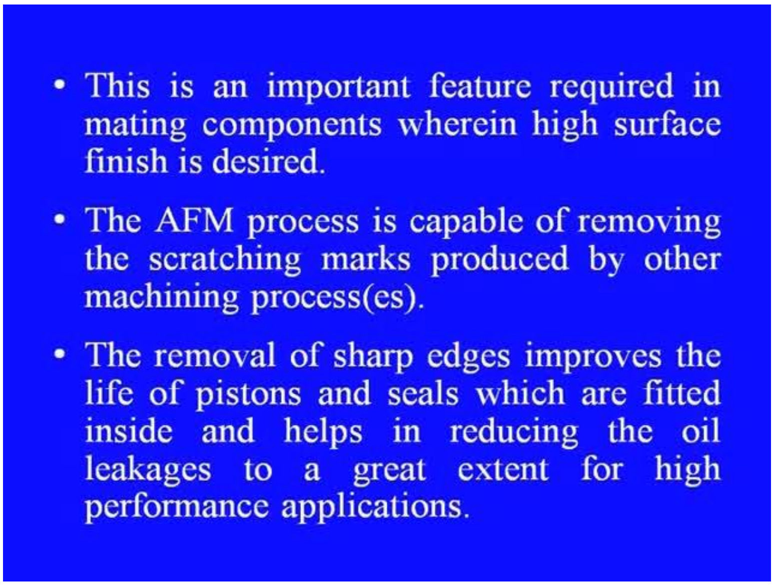

The removal of sharp edges improve the life of pistons and seals which are fitted inside and helps in reducing oil leakages to a great extent for high performance applications. This also can be removed by finishing part to a very close tolerance. In case of one way systems in AFM media is flown or passed through the work piece and it returns to the other end. Whereas, in case of two way AFM process, two opposite hydraulic cylinders push the abrasive abrasive mixed media to and fro.

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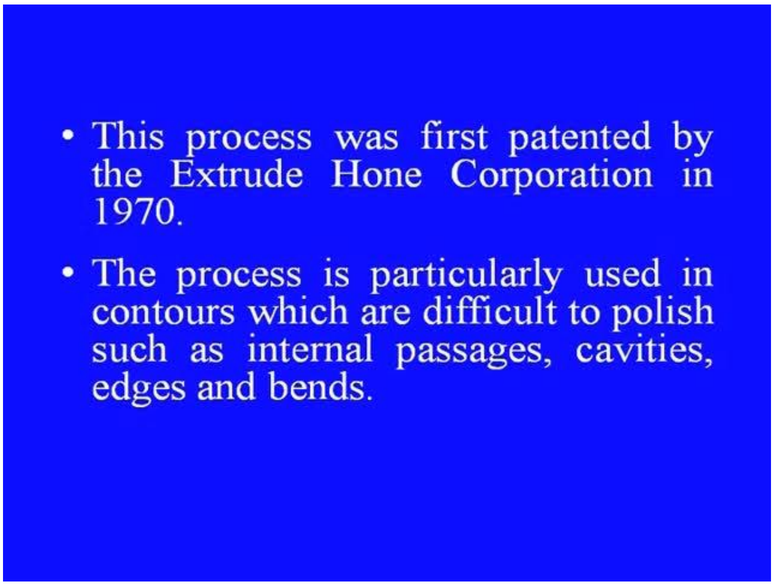

This process was first patented by Extrude Hone Corporation in 1970. The process is particularly used in contours which are difficult to polish, such as internal passages, cavities, edges and bends. The AFM process is widely used in a range of different finishing operations, at a given time it can process in number of parts or different areas of same work parts. Practical applications of this process could be in any of the situations where in the media could be flown across.

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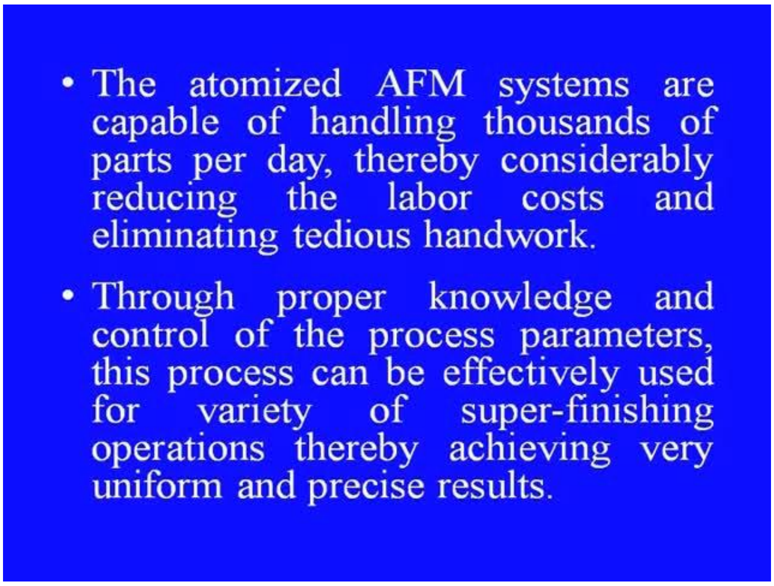

The atomized AFM process are capable of handling thousands of parts per day. Thereby considerably reducing the labor cost and eliminating tedious handwork. Through proper knowledge and control of the process parameters this process can be effectively used for variety of super finishing operations, thereby achieving very uniform and precise results.

Now, let us look at the principles of this abrasive flow machining process. In the AFM process a semi solid media is used, which comprises of a carrier in the form of a polymer base, which contains abrasive particles in a desired proportion. It is extruded under the given pressure across the surface which is to be machined.

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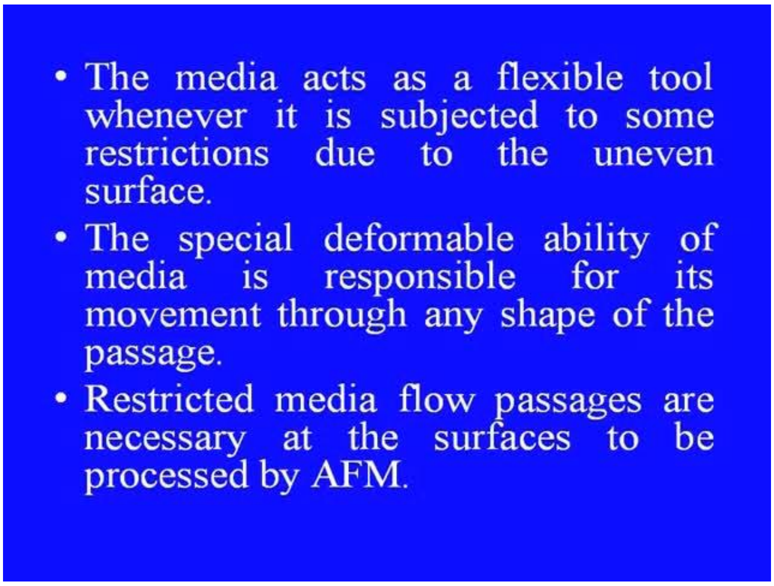

The media acts as a flexible tool whenever it is subjected to some restrictions due to the uneven surface the special deformable ability of this media is responsible for its movement through any shape of the passage this can be seen like this.

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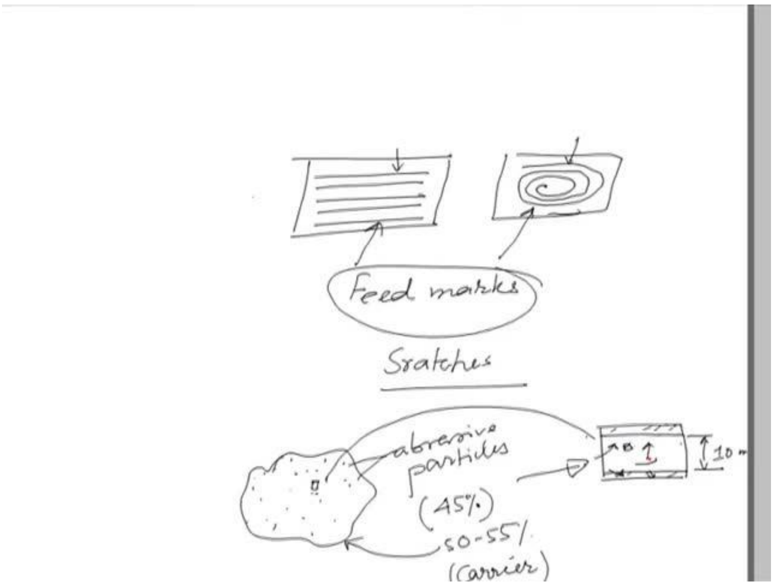

The media if it is something like this which is very soft, highly viscous media and this contains some of the abrasive particles, these are the abrasive particles, these are abrasive particles. Now this abrasive particles at some percentage, say for example, say 45 percent and remaining 55 percent, 50 to 55 percent is say the carrier. This is also called the carrier they are mixed together and made a deformable stone. Now these deformable stone which is in fact flexible can be made to pass through some restrictions. Say for example, a small hole something like this and this hole diameter is something like say few millimeters, say 10 millimeter or so. Now, this can take, this deformable stone can take the form of the feature that is fixed on this tooling and media is allowed to move through this. While moving through this, this media will come in contact with these surfaces, which are to be machined, are to be finished.

Now, in fact this abrasive particles, these tiny abrasive particles which are very small in nature will scratch these surface or we we can say which will plastically deformed. At times they will remove some of the materials in the form of tiny chips here and in the process the surface, this surface will get machined or finished. The restricted media flow passages are necessary at the surfaces to be processed by AFM. In this process the media behaves somewhat like a flexible grinding stone, just now I have told how it can be flexible that abrase the material and provides a good surface finish. Generally a fixture is required to offer restriction or to direct and focus the media to the desired locations in the work place.The figure one illustrates the principle and basic operation of this AFM process.

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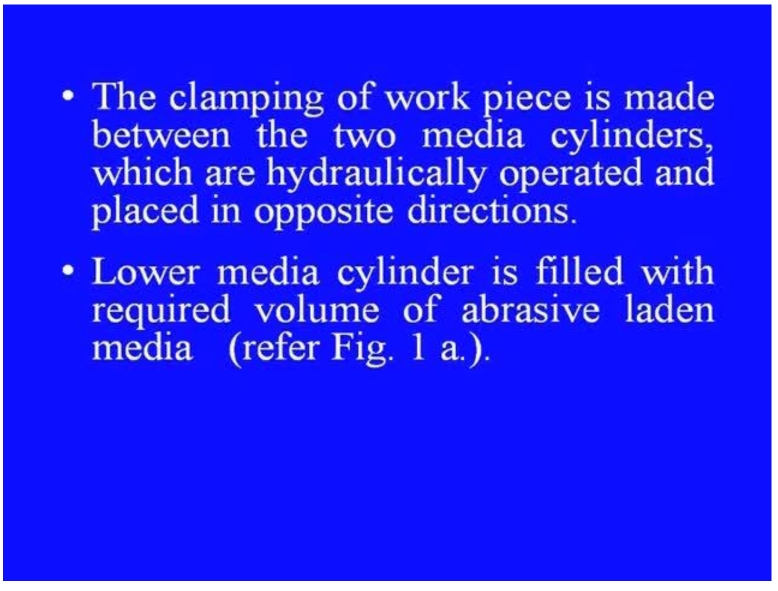

The clamping of the work piece is to be made between the two media cylinders in case of two way process, which are hydraulically operated and placed in opposite directions. The media, the lower media cylinder if it is horizontal if it is a vertical set up is filled with required volume of abrasive, laden media as shown in this figure. The media is then extruded through the work piece into the upper media cylinder, in case of vertical configuration or to the other cylinder in case of horizontal configuration. The procedure is repeated and the media is fed back through the work piece into the other cylinder. The process cycle is constituted by combination of these to and fro stroke.

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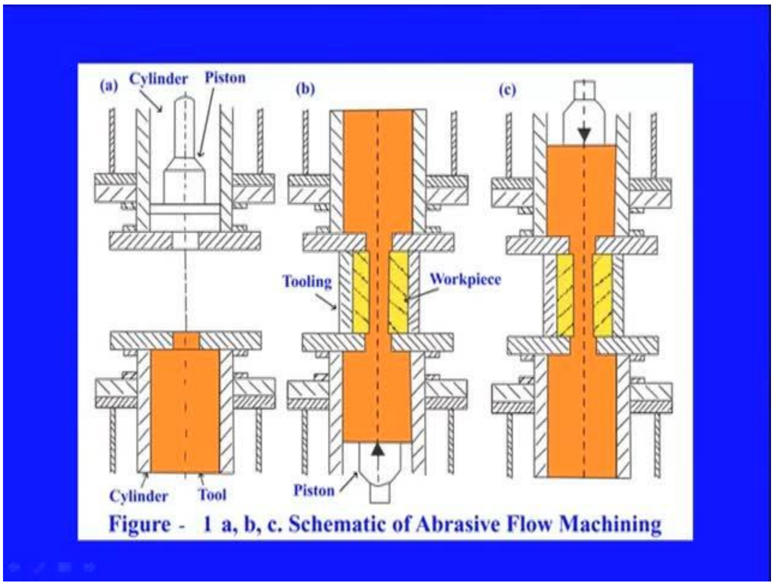

This is the entire mechanism, the entire arrangement is in the screen. So, here it is a vertical configuration is shown so this is the lower cylinder in which this orange material is nothing but the media that contains the tiny abrasive particles and these abrasive particles may be of aluminum oxide or can be silicon carbide. These will be pushed through the small openings and to the other cylinder in between there will be the work piece through some fixture. The work piece will be placed in such way that the surfaces of interest can come in contact with this media. While passing through this to the other cylinder this media will be pushed from this side and it will under pressure. It will move into the other cylinder while coming through it will interact with the work piece as shown in this figure.

So here this is, this is the work piece and this is clamp through some tooling enhancement and the media which the tiny abrasive particles are coming in contact with this work surface. In the process the tiny abrasive particles are cutting some of the portions of this work piece surface, making it better one. Then as this media will be completely pushed through this passage and the other cylinder will get filled, in the subsequent process the media from this cylinder will be pushed back to the next cylinder and the process will be repeated to and fro like this for several cycles. Depending on the accuracy required the surface finish required or depending on the material and so on.

This configuration is shown here is a particle configuration the same can can be the horizontal one as well. The, but the principle remains same the working principle, let us see in brief.

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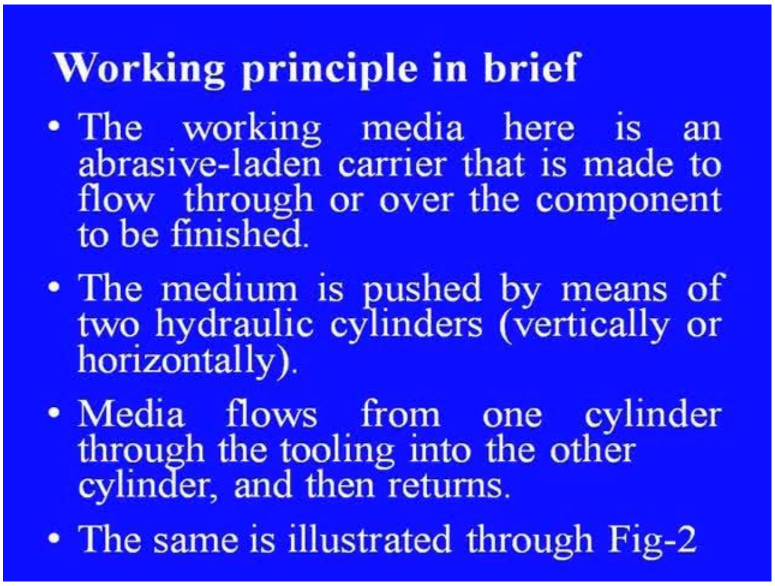

The media have here, here is an abrasive laden carrier that is made to flow through or over the component to be finished. The medium is pushed by means of two hydraulic cylinders, it can be in vertical enhancement or it can be in horizontal enhancement. Then media flows from one cylinder to the tooling into the other cylinder and then it returns and this was shown in the figure.

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Figure-2: Working principle in AFM.

So, this is this is little enhanced view of what happens while the media is pushed through the work piece. So this is the work piece, we can think of this is the work piece surface to be finished, roughness is to be removed. Now these are the abrasive particles that comes in contact with the surface of interest and they causes micro cutting here. On this asperities of the surface and removes some materials in the form of small chips. This we can think of small chips are being produced as a result of this AFM. This is the in brief the principle what is used in the AFM process, then the coming to the mechanism of material removal in this process. Let us see what are the different mechanisms involved in abrasion in AFM process.

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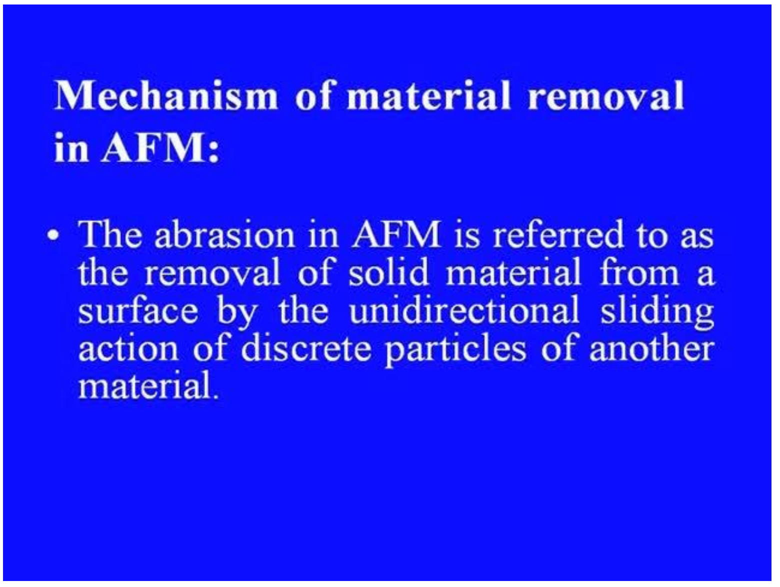

Here this is the removal of solid material from a surface by unidirectional sliding of the discrete particles of another material. Khrushchov and Bavichov identified the following factors when abrasive grains made contact with the varying surfaces, they have developed some of the observe some of the findings like this.

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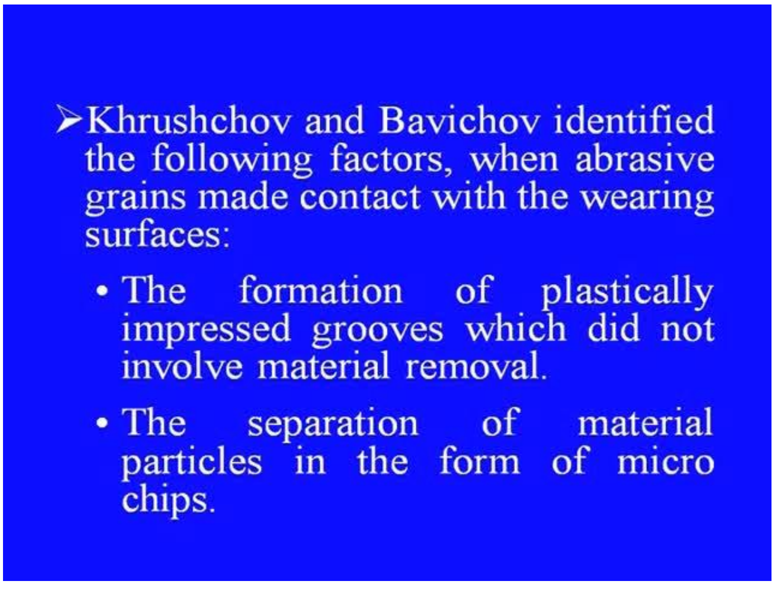

The formation of plastically impressed grooves, which did not involve material removal, but only the plastic deformation of the surface. Then the separation of material particles in the form of microchips, this is the number two phenomenon that happens. Then indentation of abrasive particles on the work piece surface and subsequently particle movements along the scratch length. In case of ductile materials micro cropping and micro cutting phenomenon are taking place. While in case of brittle materials mostly or predominantly the micro cutting phenomenon does take place.

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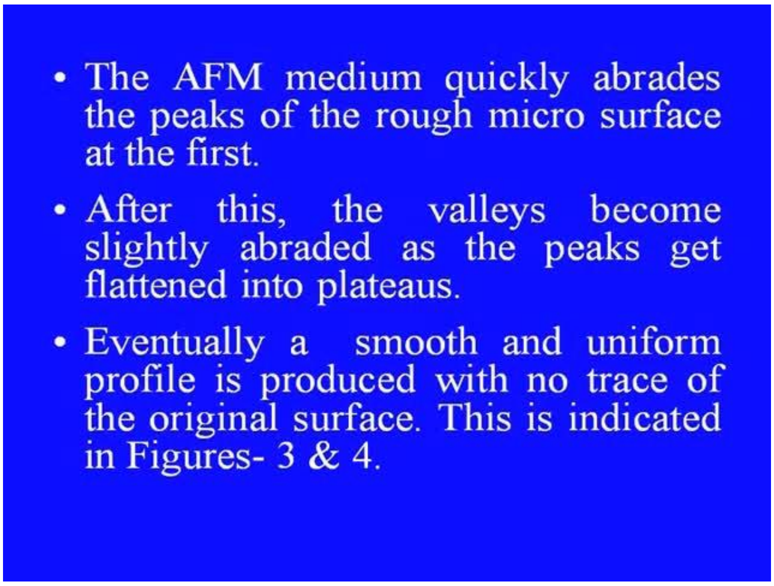

The AFM medium quickly abrades the peaks of the rough micro surface, at the first. Then the valleys become slightly abraded as the peaks get flattened into plateaus. This we will see with the help of some figures which are there in later stage. Eventually a smooth and uniform profile is produced with north phase of original surface. This is shown in these figures.

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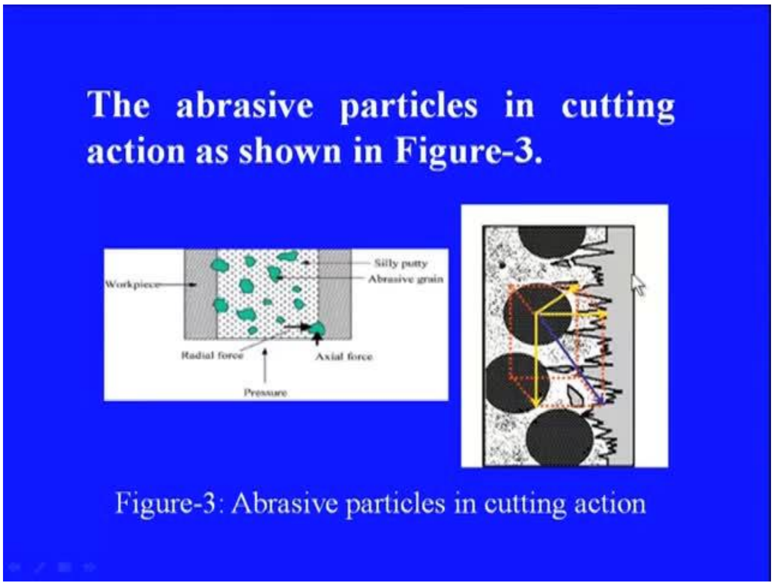

So, this we can say in a magnified view of the work piece surface, where these are some of the pics of the roughness, roughness pics we can say asperities and these needs to be smoothened out or cut so that we can get very smooth work piece surface. This can be done with the help of tiny abrasive particles, like this. These abrasive particles are pushed through this with the help of this medium, which is pushed through this under pressure, when coming in contact with these asperities some of these asperities gets cut. So, these are the abrasive particles this is immersed in this media, which is pushed under this, under pressure and while coming through this some of them will remove or cut some of these asperities like this and this has become now a tiny chip.

In some cases they may plastically deform these tiny chips as tiny asperities as well where in the actual cutting is not taking place, but plastic deformation is definitely taking place and thereby the improvement in this surface of this work piece is achieved.

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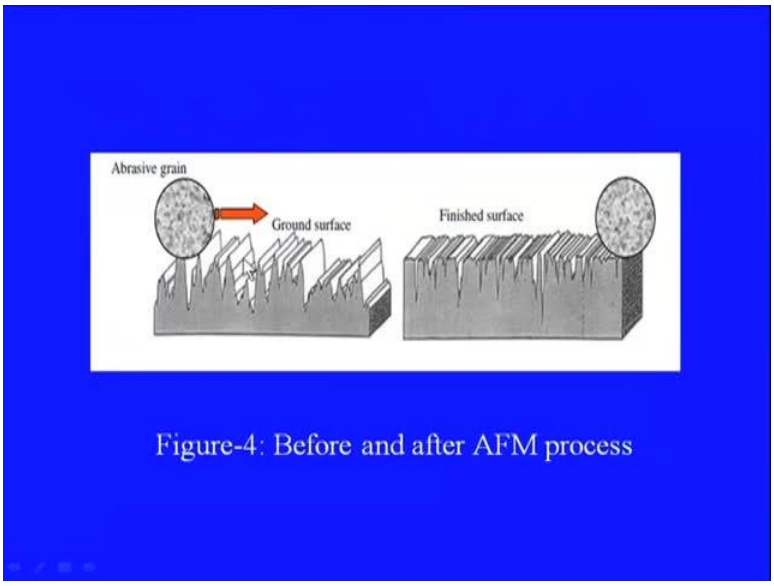

Here we can see in another form so the abrasive particles. This we can think of abrasive particles and these are some of the asperities. Schematically this is shown like this and while pushing through this, these abrasive particles will remove some of these asperities either by cutting or by plastic deformation and the resulting surface after sometime would look like this. This is, by mere comparison we can say this surface is much smoother than what we had prior to this process and if you continue this for sometime this may improve further. Of course, there is a limit and there are certain optimum conditions to which we can continue this process.

The AFM technology in details if you can see there are three major elements in this process the machine, the media and the tooling. The machine decides the extent of abrasion. The media determines what kind of abrasion will occur and the fixture determines the exact location of the abrasion. In this way all these three vital components are very very important in this process.

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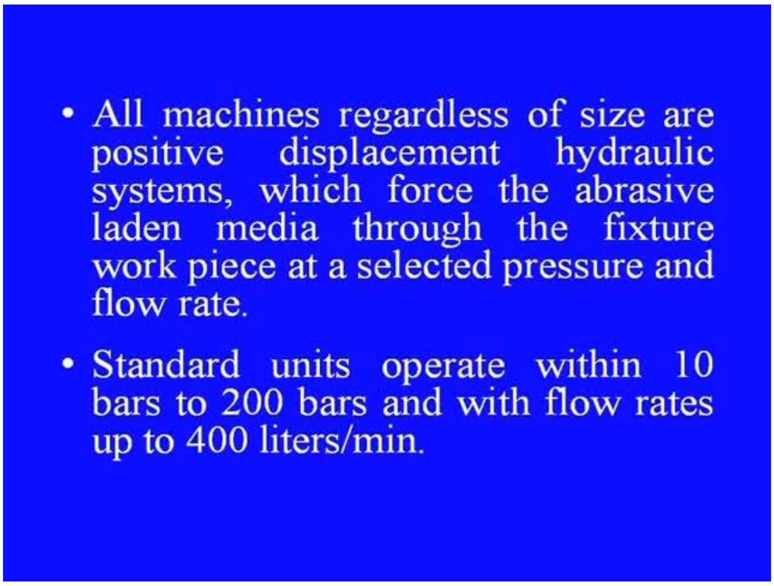

All machines regardless of size or positive displacement hydraulic systems, which force the abrasive lead in media through the fixture, and work piece at a selected pressure and flow rate. Standard units operate within 10 bars to 200 bars and with flow rates up to 400 liters per minute.

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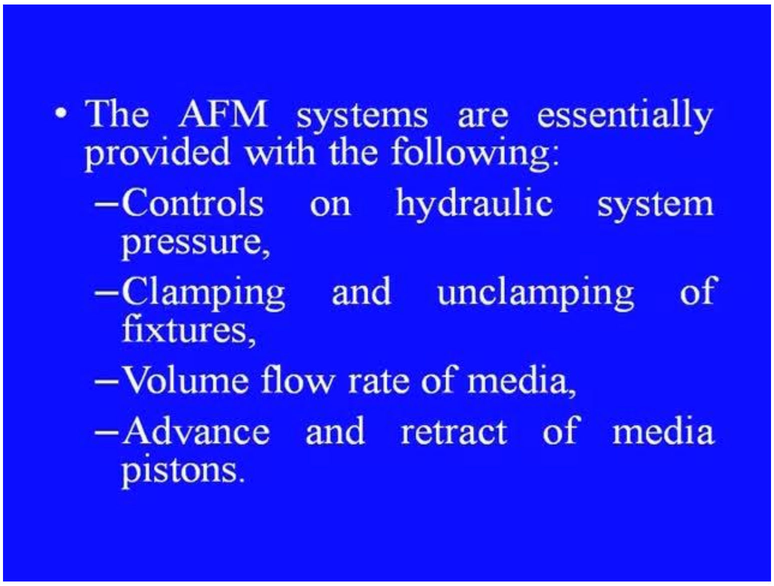

The AFM systems are essentially provided with the following things like controls on hydraulic system pressure, the clamping and unclamping of the fixtures, the volume flow rate of media, the advance and retract of media pistons.

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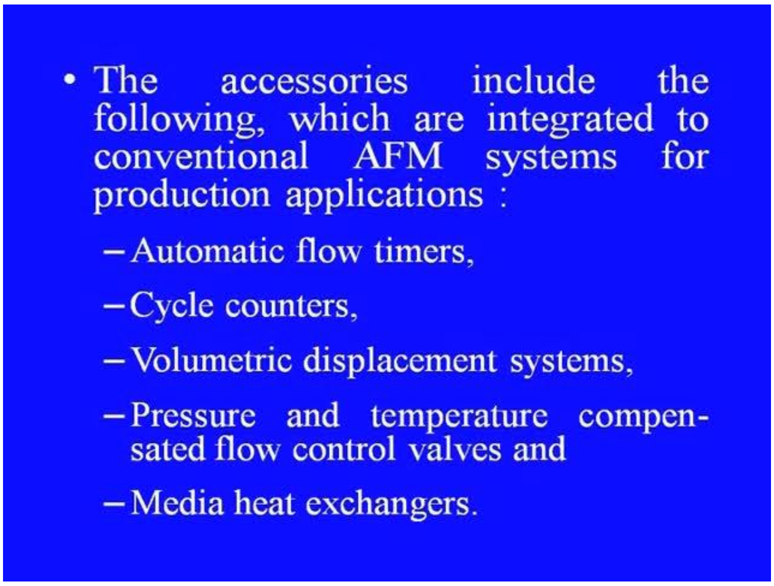

The accessories include the automatic flow timers, cycle counters, volumetric displacement systems, pressure and temperature compensated flow control valves and media heat exchangers. The most essential component of the process is the media, which is considered a proprietary item by machine manufacturers and this is also a costly component of this entire process.

It consist of base material or carrier abrasive grains and some proprietary additives, who is generally the manufacturers or the developers do not want to disclose. The most widely used carrier is a high viscosity re op, re optic fluid at any constant rate of sear its upfront viscosity increases with time to some maximum value. The base material has enough degree of cohesion and tenacity to dragged abrasive grains along with it through various passages or regions.

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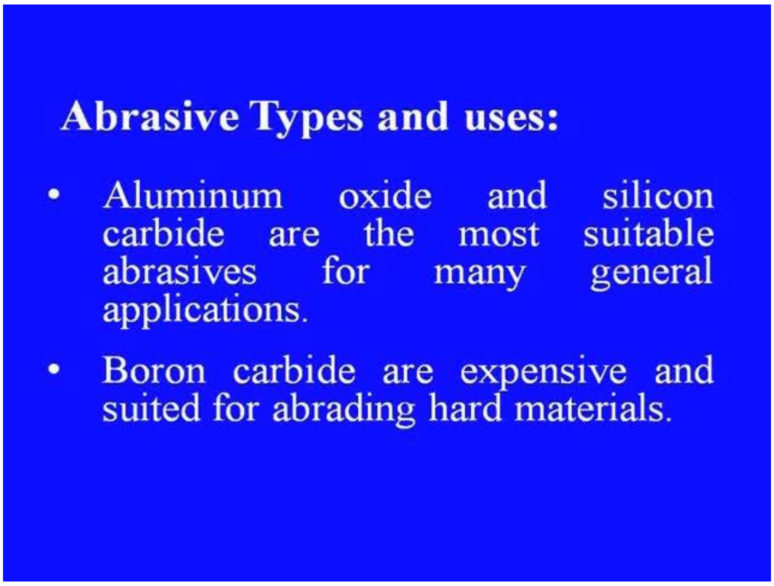

Then what are the different abrasives used in this particular process. As I said already aluminum oxide is by far the mostly used abrasive material along with silicon carbide. Almost all general applications these two types of abrasive materials are used. However boron carbides are used in some machining of some hard materials, but they are very expensive.

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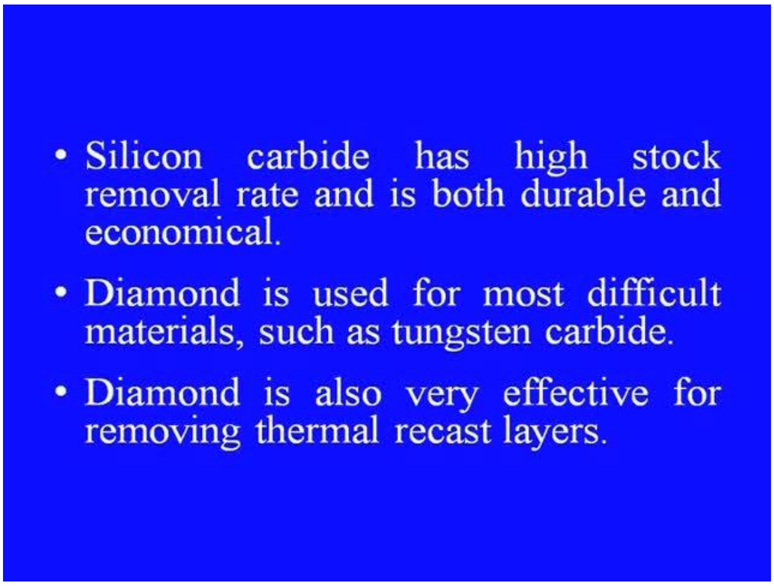

Silicon carbide has very high stock removal rate and is both durable as well as economical. Diamond is also used in these process of abrasive material, diamond is basically used for most difficult materials such as tungsten, carbide and there effective for removing thermal recast layers. The abrasive grains to base material ratio in this process can vary from 2 to 12. The additives are mainly used to modify the base material properties, they help to get the desired flow ability and geological characteristics of the media. Hydro carbon cells are frequently used in this media as lubricants all additives are carefully blended in pre determined quantities to obtain consistent formulations.

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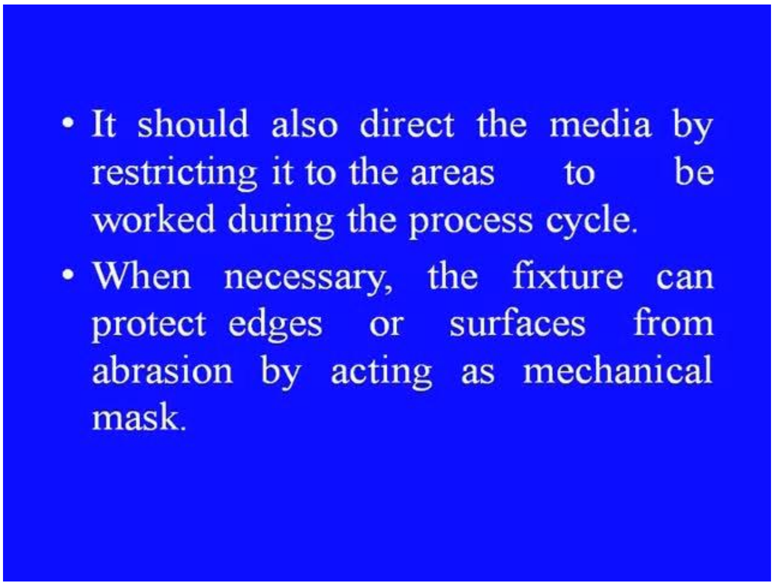

It should also direct the media by restricting it to the areas to be worked during the process cycle. When necessary the fixture can protect edges or surfaces from abrasion by acting as mechanical mask. Steel, uraton and anylon are some of the materials used for manufacturing fixtures. The fixture design may be straight forward or very complex depending upon the work piece configuration.

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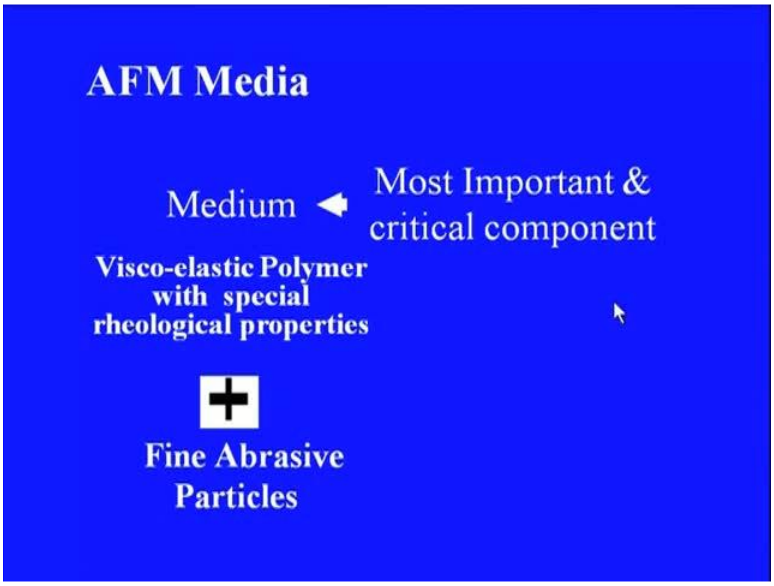

Here is the method how the media is prepared. First of all as I said visco-elastic polymer is taken with special rheological properties that is viscosities, and then added to it is the fine abrasive particles. Of course, their fineness is to be determined or decided as per the requirements, like for getting very high surface finish we have to use fine abrasive particles and so on.

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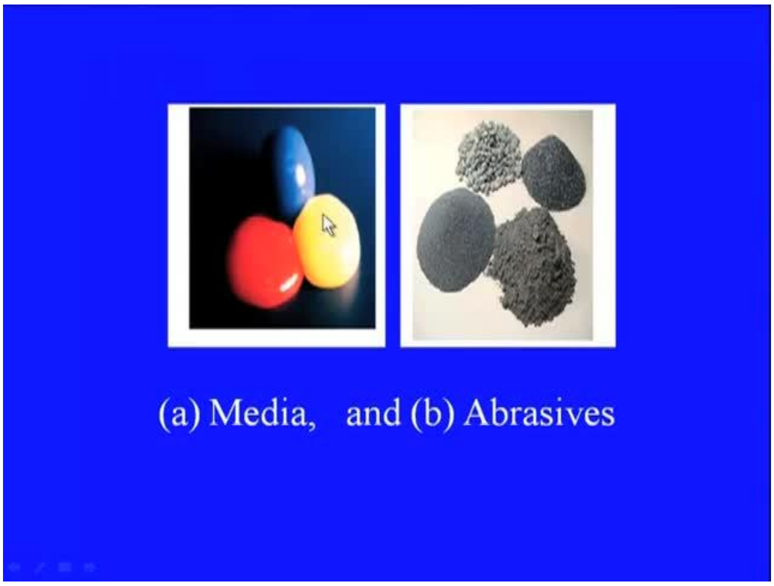

Here are some of the like carrier, and these are some of the abrasives used in this process, they are mixed together uniformly and that forms the working media. The tooling or fixture in this has the primary function to hold the work piece in proper position between the two opposite cylinder or in the part of media. Now let us quickly see the advantages of this process.

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As I said earlier already inaccessible areas can be machined in this process, the finishing rate is much faster than the manual methods of finishing. The polishing and de burring operations can be combined in one stage. High surface finish with tight tolerances are possible in this process. Then there are certain disadvantages as well. Basically this is a costly process this requires high capital investments.

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The cost of the media is very high and is mostly unusable after the process. Recently some reusable media are also developed that we will discuss in subsequent discussions. That is again development of IIT Roorkee. The work holding fixtures is at times expensive, processing of blind holds is difficult in this process. Now let us see few typical applications of this process. As I said the process was initially developed for effective de burring of hydraulic control blocks. However, later on the field of application of this process got rapidly diversified into defense, medical and other manufacturing units.

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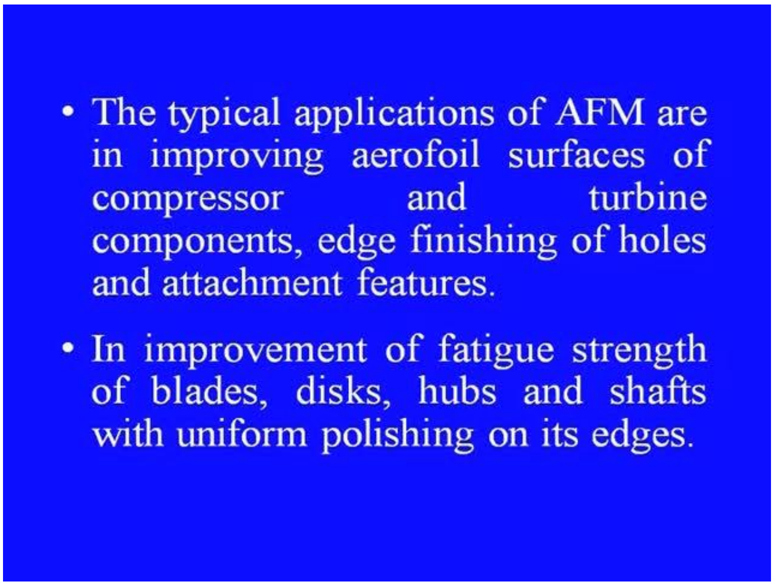

The typical application of AFM are in improving aerofoil surfaces of compressor and turbine components, edge finishing of holes and attachment features, improvement of fatigue strength of blades, discs, hubs and shafts with uniform polishing on its edges. The adjustment of airflow resistance in blades, wanes, combustion liners, nozzles and diffusers. Finishing of fuel spray, now nozzles fuel control bodies and varying components. Reworking the components to remove coke and carbon deposits, and to improve its surface integrity.

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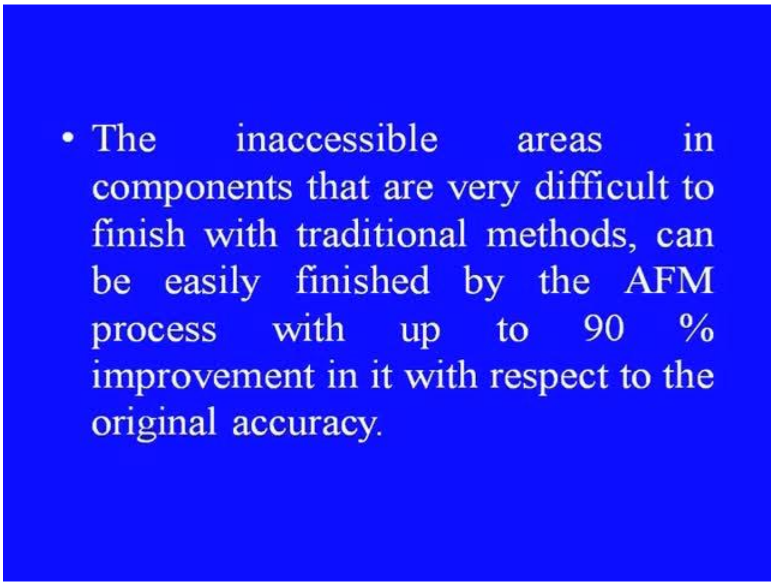

The inaccessible areas in components that are very difficult to finish with traditional methods, as I have already explained, can be very easily finished by the AFM process, which up to 90 percent improvement in the surface with respect to its original accuracy. Some other applications of abrasive flow machining are for finishing of extrusion dies, nozzle of flame cutting torches, differing of aircraft valve bodies and spools, removing recast layers after ECM or EDM or even in the casting. Then precise is finishing of gears and diverging then radius forming.

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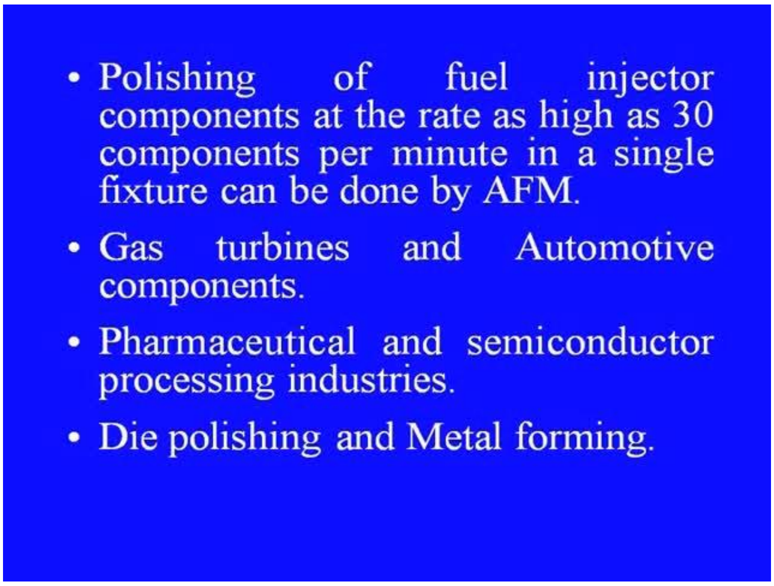

Then polishing of fuel injector components at the rate as high as 30 components per minute in a single fixtures. Then gas turbines and automotive components, then pharmaceuticals and semi conductor processing industries. Then die polishing and metal forming industries, glass forming and plastic applications, ultra clean or high purity devices. Then materials from soft aluminum to tough nickel alloys ceramics and carbides can also be machined with precision by this process.

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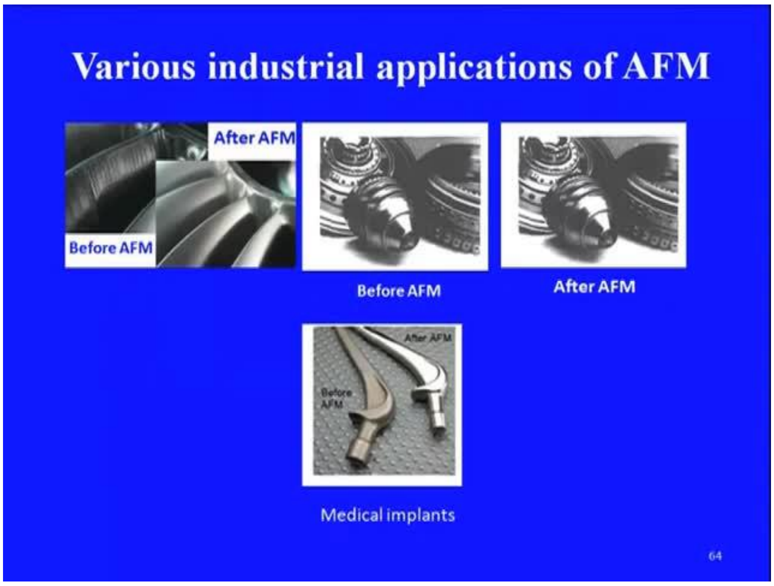

Here are few components that can be machined or finished using this abrasive flow machining. This clearly can be seen, this was what the raw material was and this is the surface after machining using this process, this looks very fine. Similarly, not only in the industrial parts, but some of the components used in human bodies, these are also finished through this process. We can see these shapes of this components, which are not regular and which are very difficult to process or finish by other processes.

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Similarly, these are some of the products that can be finished using this process. So let us summarize what we have discussed in this session. We have discussed the advent of this group of advanced machining processes and in particular the advent of abrasive flow machining process, have been discussed and its limitations, advantages and applications we have discussed. The mechanism of material removal and the working principle of this process have also been discussed. We hope this session was interesting and fruitful.

Thank you.