Thermo-Mechanical and Thermo-Chemical Processes

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Lecture-03
Non-Conventional

Hello friends in the previous lecture, we have discussed about the hot deformation processes which are conventional which are not; right now used in industry heavily. And in today's lecture we will be discussing about the different type of hot deformation processes which are non-conventional. And if I want to divide or classify these two conventional and non-conventional, on the basis of how we are deforming the material, I would also segregate into the compression and the shear based.

Most of these new non conventional processes are based on the shear deformation, shear type of a strain is imposed. And the main idea behind designing these new processes is to impose a strain without changing the dimension of the material or without changing the cross sectional area of the material. As you can see in all the conventional processes, whether you take a rolling or forging or extrusion, when you impose the strain there is a change in the cross-sectional area of the material.

So, these new processes are basically also trying to achieve a goal that you do not change the shape of the material or the cross-sectional area of the material and is still you should be able to impose the strain. And that is why these are all shear-based processes, one of them may not be shear based. But I will let you know which one is that.

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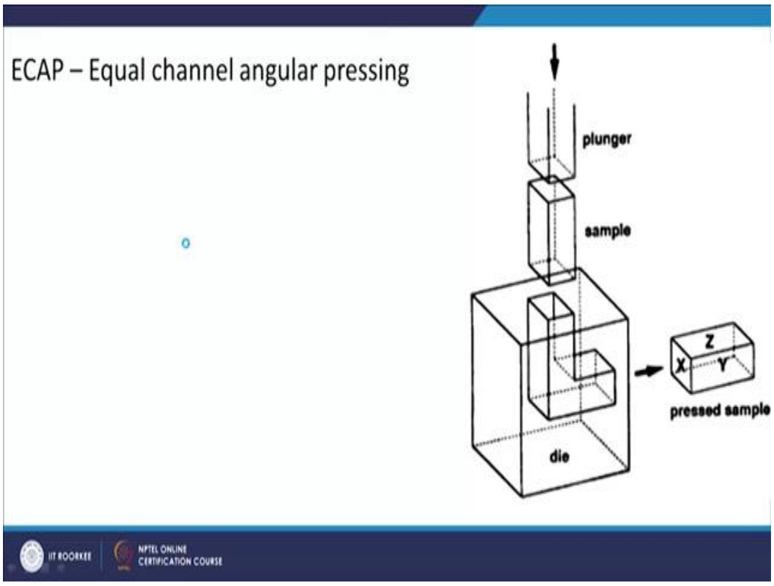

So far, first and very popular or very common process where people want to impose a lot of a strain in the material is called Equals Channel Angular Pressing (ECAP). As you can see, again the idea of not changing the cross-sectional area can be seen here because as the name suggests it is equal channel, so, channel size has to be equal. So, you can see a plunger is here and your sample block is like a cuboid and you have the same size of cavity in the die.

So, you put the material and force the material to go through the die and then the material will flow like this in this direction and we will come out of the opening here. And as you can see, because we have kept the whole size of the channel same, the same size of the block will be coming out of that, but because of this change in the angle or changing the direction of the movement of the sample, you have imposed a lot of shear strain in the material and that is how you are going to refine or break the dendritic structure.

All those things you can do in this without changing the size of the material. Because when you change the size, you have a limit of imposing the amount of strain and how lower you can get because as you keep putting strain the thickness of the material keeps reducing. Here. there is no reduction in the thickness of the material.

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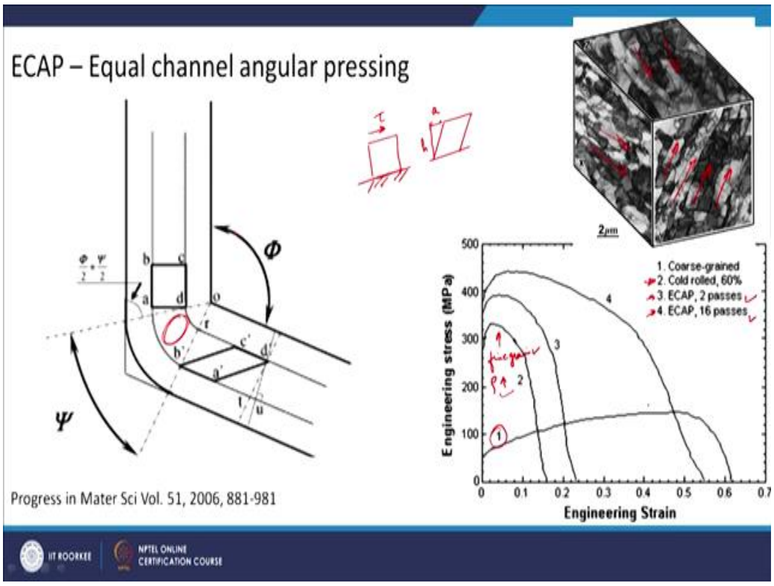

If you see in more detail that how the die will be there. So, you have different angles shown here to design the die that what will be the angle Φ here what will be the angle ψ, so, you can take different angles for these. And depending upon this angle that will decide what amount of strain you are putting in ok. So, the initial one element in the block is shown by a, b, c, d here; a rectangle.

And when it goes through this angle, so, you have maximum shear strain imposed somewhere here at 45°, depending upon what angles you are taking, and now this abcd rectangle has become a'b'c'd' parallelogram. So, this shape has become this and the change in the shape is because of the shear strain which you have put. So, basically if you have some block and if I put the shear strain the block which is something like this, let's say I fixed it at one end, I am applying a shear stress on the top part.

So, what it will become, it will become something like this and the amount of strain can be you can get from how much is the displacement divided by the height. So, let us say displacement is a then a/h will give you the amount of shear strain which you have introduced in the material. So, similar thing you can see here. Now, you can also see a very nice micrograph here. So, I think XYZ directions are shown here and they are also showing the grain structure in the different planes.

So, you can see that how the material has flown in this particular cross section the material flow direction is like this, the grains are stacked in this direction. In this direction, the grains are elongated. Similarly, I think in this direction. So, the shear strain is I think seen by this particular plane and they are also trying to show you what is the effect of this kind of deformation process.

So, this curve 1 is the initial coarse grain material. And then it was called rolled to 60%, effect of that you can see here. So, you can see the increase in strength can be due to fine grained microstructure because the increase in the dislocation density and maybe some precipitates of course, will not be a problem here. So, basically the increase in the strength can be because of two reasons refinement or breaking of the grain and increasing the dislocation density.

Instead of cold rolling you can do this ECAP process. So, two passes are introduced and 16 passes are introduced. So, two passes again you can see that the strength has increased and in 16 passes again the strength has increased and also there is a good amount of ductility in the material. Of course, there must be some microstructural changes which we do not know but if you go to paper here you will be able to get all the details that why the strength and ductility both has improved.

But the idea here is that from coarse grain if you keep refining if you keep putting strain in the material there is a increase in strength and sometimes there is also increasing ductility with the strength.

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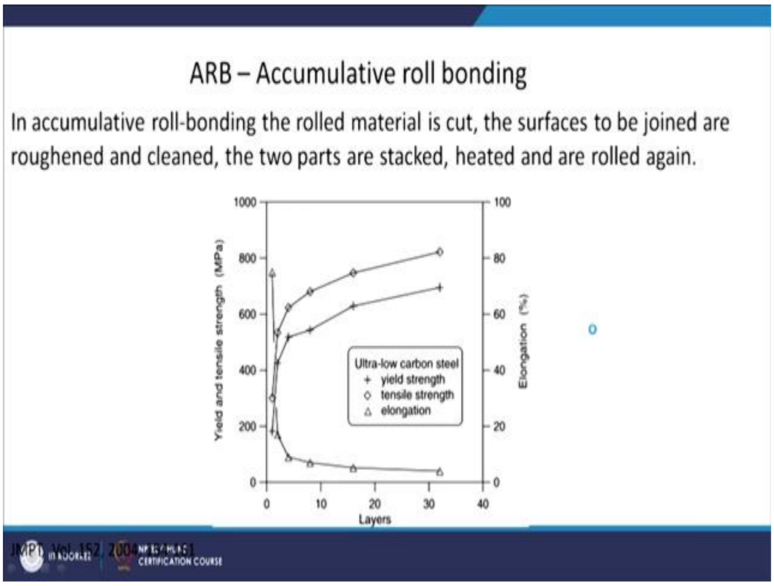

Another very important this type of technique non conventional or deformation processes is called Accumulative roll bonding. So, in accumulative roll bonding the roll material what you do is it is a simple rolling process only. So, this is one of the conventional process modified as a nonconventional one. So, again what do you do you roll a sheet its cross sectional area will be reduced. Let us say it is becoming half the thickness is becoming half after rolling from the initial thickness. So, there is a initial thickness and now it is becoming let us say half.

So, this t_1 let say this t_2, so, $t_1=t_2/2$.
So, what do you do once you have this t_2 thickness now you cut it and again fold it. So, you put it one over another. So, now again it has become t_2 and again you will be rolling it and making it t_1. Again, you will do the staking. So, accumulatively you are doing this rolling and at the same time because of the deformation, when you are putting the deformation and all these are done at high temperature also.

There is also a bonding between the metallurgical bonding between the two sheets. So, this is cut the surface to be joined or roughened and cleaned of course, you have to do all this because if there is any oil, then there would not be a good contact. So, you have to make a increase in the surface area by doing some roughening process by some kind of emery paper or maybe silicon carbide paper.

And again, you stack it, heat it and again you roll it. So, if you see here, on the x-axis in this graph, you are seeing layers 10-layers, 20-layers 30-layers, so, that many times layers are stacked and are allowed to go through the rolling process. So, that much amount of a strain is there. And the yield strength is plotted here as a function of this layers. So, you can see that the yield strength is increasing from around 200 MPa and going up to maybe around 600 Mpa.

And similarly, tensile strength is also increasing from around 300 MPa and going up to around 800 MPa, but your ductility is reducing somewhere from it could reach 80% elongation, now it has reduce up to maybe around 5% or so. So, the increase in strength is at the cost of decrease in the ductility. In the earlier slide, we saw in ECAP, of course they might have done some nice fancy things there and with the strain there was a increase in ductility. But here that ductility has reduced though the strength has increased.

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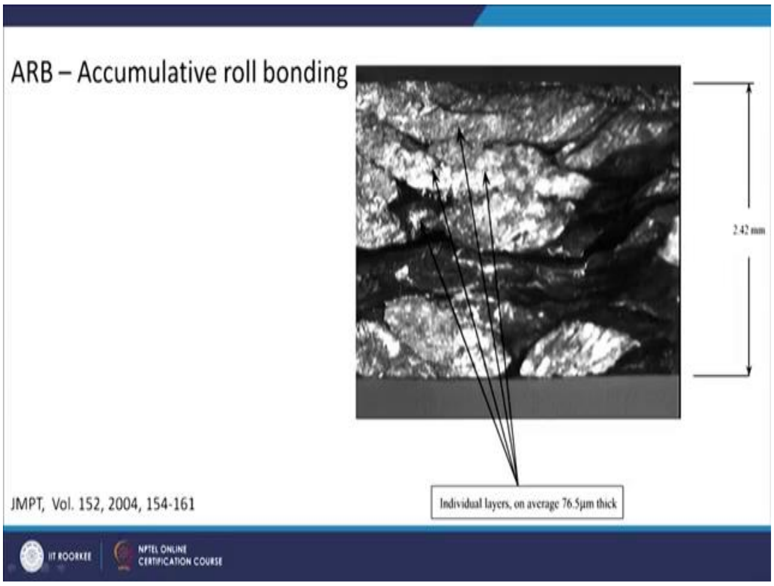

You can see in this micrograph that how accumulated role bonding layers are seen. So, you can see that all these black lines here, these are the interfaces where the stacking was done. So, when you do the stacking there has to there will always a interface will be formed. This is the initial layer and then you are stacking it so, you will also see the effect of the interface. So, all these are interfaces here.

So, individual layer they are saying that it is around 76.5 micron thick. And because of this interface which you form actually you won't get very good ductility in this material, because this interface will give away the material will separate out and then you won't reach the deformation which you want.

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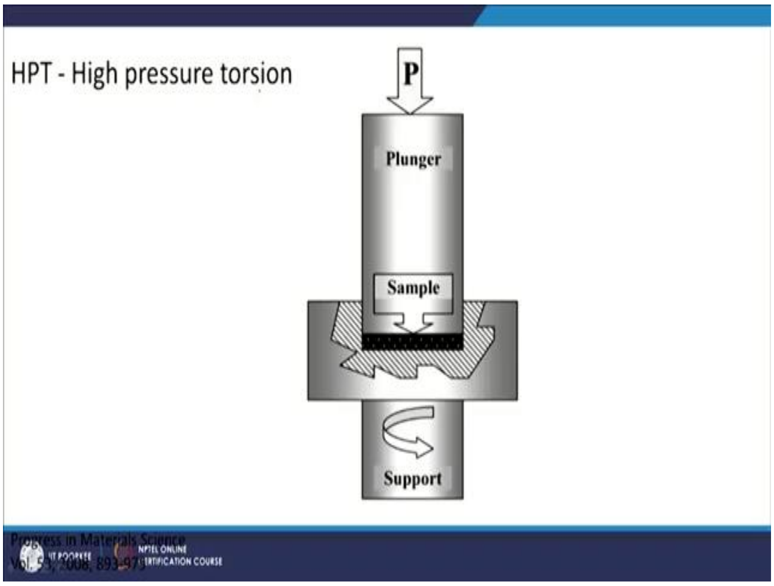

Another very lot of literature is there in the journals and this is called a High-Pressure Torsion (HPT). The drawback here is that the sample size which you take is very small, and the processes like this, so, you have a die here, lower die, and then there is an upper die, which is putting a normal force here. And at the same time, you are also rotating it, you are rotating the tie. So, what you are doing is at very high this normal load and you are forcing the material to also rotate.

So, you are introducing a lot of shear deformation because of this, this kind of journey. So, you can understand it like that, you take a wet cloth and you want to take water out what you do is you can kind of put at torsion kind of deformation. So, this is the similar one here. And again, there are lot of effect of this kind of straining.

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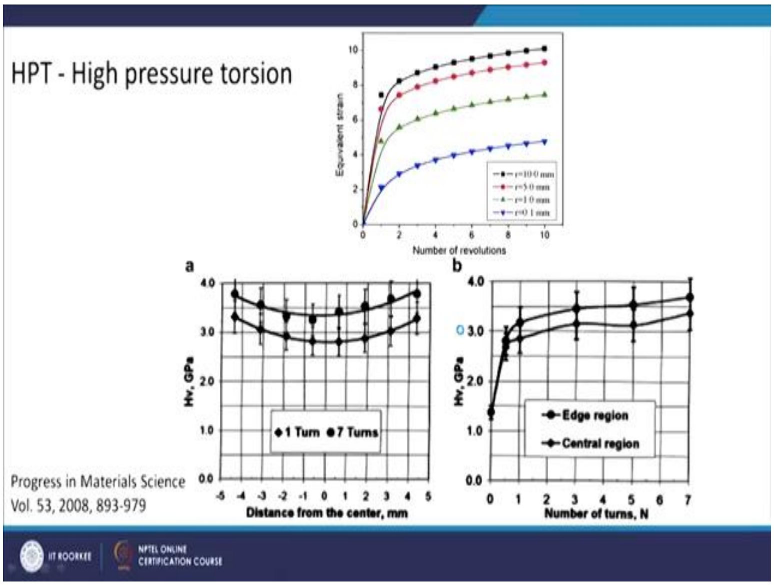

So, you can see numbers of revolutions are shown on the x-axis here, 2 revolutions has gone or 3 revolution for up to 10 they have gone. And they have also plotted what is the equivalent strain which you are putting in the material that is also of course going up and this is at different radius. So, you can understand that when you do a torsion experiment, the strain will increase as a function of radius from the centre, at the farthest point you will have maximum strain.

So, you can see the strain at the farthest point is increasing in this direction and at the same time because we are putting more number of revolutions the strain is increasing in this direction also. So, with the number of cycles and at what distance you are measuring the strain both will be important. So, again as you can see in earlier conventional ones, we saw that there is a strain distribution in the material.

Similarly, here you will have large number of strain distribution and effect of that also can be seen on the hardness value. So, these are a hardness value shown here in Giga Pascal and this distance from the center in mm. So, you can see where the strain is minimum the hardness is also minimum. And as you go away from the centre the hardness in the material is increasing because strain is more as you can see in the first graph.

And this for one turn, if you put more turns of course the hardness will increase. And also there will be again another variation from centre to the edge. You can see the variation in the hardness from edge to centre region here also that at edge region the hardness is going like this. So this is at edge region and this is it center. Variation in the strain and you can see effect on the strength. Another one again taken from conventional processes forging a modified for a nonconventional process.

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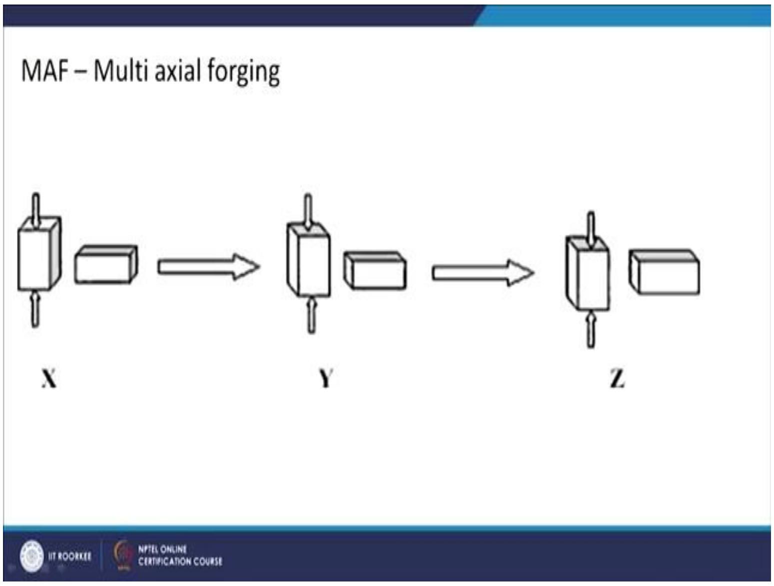

So, basically the idea is that you start with a block like this, which has a higher length in one direction and you forge it. So, what it will do it will flow in this direction when you are forging like this and now you will have a higher length in one of these directions. And it will be because you have a constant volume processes during plastic deformation, volume constancy is there, the reduction in the other two sides will be again the block will look similar to this.

So, you rotate it again, you kind of forge it again it will get this shape you rotate it, it put it here again you put it, forge and you get at this shape. So, in these three steps, you get the same material as you ever started with. And the amount of strain which you are putting in each of these stage, if you are calculating true strain you can just do an addition and find out what is the maximum strain you have imparted. And also, you can see the effect of that in the mechanical properties.

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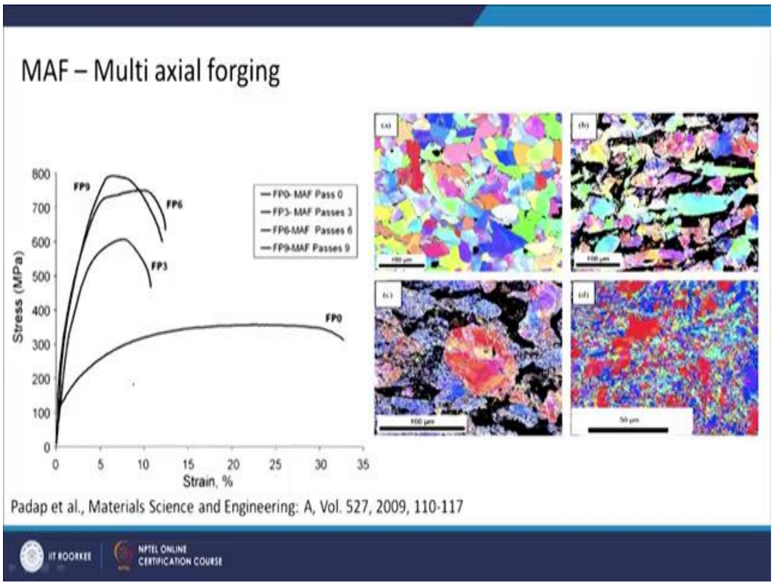

So, as you can see here, this is the original material it has this strength, around 300 MPa UTS and ductility of about you can say 32%. So, this is after 3 passes means 3 stages as we have just seen, then this is after 6 passes and this is after 9 passes. So, you can that effect of passes means effect of a strain you can see in increase in the strength of the material. And also, these are the microstructure at different stages.

So, this is the initial microstructure. And this is after the first pass, this is after 3 passes, this is after 6 passes and this is after 9 passes which are shown here and you can see that how the microstructure refinement is taking place because of this kind of deformation. So, you started with a very coarse-grained material. So, the scale is here it shows 100 microns So, I can take intelligent guess here and maybe the grain size here must be around let us say 30-40 micron.

And this is the first part of the deformation, another part of the deformation and of course, you can also see there is a change in the scale here and here it is only showing us 50 microns. And you can see the microstructure has refined a lot. So, because of the deformation there is a microstructural refinement also there will be large amount of dislocation density will be there and effect of the these two you can see on the strength of the material. Again, you can see here that it is at the cost of ductility. So, elongation has come down from 32% to around 10%.

Another one important process which is gaining a lot of attention nowadays is called Friction Stir Processing (FSP).

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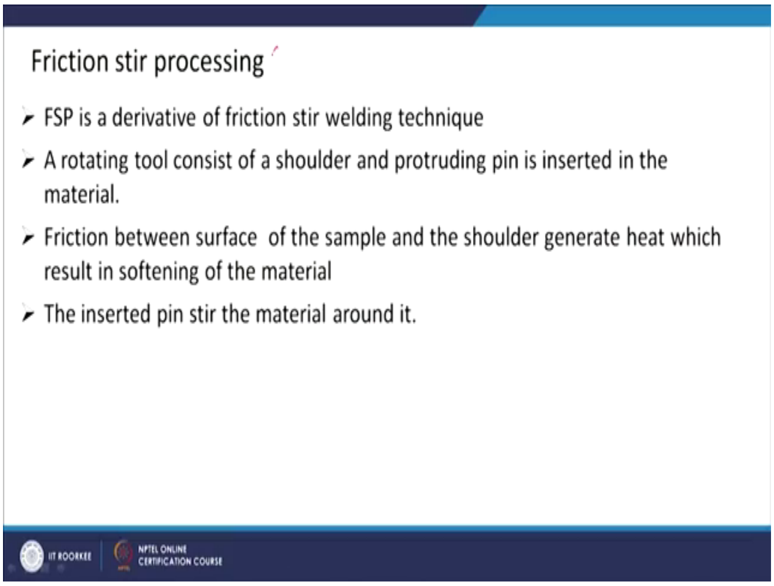

So, friction stir processing, you can see as noted here is actually the processes has started as a welding process. So, if you take two sheets you can do welding using this particular process. But now, it is also modified to made it as a processing technique. So, it is a derivative of friction stir welding technique. In this there is a rotating tool consist of a shoulder and a concentric pin is inserted in the material. Friction between surface of the sample and the shoulder generates heat which results in softening of the material.

And this inserted pin stir the material around it. So, I will show you the photograph or a schematic of this to clarify you this particular process in more detail.

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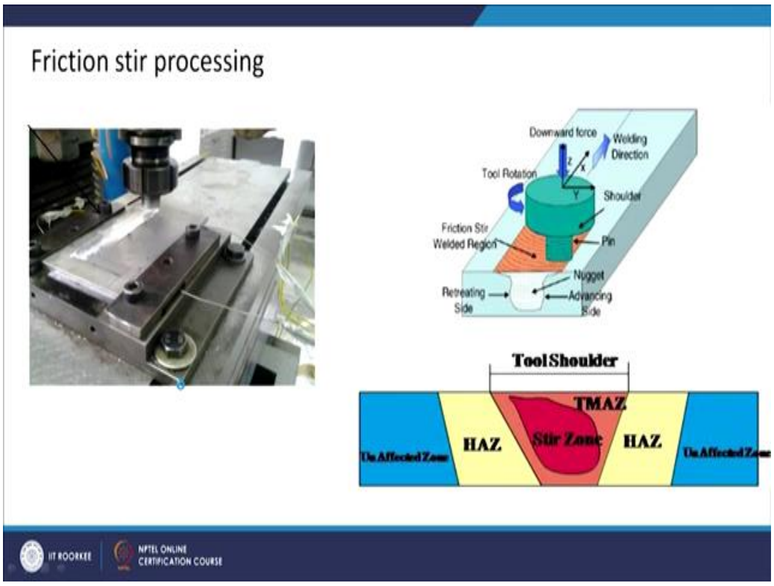

So, as you can see this, these are two sheets. There is a joint here. This is actually right now in a welding condition. So, what you are doing is, you have a tool which is rotating and you are also applying a normal load here, along this direction, and there is a rotation. This shoulder surface if I want to see from this side, if I do not want to see in perspective, it will look something like this, let me change the colour here.

So, the shoulder and pin if I want to show the shoulder will be just touching the surface of the work piece. And the pin is going inside the work piece. And now it is also rotating. And there is a normal load. So, what you are doing is this friction between the shoulder surface and work piece surface is generating heat, very high heat and because of that the material around this region is getting soft, because of the temperature and this rotating pin is now stirring the material around it.

So, you can understand these processes what do you do in a mixee, or in a mixer, you are rotating whatever is kept inside the container. So, here also you have a rotation of the material around the pin. So, this both, the thermal and mechanical processes are combined here and because of that, you actually do if it is a welding process, you do the welding. And if it is a monolithic material, then you can consider it as a processing.

So, in the stir zone if you see, so, they have shown stir zone then you can call zone which is called a thermal mechanically affected zone, then heat affected zone and an unaffected zone. So, in this what we call as nuggets here also some sometimes some people call it as stir zone or nugget zone because of this shear deformation the grain size gets refined and also you get better properties because of the reduction in the grain sizes.

This is a actual image of friction stir processing. So, you can if you have in your place any milling machine, you can easily modify that milling machine to do this kind of process. So, in that way it is a very simple process and with existing equipment you can use that equipment to do this kind of welding or processing and that is why they it is very popular because existing equipment can be used.

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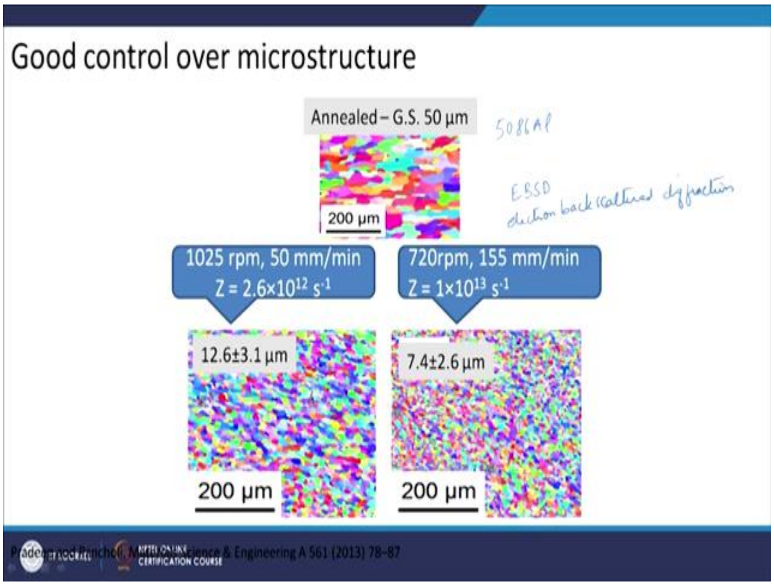

So, there is a good amount of grain refinement when you do this process as you can see here this is annealed 5086 aluminium alloy and the grain sizes around 50 micron as you can see here very nice grain. Again this is a coloured map which shows orientation and these type of maps are called EBSD maps or EBSD is for electron back scattered diffraction, EBSD which gives you orientation information.

So, now depending upon how you are rotating at what rate and how you are moving the tool. So, these two parameters if you control as is controlled here and here. You can see that you can do a variety of refinements. So, at one particular processing condition you have reached grain size of 12 micron from 50. In another processing condition at lower rpm and higher treverse speed, you have reached another grain size which is 7.4 micron from 50 micron.

So, very good control over micro structure you can achieve in this type of processing. So, these are the different processes which are which you can combine into a non conventional processes and most of these processes are shear based processes that means you are imposing the strain under sheer condition. Also, you can see that the idea here is that you should not change the cross-sectional area or the overall shape of the material and still you should be able to impose a strain in the material.

These are only few of the nonconventional processes I have covered here in the given time. If you go look at the literature, there are even larger number of processes on which people are working. So, it will be an interesting exercise for you also to look for these processes, what are these non-conventional processes. And in fact, if you like you can design your own process also which is not till now anybody has thought of like this one frictions stir processing very nice technique to do welding as well as processing. So, with this, I would say thank you for watching this lecture.

Key words- Nonconventional thermomechanical processing, Microstructure, ECAP, ARB, HPT, MAF, FSP.