Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-29
Surface Modification Techniques: Controlling Surface Metallurgy IV

Hello I welcome you all in this presentation related with the subject fundamentals of surface engineering and we are talking about the methods which are used for modifying the surface properties. So, that the required improvement in mechanical performance as well as the wear resistance can be improved, under this heading we have talked about the various methods related with the surface modification without changing the surface composition just surface metallurgy is modified.

So, that the required improvement in surface properties can be achieved, under this we have talked about those methods which where related with the transformation hardening then methods which where related with the re-melting of the substrate and also we have talked about the 2 methods where in the control surface layer deformation is used to enhance the surface properties through the work hardening through the grain refinement as well as sometimes through the deformation assisted transformation hardening.

Now we will talk about one more method of the one more method where controlled surface layer deformation is used to enhance the surface properties.

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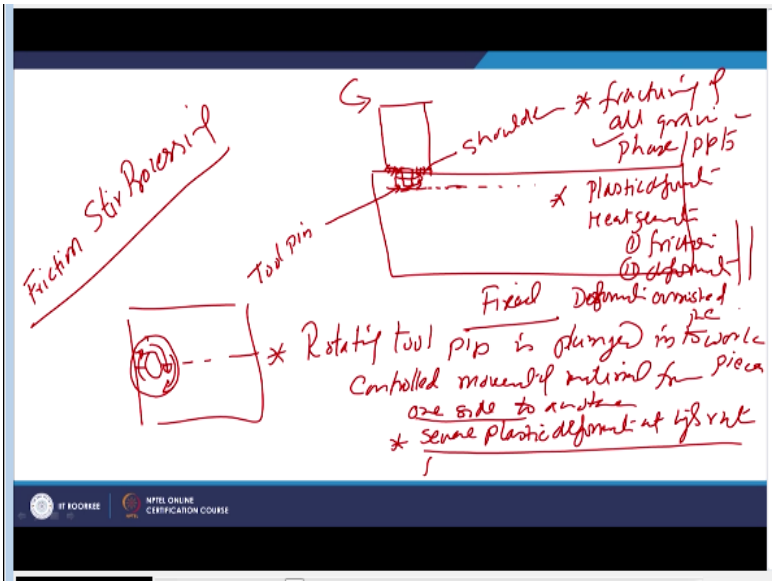

So, that method is friction stir processing, in friction stir processing like the surface whose properties are to be improved are modified using a particular tool like say this is the tool having shoulder which comes in contact with the surface and then there is a pin which is also called pro. So, this is basically tool pin and this is the shoulder tool shoulder which comes in contact of the surface.

Now initially the tool is rotated work pieces fixed or it is stationary and gradually tool is plunged. So, the first step here the rotating tool pin is plunged into the workpiece or the substrate. So, gradually plunging will lead to the entry of the pin in the substrate or to the required depths. So, the pin length will be according to the depth which is depth up to which surface layers are to be modified.

And once this the pin is penetrates the workpiece completely the shoulder also comes in contact with the work piece. So the continuous rotation of the shoulder in contact with the substrate as well as rotation of the pin which has been plunged into the work piece. This leads to the controlled movement of material from one side to another like say from if we see this in the top view.

This is the location where pin has been plunged and this is the location where the shoulder is in contact, this is the line affection along which the surface is to be modified. Then there will be

continuous movement of the material as per the rotation of the work rotation of the tool there will be continuous movement of the material from the one side to another. And in this process severe plastic deformation at high rate takes place.

That rate is to a great extent influenced by the rotational speed of the tool and the normal load under which the tool is in contact with the work piece. And under which this kind of processing is being carried out. So severe plastic deformation at high strain rate leading to the movement of material during the processing from one side to another this actually leads to the severe plastic deformation leads to the various defects.

One is like fracturing of all grains and all phases precipitates whatever present in the modified zone. So, if the compute charming is taking place in this area. Then the all constituents which are present they will be fractured refined. So, this kind of situation will be leading to the to a particular situation where combination of the plastic deformation+heat generation.

One due to the friction and second due to the plastic deformation. So the plastic deformation leads to the elongation fracturing of the various grains and precipitates followed by heat generation leads to the deformation assisted recrystallization

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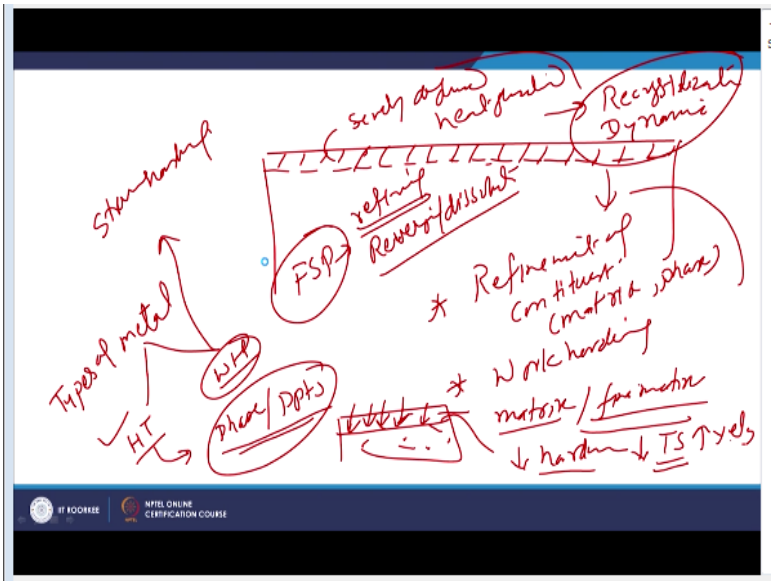

So, basically if thin layer up to certain depth has been severely deformed then and at the same time heat is also generated high enough. Then these 2 situations lead to the recrystallization and this recrystallization which is basically happening during the rotation of the tool in the workpiece or the substrate itself is called dynamic recrystallization and this basically causes the significant refinement of the constituents which were present in the substrate.

So, whether it is the matrix or all the phases, which were present, they will be refined. This is one thing, second this severe plastic deformation also leads to the significant work hardening as per the type of the material. If the material is having low staking fault energy then the extent of increase in the properties in terms of hardness and tensile strength that is too much as compared to the other cases where the material is a precipitation hard level.

Then the work hardening effect is not much and simply refinement will be taking place. So, the type of metal system actually place big role as for as the change in properties after such kind of the processing is concerned like in friction stir processing where in we are although refining the grain structure. But all the constituents are being refined and sometimes they get dissolve completely.

So, reversion or complete dissolution of these precipitates and the phases take place in the matrix. So, if these precipitates or the phases are contributing significantly to the metal properties then despite of refinement we do not get much improvement in the hardness and is strength. And this is the particular case like we can have the heat metal systems and we can have the other work hardanable systems.

So, in case of the heat treatable systems which get there is strength from the presence of particular kind of phases, presence of particular kind of precipitates and if these precipitates which are present in the matrix here and there after the FSP all these will get be broken, refined and fractured to such an extent that they may get completely dissolved in the matrix. So, we may get very homogeneous and the refined very fine matrix.

But the dissolution and complete reversion or elimination of these kind of precipitates in heat treatable systems despite of refinement leads to the reduction in the hardness, reduction in the tensile strength with the increase of percentage elongation. Because percentage refinement leads to the improvement in elongation and but at the same time reduction in hardness and tensile strength takes place.

So, this is one side and other metal systems are strengthened primarily by the work hardening in those cases primarily we get the increase in hardness and strength due to the strain hardening effect which is important to the plastically deformed metal near the surface layers during the FSP of the material. So, there can be very vast variation in terms of the properties after the FSP of the surface layers.

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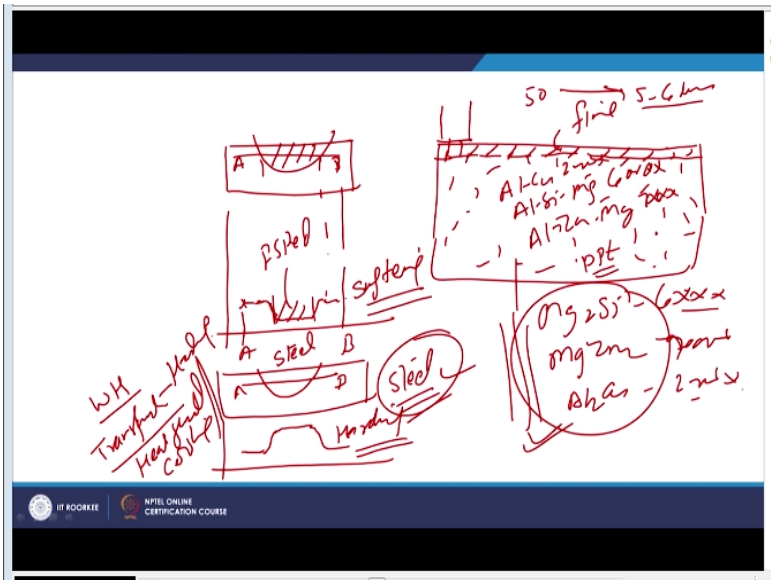

So, what kind of the variation these can be like if we take aluminium, copper alloys, aluminium silicon, magnesium alloys and aluminium zinc magnesium alloys like 6000 series aluminium alloy, 2000 series aluminium alloy and 7000 series aluminium alloy. All these kind of the alloys. These are the precipitation hardenable alloys. These are heat treatable alloys so, they get their strength from the presence of precipitates and such kind of the metal.

When it is subjected to the FSP through the use of the suitable tool and surface layer is modified up to the certain depth through the plastic deformation despite of getting very fine grain structure

like grain refinement may be from 50 micrometer to 5 to 6 micrometer as well. But despite of this we find that there has been significant reduction in the hardness, because these alloys are the precipitation hardenable and the phases like mg2si in 6000 series.

And mgzn2 in 7000 series and CuAl2 in 2000 series alloys, these precipitates actually after FSP these are mixed up or dissolved with the matrix itself. And since the strength was primarily coming from these precipitates and if these get dissolved then our hardness is reduced at the surface. So, in this particular case if we see that in this substrate if this is the zone which has been FSP and which try to check the hardness from the A to B.

Then variation in hardness from the location A to the location B we may notice that the hardness here is high up to this much distance, hardness is same and as soon as we get there is a drop in the hardness like this. And then again hardness increases as soon as it is crossed. So, this is the zone which we can say this is the FSP zone friction is process zone showing the lower hardness.

On the other hand if we take that this material which has been FSP in particular zone. And then we try to like say in case of the steels simple carbon steel or alloys steels if again we take A and B the 2 points and along which the in case of the steels subjected to the FSP and if try to major the hardness then the hardness may be lower and as soon as the we reached the Fspeed zone.

We find the significant increase in hardness and then again soft zone is observed. So, if we see there is a lot of difference in the type of metal system and the hardness, the kind of hardness the FSP. So, for work hardenable systems and those which respond to respond effectively to the transformation hardening during the FSP there is a significant difference in the hardness. And so, the there will be significant difference in the wear resistance which will be observed in the 2 cases.

So, here if we see here we can say after FSP softening is taking place and here in the FS speed zone hardening is taking place. So, the hardening here is attributed in case of the steels or such kind of systems is attributed to the 2 factors 1 is the work hardening and the second if the

transformation occurring due to the heat generation followed by rapid cooling. So, basically this is the transformation hardening which is also observed.

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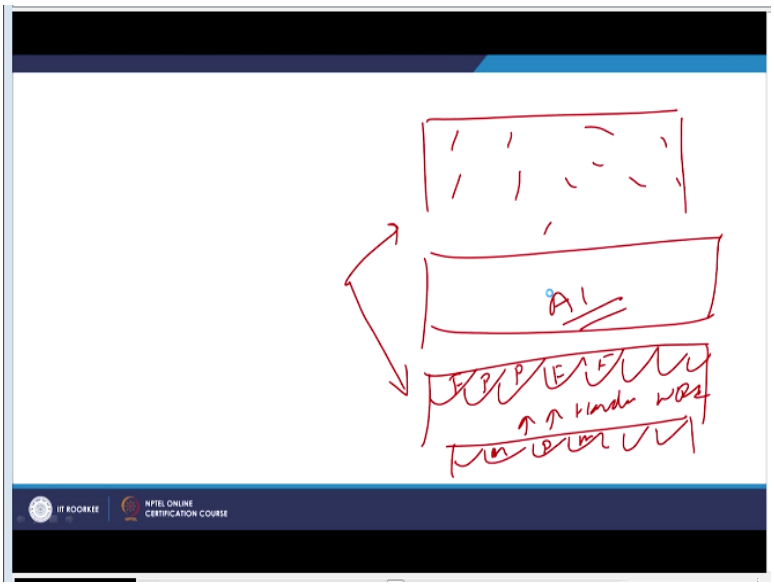

So, initially if we see if initially in the alloys we had precipitates like this in aluminium alloys these will be vanished in the FS speed zone and only the aluminium matrix will be visible while in case of the steels initially if we had like the mixture of the ferrite and perlite at the surface. After FSP it will get transform primarily into the marten side and the perlite. So, the formation of the marten side and perlite at the surface will be leading to the improvement in the hardness improvement in wear resistance.

So, this what we can see FSP of the heat treatable alloys can lead to the reduction in hardness well FSP of the heat treatable sorry heat treatable alluminum alloys can lead to the reduction in hardness while in case of the steels FSP can lead to the significant improvement in terms of the hardness and the wear resistance.

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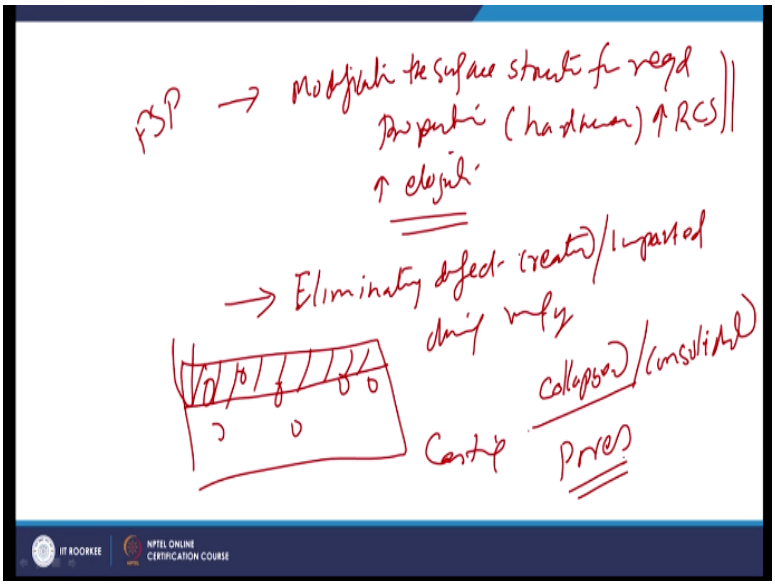

Now so what are the purposes of the FSP which will be realized there is 1 main purpose is to modify the surface structure for required properties. So, the surface modification for the required properties this may be in terms of the required increase in hardness or development of the residual compressive stresses, then there is a another, so in this case basically structural modification is achieved.

And if we precisely see when are the structure is refined primarily we find that there is increase in percentage elongation of the material. So, which is observed across the metal systems and then there is another side apart from just structural modification the FSP is also used for eliminating that defects created or imparted during manufacturing stage. So, like if component is produced using the casting process and it has like pores and inclusion like this at the surface.

So, when FSP is carried out the material consolidation by the severe plastic deformation happens and in this process all those zones wherever the defects and inclusions were present all these defects are collapsed and consolidated. So all types of the porosities whether they are these are gas porosity or shrinkage porosity all these will be collapsed and consolidated by the severe plastic deformation which is being realized at the surface layer.

So, all such kind of the pores will be eliminated and if they are fine inclusions then these will be broken down if there were inclusions like this which are non-metallic. These inclusions will be

broken down into the fine pieces. So the fine inclusion particles present here and there either they will get mixed up with the matrix or their size will be reduced to such an extent that they are adverse effect on the mechanical properties will be reduced drastically.

So FSP also helps in eliminating the defects if these were imparted during the manufacturing processes or it can also be used to eliminate cracks. If these are there at the surface because severe plastic deformation will eliminate the any such kind of the cracks. If they are at the surface FSP will lead to the severe plastic deformation of all those near surface layers and will consolidate all such kind of the discontinuities if they are present at the surface.

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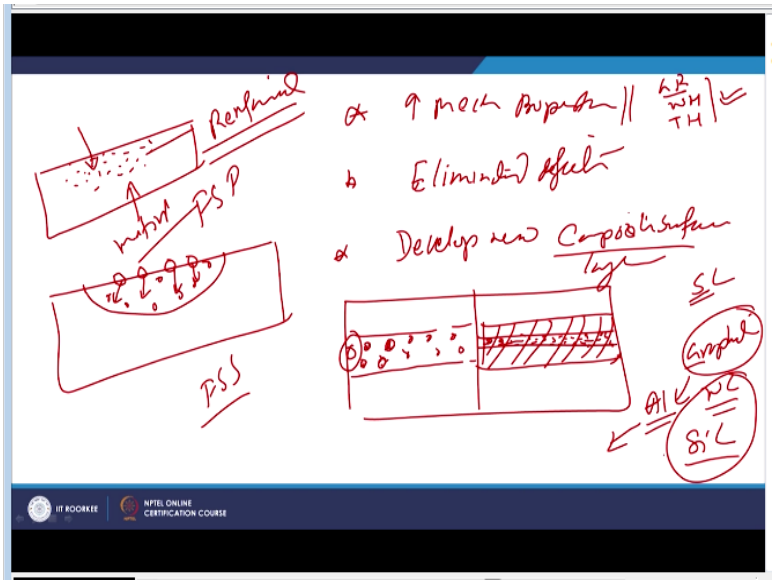

So, there are few favorable effects of the FSP one improves the mechanical properties to eliminates the defects and discontinuities and third it also helps to develop new composite surface layers. So as aspect the mechanical property improvement is achieved through the grain refinement, through the work hardening and sometimes even through the transformation hardening.

But if these mechanisms are not good enough to achieve the required improvement in mechanical properties, then sometimes combination of such kind of the properties are required which cannot be achieved only through the structural modification. In that case FSP can also be

used to develop the composite materials. So in that case what we do like this is the surface so, will be drilling the holes here and there like this.

This is one approach or will make a slot like this and will fill the in the slot will fill the constituent that we want to reinforce to make the composite material and similarly the reinforcing agent will be filling this holes. And after that FSP of the surface is carried out so, that these particles get uniformly distribute in the FSP zone. So, all these particles will get uniformly distributed after the FSP.

So, if this is the surface and at the surface we have introduced some of the reinforcing agent when FSP carried out the modified zone is created like this and all these particles get uniformly distributed in the FS speed zone. So, whenever we achieve a situation where at the surface the particles need to be introduced of such kind of constituents which will helps to improve the properties desired at the surface.

And which cannot simply be offered by the substrate itself then we need to introduce some of the reinforcing agent. And for that purpose we have to make composite. So, basically in composites will have one matrix and one means the reinforcing agent. These reinforcing agents will impart the different kind of the properties as compared to that of the matrix and matrix place primarily role of holding such kind of the particles in it.

So, the completely dissimilar kind of the properties are realized through the presence of the reinforcing agent say like in aluminium we can reinforce graphite or we can reinforce tungsten carbide. We can reinforce silicon carbide, aluminium being very soft and ductile while these materials this is softer of the solid lubrication effect, while these particles are very hard and brittle.

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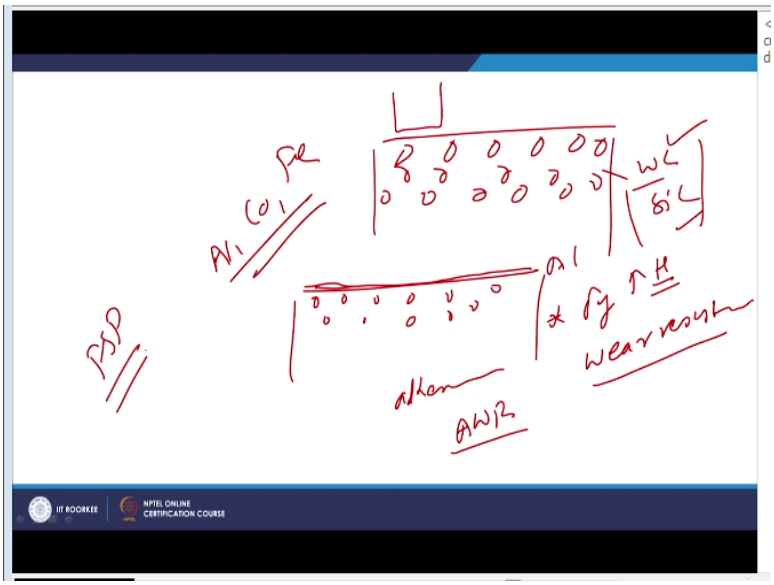

So, once the these particles are reinforce in the soft matrix then they will be able to so, provide the required support to the surface layers, will be able to provide the support to the external load whenever load is applied through the surface layers. So, basically the presence of such hard particles like tungsten carbide, silicon carbide in aluminium matrix reinforced through the FSP.

They will provide the required support to the matrix to take the external load. So, resistance the deformation is enhanced which in turn increases the yield strength which in turn also increase the hardness. So, once the these are present then they will be improving the wear resistance of the material, this one purpose similarly in aluminium matrix so, which are used for making the pistons and another components wherever the metal to metal rubbing is involved like in adhesive wear conditions what we try to do.

The graphite is reinforced in the aluminium alloys. So, that whenever these are present these will be acting as a solid lubricant. Because these graphites will reforming a thin layer over these surface of the substrate and thereby they will be reducing the direct metal to metal contact. And so, they will be able to reduce the adhesive wear of the material. So basically adhesive wear resistance is improved through the presence of such kind of the graphite.

While abrasive wear resistance can be enhanced through the presence of such hard reinforcing agent in the soft matrix. It may be aluminium, it may be cobalt, it may be iron or anything else

wherever we find that conventional methods of putting such kind of the reinforcing agent in the matrix is not fusible there FSP can be effectively applied.

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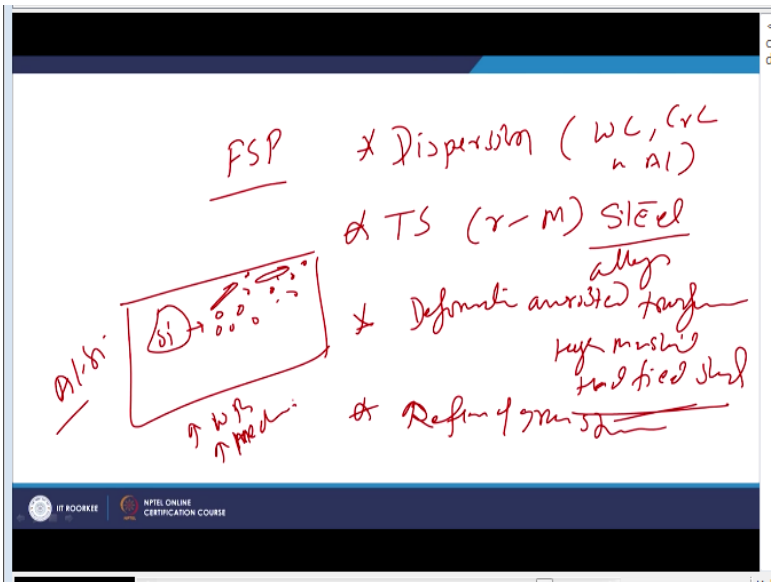

So, in this case the basic mechanism which is helping to enhance the properties. So, in case of FSP what we can say FSP the dispersion hardening like presence of tungsten carbide, chromium carbide in aluminium matrix will be enhancing the hardness and wear resistance through the dispersion hardening, transformation hardening like through the transformation of austenite into the marten side disfacilitated.

When FSP of the steels like carbon steel or alloy steel is carried out even they are can be deformation assisted transformation in case of the high manganese steels had field steels. So, that can lead to the improvement another mechanism which can work for improvement in properties is the grain refinement. The refinement of the grain structure whatever grains are there whatever unfavorable grain morphologies like in aluminium silicon alloys.

If we are having the big primary silicon particles or needle shaped silicon particles these will be weakening the material with regard to the mechanical properties and the wear resistance. Because nedular shape structures act as a good stress structure and which in turn nucleate the cracks easily and reduce their capability to take up the load and so, when the FSP of such kind of system is carried out.

These primary big particles are broken down to the small size and needle shape particles are also broken down to the a small size. So, such kind of the fracturing and refinement of the big unfavorable phases into the fine size helps to improve the wear resistance, improve the hardness improved mechanical properties.

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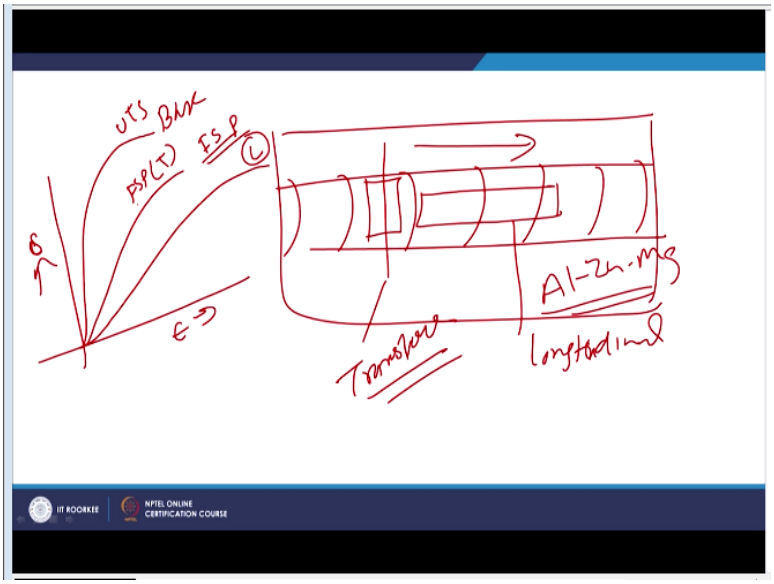

Now if we see whenever FSP is carried out there will always be like this is the surface of the substrate and FSP is carried out by passing the tool along a particular direction like this. And in this direction if we take the sample from this direction which is perpendicular to the FSP direction and if we take sample from the longitudinal direction which is the direction of the FSP. So this one will be termed as longitudinal**.**

And this one is the sample taken from the transfers direction with the transfers direction sample, the sample taken from the two directions of the FSP region will be showing that different value of the mechanical properties. So, say if this is an example of the heat treatable aluminium alloys like aluminium, zinc magnesium when subjected to the FSP. So, the base metal in general shows good strength high UTS stress and strain for the base metal.

Whenever FSP carried out grain structure is refined significantly however the matrix the precipitates present in the matrix or dissolved. So, in this situation what we find that our

elongation longitudinal directions shows somewhat lower strength but greater ductility. So, this is for the longitudinal direction FSP sample taken from the longitudinal direction well the FSP sample taken from the transfers direction shows somewhat higher strength.

But the lower ductility, so we will notice that even the FSP material also which were in the structure is significantly refined through the fracturing and the dynamic recrystallization, this also show some kind of an isotropy in the longitudinal direction. It shows much better elongation as compared to that in the transfers direction.

Now I will summarize this presentation, in this presentation basically I have talked about friction stir processing, friction stir processing can be used for 3 purposes. One is improving the mechanical properties and so, the wear resistance is enhanced, the second purpose is to eliminate the surface defects if they are at the surface due to the manufacturing issues and the FSP can also be used to make the surface composites, thank you for your attention.