Welding Processes
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Friction stir welding Part 02

So, we will start from last class, so last class we already start looking at friction welding, right. So, we looked at the friction welding itself there are various ways of, you can apply load as function of direction with respect to the rotation, okay so we looked at the radial friction welding and then orbital friction welding, angular friction welding and linear friction welding so we looked at video as well, okay?

So, in radial friction welding so what happens, either one of the rods that supposed to be welded, it is fixed, the other rod is rotated with respect the fixed the rod, the heat is generated and upon reaching sufficient temperature the interface the offsetting force is given, then you make a joint. So, I brought one of the joints from our lab, so this is actually radial friction welded, okay so we keep one of the rods fixed so this case this is fixed, and this rotated and then you do an offsetting and make a joint.

And subsequently we have done 4, 3 joints, joining 4 rods. Isn't it? So the video I showed you already so when the welding is done so it is not done in I mean at once so there will be a process characteristics so the initially rotate and make some joint so that the surface become smoother and subsequently we increase the offsetting force, the RPM, rotation ford and the rotational speed and the offsetting force, right.

So, if you can if you remove this flash, I need to look like the actual rod itself, right? So whatever the surface contamination, the oxidation that happened is all removed and then it sent to the flash and you can machine it off, the same diameter of the rod and it will be as good as any other say the homogenous rod itself, okay so this is stainless steel 316, okay so one of the difficult material to weld so we could weld it very easily by the radial friction welding, right, it's clear?

So, we will, after looking at the frictional welding we moved on to frictional stir welding so frictional stir welding, the difference between friction and friction stir and friction welding so you need the interface itself is rotating or moving with respect to the each other, isn't it? In friction stir welding the interface to welded, the faying interfaces they don't really move instead we have a tool which actually plunge into the interface and then rotates at the interface creating a frictional heat and apart from the heating we also have a mechanical deformation, right so the tool itself deforms, carries the metal around the pin from one interface to other interface, right, it's clear?

So it is like (())(03:11) a small nail or the interface and rotate the nail and there is an interface heating between the pin and the tool, the tool and the interface and during this rotation and because of the high temperature material heats up and it becomes easy to deform and deformation happens and the material is carried forward from one interface to other interface, isn't it? It's clear?

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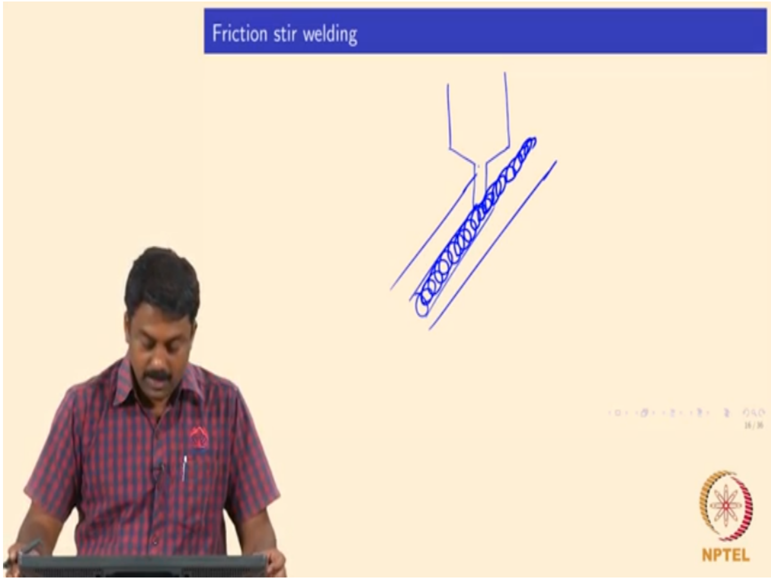

Okay so in Frictional stir welding, if you look at so the important process parameters say we looked at the shoulder itself and the pin so I am just drawing a very simple sketch of frictional stir pin and the interface to be welded so it is actually somewhere over there so pin is actually inserted onto the interface and then you make a mechanical deformation, isn't it? So, this mechanical deformation happens from one interface to other interface creating a joint at the interface.

And there are lot of process characteristics, okay so the RPM of the tool itself, the material the tool material, okay and in most of the cases we had to make in with a material which does not soften at high temperatures, right and it also have a very good wire resistance so that's the reason welding hard materials even steels using frictional stir welding process is difficult because the tool should withstand the temperature, the wire, that is happening during welding.

So for Aluminium alloys it is highly used nowadays to make say longitudinal seam welding for various applications using Aluminium plates and sheets, right and there are other process parameters we were discussing for example the pin size, pin shape the shoulder dimensions, right, the rotational speed, the velocity of the welding, right so all these things, heating, pre-heating and cooling will all influence the welding characteristics.

So generally in Frictional stir welding there are defined zones like in a conventional friction welded material we have a heat affected zone in heat affected zone we also have a fine (()) (05:21) heat affected zone, course (())(05:33) zone, okay and the fusion zone, in Frictional stir welding we have distinctive zones, we are going to do, we are not going to detail in that but we will just see an overview and then we will go further in this class, right, it's clear?

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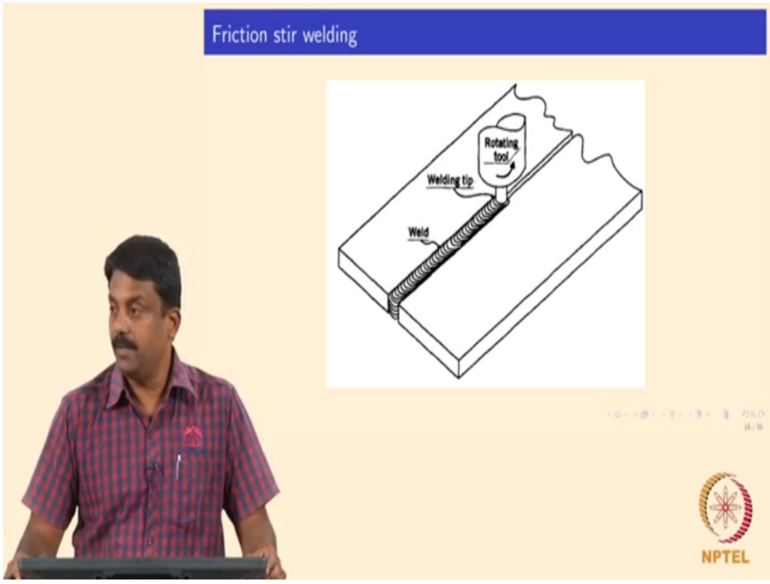

So, we also brought some sample, we look at it after looking at the slides, so this is clear, right? A rotating tool is actually plunged onto the sample and then that material is deformed at the interface during this process, so its high temperature enables easy flow of material, mechanical behaviour of material, okay because material softens at high temperature.

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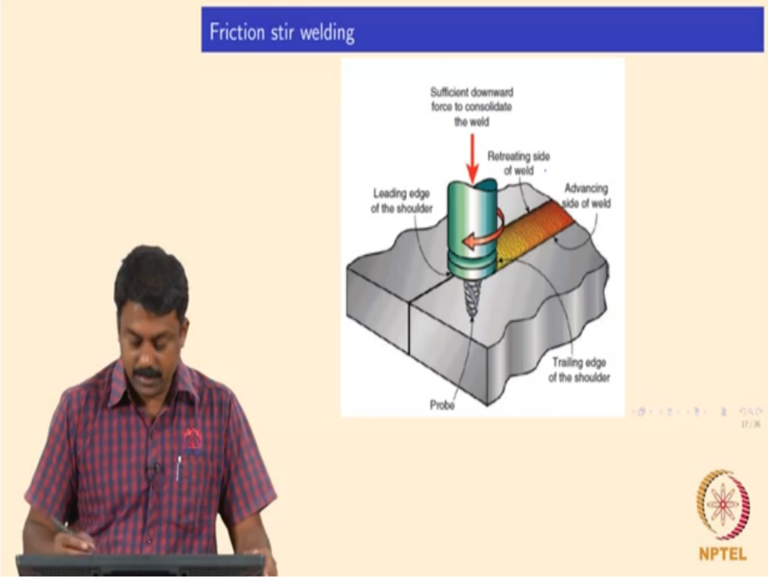

So now so there are some distinctive regions along this weld interface and we looked at this slide in in last class. So, when a tool is rotating along this direction, so we have an advancing side and retreating side, okay, so if it is rotating like this so you have advancing side and retreating side, isn't it?

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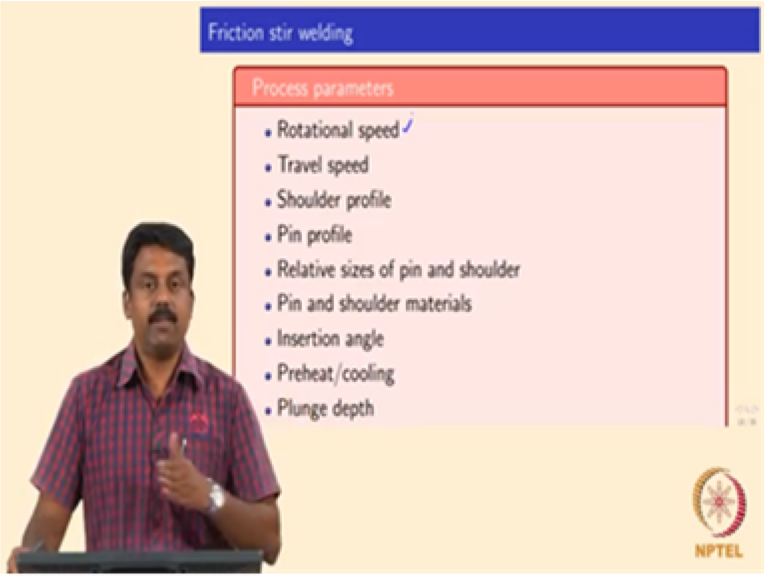

And then the process parameters we looked at last class is rotational speed that's RPM of the tool itself, the welding speed or the travel speed and the shoulder profile, pin profile, okay and the relative size of the pin to the shoulder, that will all influence the flow of material as well as the frictional heat generation.

So angle of insertion and pre-heating and cooling and plunge depth so plunge depth means how deep the tool is actually penetrating the material so generally we are keeping if the thickness is 10 mm we have a slight material left at the bottom because it has to flow otherwise you may have swaging of the pull, okay, so the plunge depth is always less than the thickness of the material, okay, so plunge depth so that we can achieve at the bottom a good finish otherwise you may have a swaging.

What is swaging? Swaging is you may have an sort of material is flowing and at the top you may have a some concave cavities so always keep the plunge depth slightly lower than the thickness of the plate you are welding. Good.

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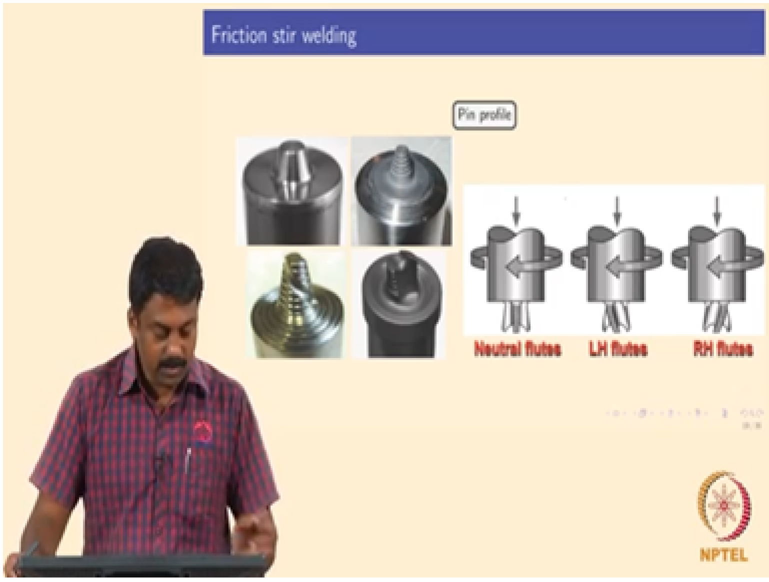

So we will go in further in the frictional stir welding process, okay, so the pin profiles are displayed over here so these are commonly used pin profiles, what you use, so generally if you have smooth interface obviously you also generate less heat because friction heat may not be sufficient and material flow behaviour can be changed by changing the pin profile, okay.

So, I have one example so this is Aluminium, Aluminium to Aluminium weld so this is starting position, notice it over here, okay, so this was done with I think the hexagonal pin, it's not there, so initially you plunge the pin inside and there is always an some waiting time so you establish the heating, okay, once the heating is established and then you continuously move the pin along the interface until you finish welding.

So, you always have this dealing effect, the plunge when it actually inserted onto the interface, so you will always have some cavity, so you have to machine off the initial starting position and also the ending positions as well, right? So, if you look at the bottom, so interface you don't see because plunge depth will be always maintained slightly lower than the smaller than the thickness of the plate (())(09:18) plunge depth but that will also influence the weld seam.

If plunge depth is higher so you may also have more deformation is happening at the interface, okay, so by controlling the plunge depth and if you spend more time for example if the speed of welding is low so you also heat up a material more so material flow will be higher, right? So, the weld metal properties can be changed by changing all these parameters what I showed in last slide, okay.

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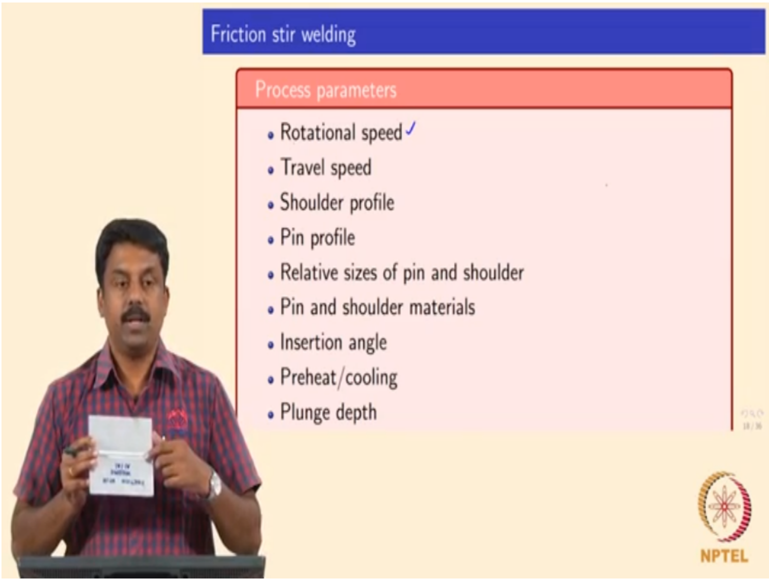

the speed of rotation, travel speed, the shoulder profile and the ratio the size between the pin and shoulder.

And that will also influence the frictional heat generation and mechanical deformation, the material flow across the interface, right? So that will all influence the weld formation so as I said this is very highly used for Aluminium alloys because Aluminium alloys are generally they are actually very what you call that, naughty when you are doing it in a arch welding because of hot cracking issues, the issues with thermal conductivity okay and distortion, stress generation and (())(10:25 to 10:28) Aluminium alloys they have offering, deficient zone you have to do and oppose for heat treatment.

So, until 90s welding of Aluminium alloys were considered challenging and we had to use various techniques to avoid hot cracking issues during welding of Aluminium alloys. So once the frictional stir welding came into picture so for most of the applications which required longitudinal welding like in the video I showed you for making the aircraft (())(10:55), okay structures which demand very large seam welding.

So nowadays our PSLV, GSLV, okay, so the outer body these are all 4 or 5 meters Aluminium sheets are welded longitudinally the seam, okay, so those are all welded with frictional stir welding, so in most all the Aluminium plates used in the aircrafts being an airbus or Boeing so all the components which actually uses Aluminium sheets, plates they are all frictional stir welded, okay, because you can achieve reasonably good weld, very stable mechanical properties at the weld zone and there is no significant softening of the welds.

Because at this stir zone what we call it, okay, so you will also have severe grind refinement because of the dynamic (())(12:00) rejection, okay, so you have a deformation and the deformation is done in very high strain (())(12:07), okay, so for all Aluminium alloys generally after heat treatment so if you have what you call it T6 heat treatment, okay, so you will have empty space not in material, T6 means, what is T6? (())(12:26) artificially edged, okay, so the T6 heat treatment, okay, so metal edging, sorry guys.

So, materials are already edged, okay, so when you do a fusion welding at the heat affected zone you have a coarsening of precipitates leading to a severe softening, isn't it? But in frictional stir welding and because of the mechanical deformation would also lead the grand refinement and then the temperature at which it reached, can be controlled, so you will not have a severe coarsening of precipitates, so we can.

There will be some softening but because of the mechanical deformation what you subject, you may also solutionizing subsequently may also precipitation upon welding, right, it's clear? So, it's done. Yes.

Student: While welding this, these were two different sheets?

Professor: Yes

Student: And when they were connecting,

Professor: Not connected, when they welded

Student: Yeah, they were welding

Professor: Yeah

Student: In case of ours the surface tension fills the down thing

Professor: Not down thing, okay so you mean the weld cavity

Student: Yeah, beneath the weld

Professor: The weld is this, what do you mean by beneath the weld?

Student: The down part?

Professor: This part?

Student: If this is the weld

Professor: Yeah

Student: Here it should be what control like joining of this

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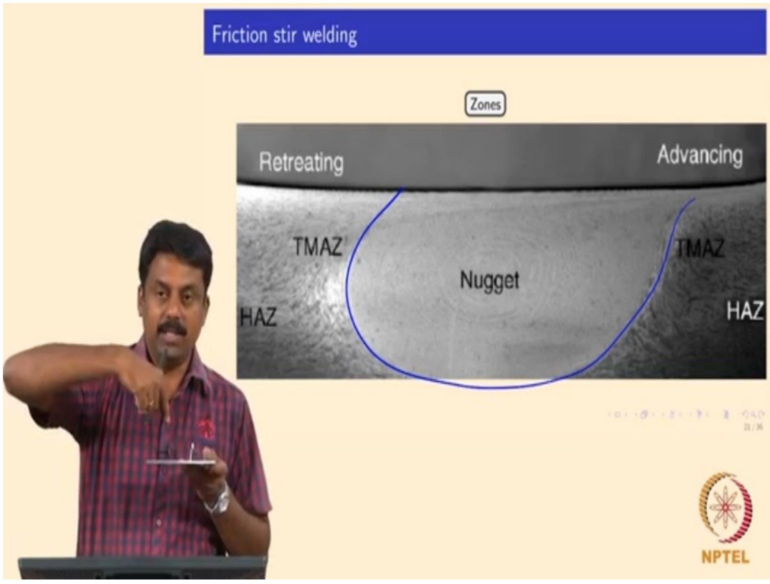

Yeah so, the material is flowing only along the plane, okay, see, you look at the microstructure, okay, see over here, so what you see over here is the various zones which I am going to cover, anyway you asked the question, so this, what you see over here is the sister zone, right? So, when the plunge is, the pin is actually plunged into the material we always maintain some gap from the bottom, okay, so the plunge depth is always lower than the thickness, right?

So, when material is rotating so rotational direction so the advancing retreating side only, okay because the pin is going to (())(14:45) and the mechanical deformation is going to happen, okay, along, because of the centrifugal motion of the pin which would carry the material from advancing side to retreating side, right? So, your question is why it is not going down?

Student: My question is how is the bottom part being welded when there is no surface tension, no molten metal?

Professor: Yeah

Student: How is the bottom part being

Professor: So, you also have material beneath the pin would also be deforming it, right? So, it will not be only at the tangential direction, so you will also have some material here as well, okay, so that will also be moved, right? So, along the circumferential direction I mean tangential direction you will also some material at the bottom as well will be stirred, right? So, the gap between the pin tip to the bottom thickness will be very minimal.

So, you can't keep, otherwise you will have just (())(15:42), isn't it? If the plunge is, pin is coming out of the other surface, I mean that's not effective, isn't it so you will just make a cut, right? So, you need to maintain some gap and that is good enough, so material is also going to flow beneath the pin as well, right? So, we are going to make weld so if you are, plunged up this really minimal so you may not see I mean you may see interface at the bottom.

So this this just cut off so there is not extra material which has to be machined off but you don't see the interface, you see the interface at the edge here but this region you don't see the interface so the plunge depth is carefully controlled in this weld in such a way that the interface is disappearing, you will have just enough flow, okay, which controls the swaging as well, isn't it?

So, interface looks smooth, I don't see any extra material at the bottom, okay, just enough, if you have extra material obviously you will also see cavity here because it must (())(16:51) material has to be sent from one end to other end unless you are taking out.

So, this perfectly welded, frictional stir welded Aluminium plate, right? Yeah so you have to machine off this region, you can’t use it so you will cut it out and then if you polish or if you just mill it about mm you don’t see joint, okay, so you will not see in naked eye the joint unless you see the microstructure inside you will see this so what are the regions you see?

So this is weld nugget so this is stir zone, okay, in stir zone you see grind refinement generally in Aluminium alloys, the harness will be higher than the (())(17:37) zones and just at the boundaries of stir zone so you will also see thermo mechanically affected zone so in this case, temperature will be much higher and when you move away from central line you will also thermo mechanically affected zone, it means that you will also have some mechanical deformation but that is not sufficient to cause a plastic flow, okay.

So, you see some deformation and effect of temperature because temperature can also rise significantly but the temperature is not that significant to cause any (())(18:17) or so, you will just see only a deformed zone and you have a material which has some (())(18:26) deformation, right? It’s clear? And then if you move away and you will also have some heat effected zone so you don’t see any mechanical deformation, but you still see some temperature effect.

Because the heat is actually dissipated from weld central line. So, the temperature distribution will be similar to arch welding, so you will have a maximum temperature okay, so in the fusion zone, it will be going down like this, isn’t it? Yes, it’s clear? So, in (())(19:01) arch welding you will have fusion zone and heat affected zone but, in this case, you also have a additional zone that we know as thermo mechanically affected zone.

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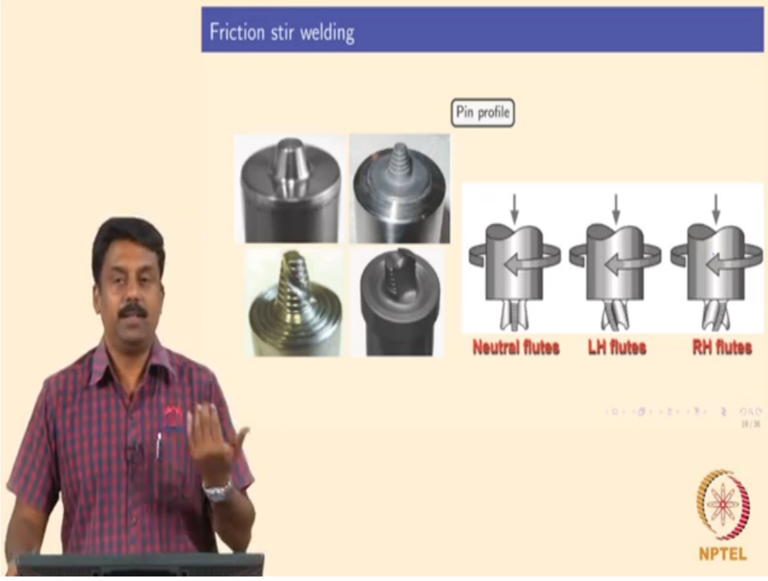

Okay the pin profiles, these are some of the pin profiles which we use in our lab but there are as I said tons of volumes of manuscripts, literatures published in frictional stir welding last 20 years and people have figured out changing various pin profiles, shoulder profiles, the relationship, I mean the ratio between pin and shoulder depth and material of the pin and yeah manufacturing processes, various manufacturing processes they use tools I mean change the properties of the pin with respect to the shoulder.

But these are some of the pins generally we use and you may also have some profiling at the pin for example you can also have a Neutral flute, okay, so where you have an hexagonal structure or you can also have Left Hand flutes or even Right Hand flutes and this would influence the mechanical behaviour as well as the temperature, heat generation, right, and you see the profiles, various profiles people have tried and optimized for achieving good weld seam properties. Good, any question, so far?

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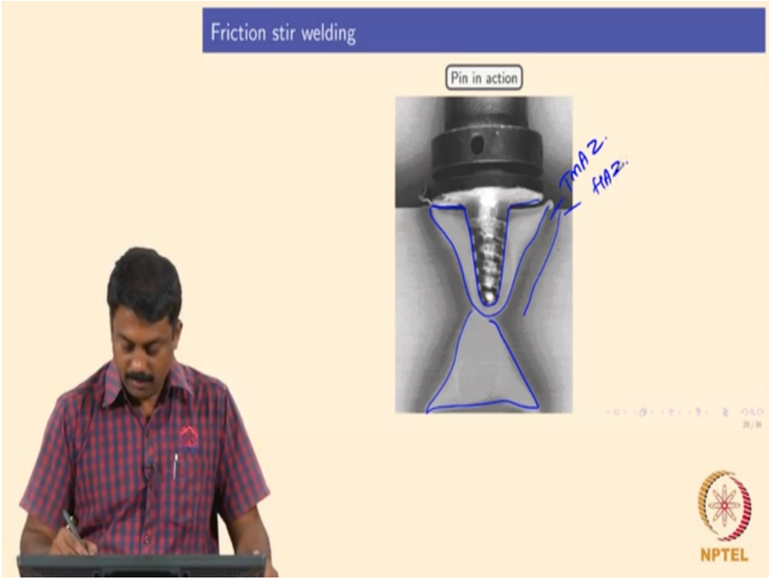

Okay, so we will move onto next so this is the pin in action so one of the pins what you see over here so pin profile and you have a shoulder here, okay, and then this is the pin and this rotating along clockwise so if it is clockwise you have advancing side and retreating side and you see the depth is not controlled so in this case we are doing it in both sides so this is the bottom side and this is top side, right?

And in some cases if thickness is higher and in this case for example so the welding is done in both sides on top and bottom so you do a welding on top, reverses and then you do it on another side, okay so this is this stir zone, you see over there and this region so this is TMAZ, right and then you have a heat affected zone, yes, it's clear? Okay, good.

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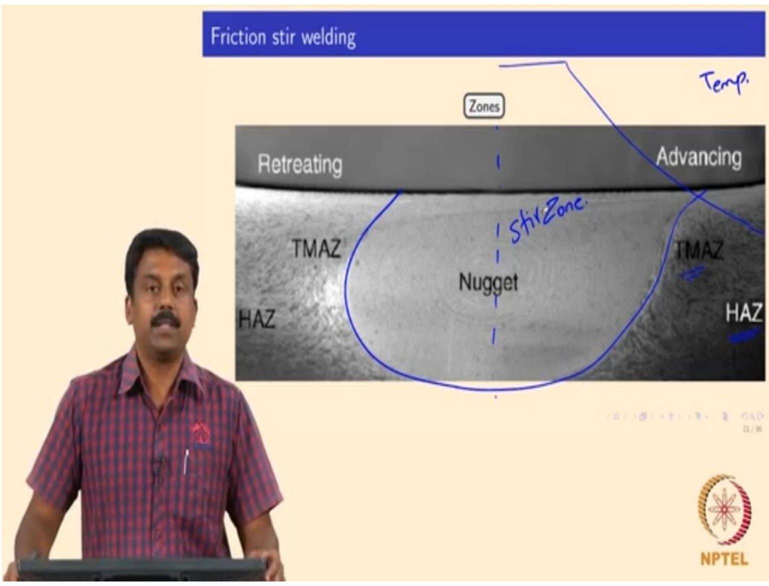

So this I have explained various zones that are present in frictional stir welding, okay so you have a stir zone where you have a mechanical plastic deformation as well as the temperature, now heating effect, both will cause a dynamic (())(22:05) simultaneously, okay and then if you move away from the boundary between the stir and heat affected zone so you have a thermo mechanically affected zone and then if you move further you don't see any real mechanical deformation, you will see only the effect of temperature. Okay, so that's we call it heat affected zone. Yes, it's clear? Good.

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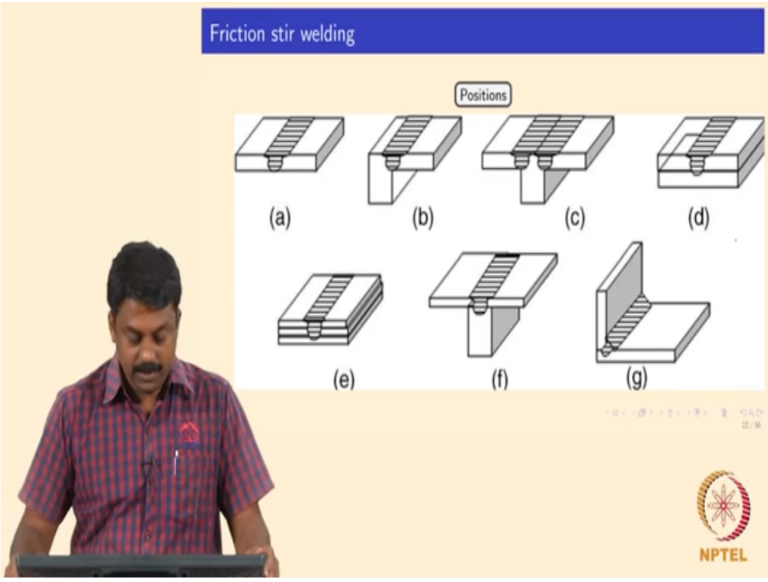

So, what are the positions that can be welded using frictional stir so one of the major disadvantage of frictional stir welding so the accessibility, okay, so you cannot same as resistance pot welding, you cannot weld it when you can't access the joint with a pin and shoulder, isn't it? So, you need a reasonable accessing otherwise how are you going to insert a shoulder and a pin and then make linear weld?

So, in most of the cases we can change the position we can play around the geometry of the weld, in such a way you can still achieve the weld so this is the most used configuration so that's a butt weld, okay, so if it is T joint, generally in T joint arch welding we do a fillet weld, isn't it? So similarly, what you see over here. But you can also do in this case (()) (23:19) spot welding so we attach it and then clamp it and then you do stir butt weld and such a weld welding in arch welding case. It is not advisable, right?

So, we can also do, yeah same configuration so we can also do two welds and you can achieve an T configuration and in this case overlap joint, okay, so you can also make, make sure that you have some mechanical deformation happening at the bottom plate as well so you can have simple overlap joint without any pre-set gap, okay.

And multi sheets so this kind of layer by layer (())(24:02) so in this case it is not really friction free form fabrication but you stack layers, individual layers and then do a frictional welding, okay, so various configuration it is done and this is bit tricky so T joint configuration, so you have to make sure that pin is plunging onto the interface and the interface would be clamped that's why, you know, when I presented (())(24:25) unit, the touring, (())(24:27) touring we need to have so in this case if the clamping loading is not maintained, it's going to deform, isn't it? So, the weld integrity will not be achieved.

So, you may have defects in overlaps. Good so these are the positions and so you compare all the positions, this is most commonly used simple butt joint, butt weld, right, it's clear?

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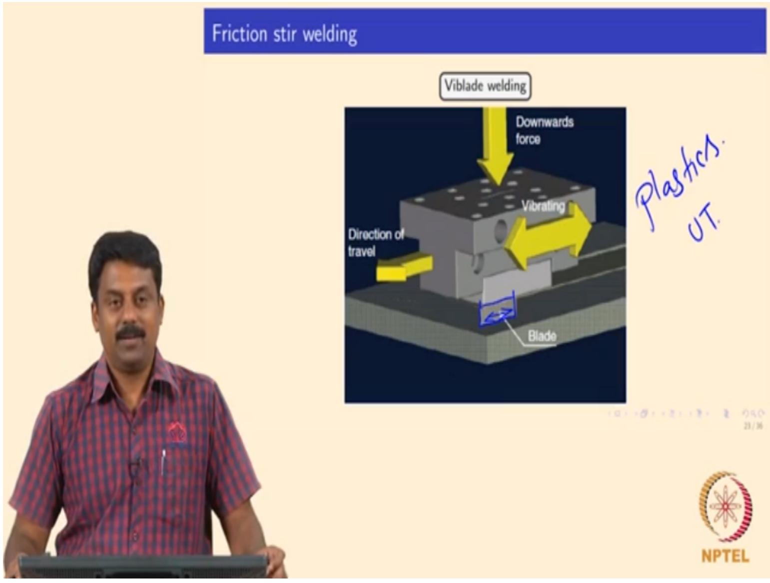

So, there are some, various modifications as I said last 20 years people have tried so many and people also use nowadays frictional stir to weld plastics, woods, wood, solid wood so they are all welded using friction, okay so for plastics one process actually right now it is commercialized, it is called Viblade welding so how it is done?

Actually it is very simple, so what is done is we insert a small blade, steel blade into the faying interface, okay so this blade goes inside and then you have a vibration so you have a linear vibration so linear friction, the blade is vibrating but you have a downward force so blade vibrates and generates heat and you also apply some pressure so once the temperature is reached you do a slight pressure so that the material can flow with the temperature.

Okay, so you have a downward force, and this is the tool, what you see over here and then you insert a small blade you see here, isn't it? So, this attached to the tool, you clamp two plates so in this case Viblade is commonly used for plastics. So, this blade actually vibrates, okay, along the interface and simultaneously you vibrate, and the entire tool is moving, isn't it? So, this vibrating tool causes the interface to heat and the plastic at the interface is not so flowing makes a joint, okay, so that's possible.

So, there are equipment now available to join woods, wooden blocks and ply woods by linear friction welding. So, one block is kept, and the other block is vibrated, and you apply a downward force and you can join 2 wooden blocks, okay, so these are friction enables the heating and localized flow of wooden particle causing an joint, right? So, bamboos, they are also welded. Basically, angular rotation welding. So, I have seen various videos, my students used to forward so there is a welding for a bamboos, you will see angular friction welding. Okay, yeah, good.

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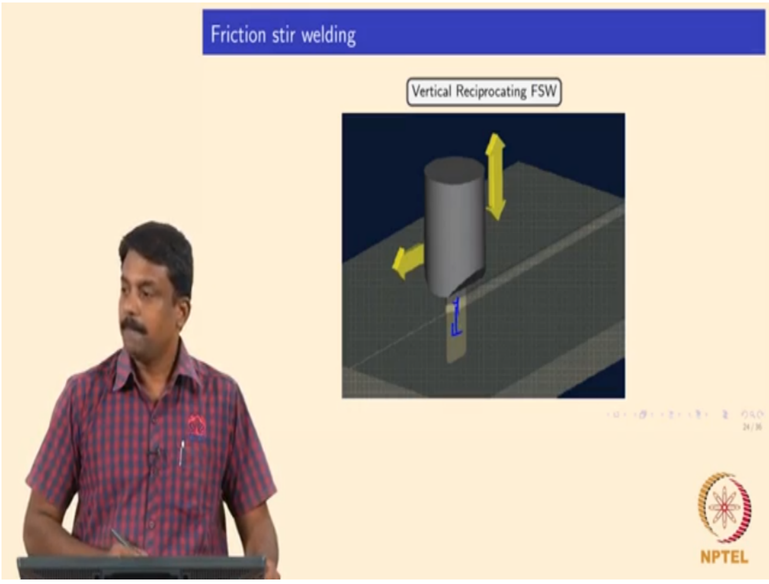

So, the other variants, instead of a linear reciprocating motion you also have a vertical reciprocating motion, okay, you still have the blade instead of going linear way, so you also have vertical, going up and down, isn't it? And this can also cause heating at the interface, so the clamping of the plates enables mechanical deformation across the interface and you end up making a joint. Yes, it's clear? So ultimately all the process parameters are important what I talked about, okay.

So, in this case the vibrational frequencies, right and the blade configuration, you are having flat blade, you can also have, some profile of the blade, that can change the local heating as well as the deformation mechanism of the interface. And then the amplitude of the vibration so the pin material itself, pin to shoulder ratio okay so all these process parameters would carefully be controlled to achieve a nice weld like this, yes, any question so far? Yes or no, nope.

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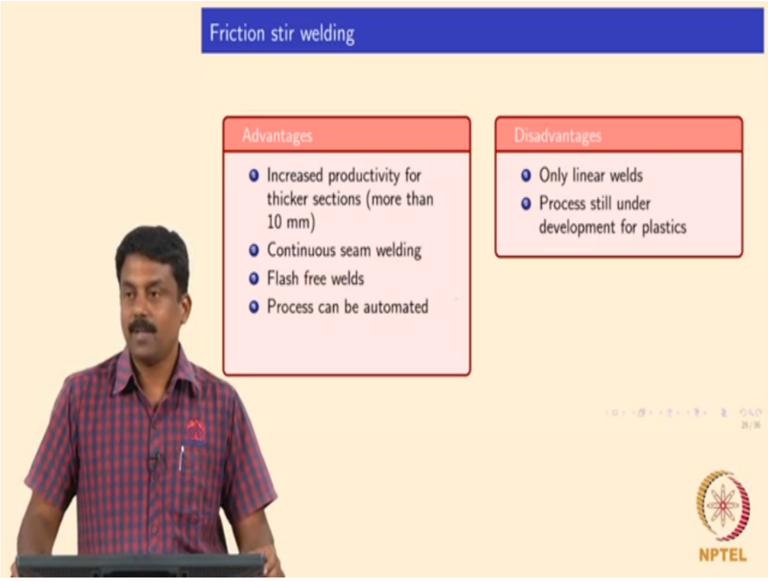

Okay, we will move on to the some of the theories and then we will move to the next welding process, right? So frictional stir welding, what are the advantages? So main advantage of friction stir welding is in my opinion, so you can weld softer material I mean material which can flow easily, right, material which softens easily with the temperature, okay so Aluminium alloy, it softens significantly when the temperature is increased. So, right?

And material with (())(29:45) at elevated temperature can be welded very easily using frictional stir welding and we can increase the productivity say for example in this case, this is say about 5 mm thick so if you are using simple gas (())(29:58) welding so you need to have a filler, unless you use plasma, okay so that increases the time of welding also cost, right?

But in this case the welding is achieved in significant less time without using any filler material, right? That means that productivity increases and specially if it increases the thickness further in conventional fusion welding you have to use multiple process.

And there are lot of problem associated with fusion welding itself, right so we can achieve a continuous seam welding, so welding can be done continuously, infinite distance as long as you have a proper tooling in place, okay and most of the cases we don't generate flat, flash especially frictional stir, in friction welding you still have a flash, isn't it? So, this is friction weld as I showed in class, but you have to remove the flash, right? In frictional stir you don't need to remove the flash.

So what you need, during the start you may spend some time, initial waiting period to achieve enough heating so you will have to just machine off the start position and the process can be automated, you can also have a robot, it is it is a machining in a way so you have drilled milling machine can be converted into a frictional stir so you can also achieve complex geometries welding various configuration in butt weld, okay.

So, what are the disadvantages, only linear welds, cannot do it in a angle, right? So, for a materials which don't flow as hot materials it is difficult for steel for example it is difficult to achieve, right. So other than that, because its problem in frictional stir is this hole at the end, okay, so when the pin is coming out you always see this effect, isn't it? Okay, so, this is okay, this is reasonably good but in most of the cases you always see the both you see the effect of pin geometry. Good.

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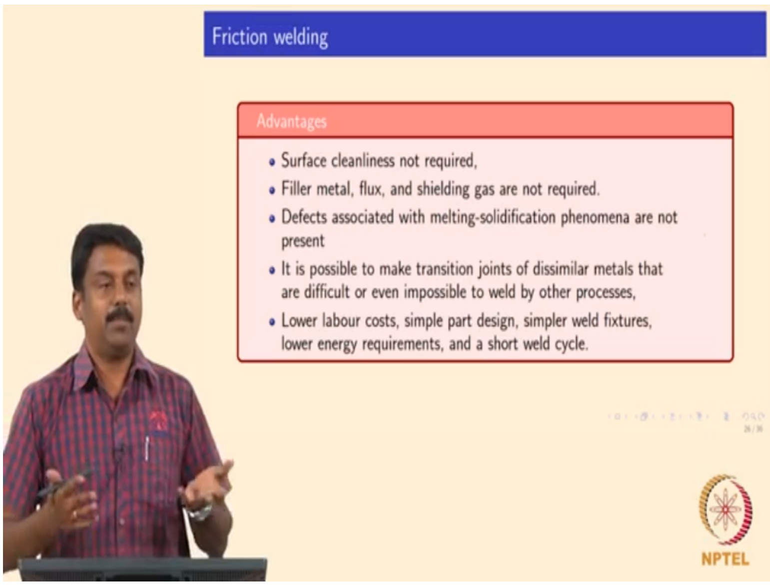

So, in Frictional welding in general what are the advantages compared to the arch welding, it's not only friction, Frictional stir so the biggest benefit of friction is surface cleanness preparation, you don't need because you can clean the surface by yourself so that's why you have initial time, okay so.

If you look at the process characteristics we don't apply load immediately, you can have a waiting time where initially you can smoothen the surface. Remove all the contamination so that's possible and no need to add in extra filler material, fluxes, shielding gas so it becomes cheaper, right? So, you don't need to add any filler or flux.

So you don't have solidification of the micro structure at the weld so the all the problems, the cracking issues and segregation associated with the solidification, they are not there, okay so you don't have hot cracking or inclusion formation or some porosity formation, okay and it is also possible to make an transitional joint suppose you are welding at two dissimilar material say Aluminium and Steel, okay so you can also have a transition layer which is actually compatible in both material.

So in most of the cases when you are welding Steel and Aluminium, it is always good to have an galvanized layer because Zinc is compatible with both Aluminium and steel so the joint integrity will be much better, okay or you can also try for example have a butter layer and you can deposit let's say Aluminium Copper and then Copper Iron you can deposit or Aluminium, Nickel, Copper or Aluminium, Nickel, Steel so you can also it is also possible to make a transition joints, okay, so that you know so let's say possible metallic formation can be avoided.

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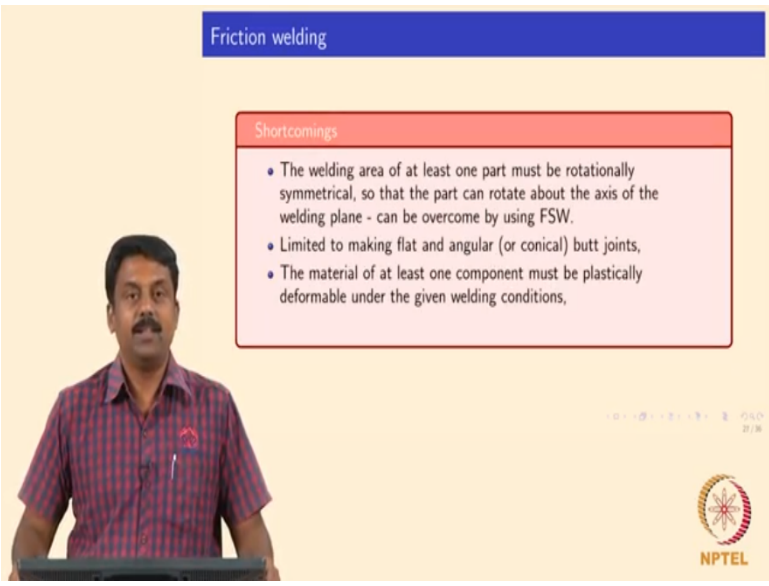

The other major advantage is low labour cost, good so we will move on, so what are the disadvantages? See there must be some symmetry, isn't it? In frictional stir welding so if this rod, if this rod is slightly larger than the other rod, diameter is larger, and it is very difficult to weld, isn't it? So, you will not achieve, it's very difficult unless you do an angular weld or orbital weld, so you need some symmetry at the interface.

Especially in frictional stir the similar thickness is very difficult to achieve, right, so you cannot do it in overlap configuration unless yeah, so you need to study (())(35:15) welding procedure, right so some symmetry should be there. So, you need an I mean to some extent it can be overcome in Frictional stir but still you cannot go for a highly asymmetrical interfaces by friction welding, okay. So not all the configuration is possible.

Specially in frictional stir generally it is avoided for a circular pipe configuration, it's very difficult to do continuous seam welding in a (())(35:45) configuration. So flat, angular, some extent butt configuration as I showed in the previous slides, okay and the major drawback of frictional stir is a material itself, okay, so material should plastically deform, isn't it? So, if a material is hard, it doesn't really soften for examples super alloys, so these are the shortcomings of the friction welding itself.