Welding Processes
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Introduction to solid state welding processes - Friction welding

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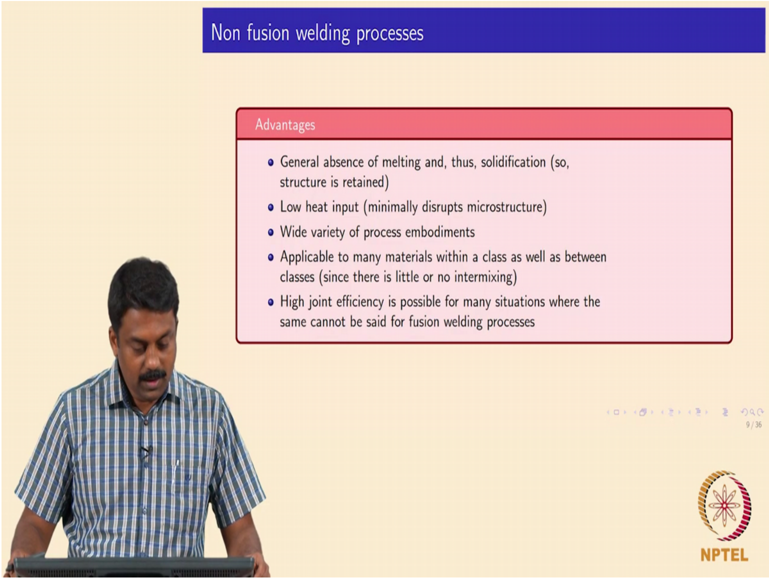

So with that we conclude all the fusion welding processes, Ok where some heat is there and liquid metal is there, Ok all the time.

So we use arc or resistance heating to melt, we form the liquid at the interface and subsequently the liquid is solidified to make a joint or liquid is expelled and subsequently the mechanical deformation would cause the coalescence at the interface, yeah.

You mean that weld efficiency? So weld efficiency in terms of like based on the base material. If you are using high magnetic steel the efficiency is as good as 70 percent. Because the microstructure what you are going to get after the thermit process is the cast microstructure, Ok.

So efficiency would, you can still maintain if the base material is high magnetic steel or conventional rail composition. You will get 60-70 if it is a cast structure, Ok.

Suppose if your base material is a high speed rail, or ferritic bainitics rail or carbide-free bainite rail then if you are using thermite welding and we are not going to achieve toughness of carbide-free bainite weld, and base material and the weld, Ok so the efficiency will be not even 30-40 percent. OK, good.

So we move on to the next types of welding processes, Ok. So far we looked at fusion welding processes.

So the definition of fusion welding we have talked about in first or second class, liquid is always there on the interface, Ok. So the moment you say that liquid is there at the interface, we term it as a fusion welding process, right?

And we can also make weld because when you look at the definition of the welding when we say the coalescence can happen either by heat or pressure or both, Ok. And we can also make the coalescence happen just by pressure, Ok.

So you can also do welding at room temperature just by applying a force. Or we can also generate heat by force, right for example using friction, Ok. So friction can also generate heat at the interface, so for that you need to apply some force, some pressure, right.

Or you can also do welding at room temperature, cold welding, Ok. And cold welding can be done, especially material is extremely soft or easy to deform. So welding can happen at room temperature as well as long as the material can be ductile and you apply some force, you can cause the coalescence.

In most of the cases, in non-fusion welding processes we need some heat because the ductility of the material is not good at room temperature, most of the metals.

So when you heat up metal becomes softer, isn't it? What happens when you heat up the metal, aluminum for example? Does it softens or hardens?

(Professor – student conversation starts)
Student: Soften
Professor: Why? What do you mean by softens?
Student: (()) (03:45)

Professor: Because of...so what happens? Yield stress decreases or increases?

Student: Decrease

Professor: Decreases with temperature, right? Why?

Student: (()) (04:03)

Professor: Dislocation, generation, I want all the reasons.

Student: (()) (04:07)

Professor: Ok, one reason. It will form more defects. Let us put this (()) (04:09) temperature. Ok and then, that is it? What is it?

Student: Leakage comes in.

Professor: (()) (04:22) increases the strength, right? So what happens then? Ok, defect density increases. So you form more dislocations. That is what happens or any other things can also happen in F C C for example, with respect to temperature?

Student: They get some mechanism when we apply heat

Professor: What mechanism? So you said yield stress increases. So dislocation density increases. Ok

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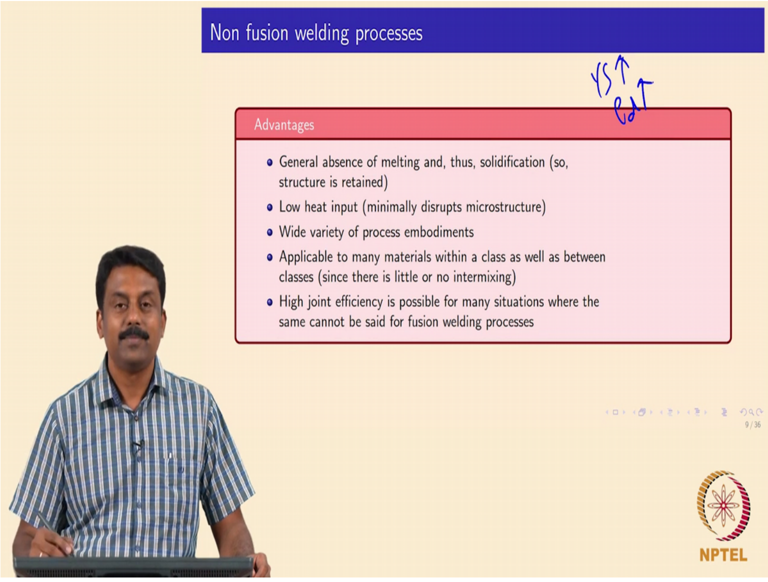

so the moment of slip, so dislocation slip, right and you also have slip systems. Would you like to keep the same slip systems?

Student: (()) (05:05)

Professor: Yeah, so there are more slip systems get activated, so dislocation slip can take place in much, more directions because you induce more slip systems. So this is all leading to increase in ductility. So material can deform easily when increase in temperature, right?

(Professor – student conversation ends)

So instead of doing at room temperature so we can heat it up to some more temperature. So the mechanical deformation which causes the coalescence at the faying interface can be induced easily, right.

So in flash butt welding for example we heat up the interface. In fact even it goes to melting in flash butt welding.

But ultimately the material coalescence happens; the interface coalescence happens by the mechanical deformation because as the temperature is increased, deformation can be induced at lower force, Ok.

So the welding can be done at much more easily than doing at room temperature. Ok in flash butt welding we generate heat by arcing and subsequently resistance heating.

Ok so we can also induce heat by friction, Ok. So we can also, because we have 2 interfaces, obviously we have 2 interfaces. Of course it is warm we also do this, right to warm up ourselves, isn't it?

So how do you increase temperature locally at the interface?

(Professor – student conversation starts)
Student: Friction
Professor: Yeah, how does friction heat up? Because of, yeah conversion of kinetic energy into heat energy, isn't it? But we also have another phenomenon in the metals now (()) (06:47) happens.
(Professor – student conversation ends)

We also have surface asperities, Ok. We also have mechanical deformation at the interface, Ok. So that is also implicitly into adiabatic heating, isn't it? So when you have mechanical deformation you also break the bonds, isn't it? So you are also breaking at the interface. You are smoothing at the interface.

So not only kinetic energy is converted into heat energy, we also have a local coalescence can lead to a heat generation, Ok. So we can use friction also to heat up the interface and subsequently do deformation. A metal can deform easily when the temperature is increased.

So that mechanic deformation can induce coalescence, Ok so we can use friction. Or you can also have a very high energy given to the interface so that interface deforms even much without heating.

For example you can do an explosion, have a T N T packed at the interface, a given explosion. So you will have a very high strained rate deformation induced at the interface.

And that could also make the interface coalesce, Ok. So you can also do it even without melting by applying a shear force, by using explosion. So explosive welding is also very commonly done, right.

And almost all these welding processes we do not melt, Ok at the interface. The interface is not molten but the welding is achieved by the mechanical deformation, Ok.

The interface is deformed and then coalescence happens in mixing of interface happens by very simple mechanical deformation.

So we look at all these non-fusion welding processes. So the basic definition non-fusion means there is no liquid at the interface. Right, is it clear? So what are the advantages?

The moment you do not have liquid, obviously

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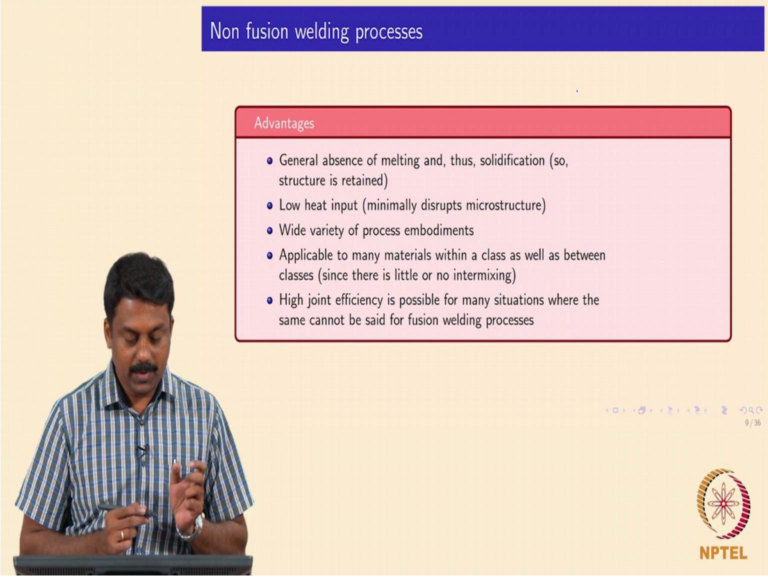

the concept of solidification is gone. You do not have solidified microstructure, Ok. So you will have a mechanical deformed and recrystallized microstructure isn't it?

So the weld interface would have better mechanical properties than the solidified fusion zone in the fusion welding process right? Because there is no melting. So therefore no solidification. So interface would be much more integral than the solidified fusion welded microstructure in the fusion welding process.

And because you do not increase the temperature much higher you do not need to give more heat, Ok. So you minimize the damage to the base material microstructure. So you can have a very narrow heat affected zone, right. And as well as you can also minimize the distortion. Yeah?

(Professor – student conversation starts)

Student: How does recrystallization increase the strength of the material because initially when dislocations are there, the strength would be genuinely increase the deformation in order to increase the strength as well. But in recrystallization all the deformations are gone; crystal is at the normalized…

Professor: Yeah, see. The recrystallization can also happen directly, Ok. So if we have grain size refined from the starting, base material microstructure Ok, in these welding processes severe deformation causes dynamic crystallization, right.

(Professor – student conversation ends)

So base material generally have coarser grain than the weld zone, Ok. So if you have dynamic crystallization, you may induce grain refinement, Ok.

So in this case, you are comparing, when you compare with the cold deformed and then subsequently recrystallized you have softening. Ok, cold work material is strain-hardened.

Whereas here you have base material and then you are deforming it, subsequently dynamically recrystallizing it. So in that case the grain size would be finer than your base material microstructure.

So then the strength of this joint will be higher than the base material because of mechanical deformation straining and subsequent dynamic recrystallization, right, good.

And we can use a wide variety of processes embodiments, Ok. So we will see that in subsequent slides. And it can be applied to many material. So even dissimilar material can be welded.

Ok so copper aluminum for example we can weld it, selenium aluminum we can weld it. Ok and you can achieve because of absence of solidified microstructure, the join deficiency. What is join deficiency?

How much deterioration happens in terms of property, Ok? So that determines join deficiency. We have 500 mega Pascal strength base material, well the mechanical property for example the yield stress becomes 350 so ratio between 350 and 500 is join efficiency, Ok.

So join efficiency can be achieved much higher in non-fusion welding process because there is no solidified microstructure, isn't it? So just simple mechanical deformation.

In most of the cases you will have grain refinement compared to the base material because of dynamic recrystallization. The strength can be increased substantially of the fusion (()) (12:14) zone.

Ok so we look at the other processes one by one. And then we wind up, right. Good.

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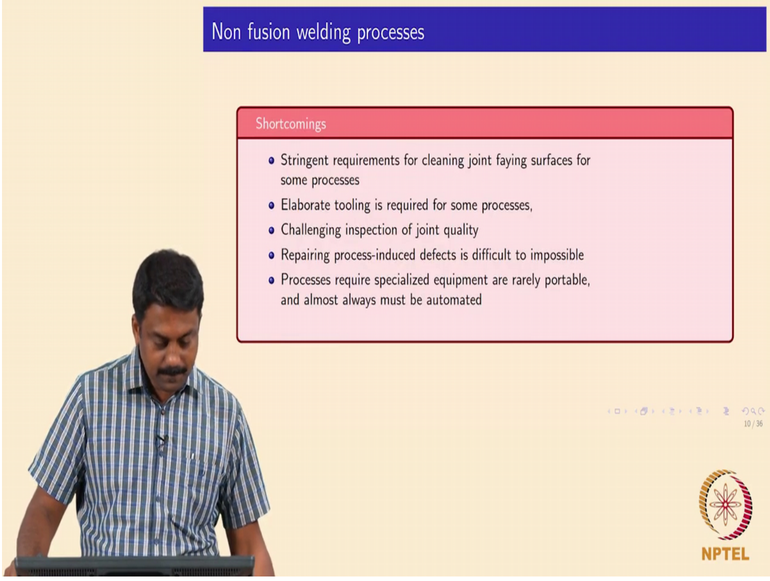

So what are the disadvantages of non fusion welding processes? The interface in most of the cases should be cleaned properly.

Ok so if it is oxidized, obviously the oxide inclusions would still get penetrated because you are not going to remove like in earlier, in liquid welding, fusion welding. Ok.

In some cases, in friction welding process, the tooling requirement, Ok what do we mean by tooling? Because in some cases in friction stir welding process an example, so there is a pin rotating.

And the pin rotates and causes friction as well as the mechanical deformation of the interface. So the tooling has to withstand the pressure and temperature, the heat at the interface, Ok.

Whereas in rotary you have rotary friction where two jobs are rotated and you will have to make sure that the jobs are clamped and fit without any deviation from the axis.

So you need to have enormous amount of tooling, the load, the pressure, the capability to keep the rods together so that no you can make weld joint without any defect, Ok. And some other challenges I listed.

Say for example, inspecting the weld joint quality Ok and then the equipment, sometimes can be difficult, for example explosive welding, you cannot do it on every time, right.

So we look at one by one all the other processes.

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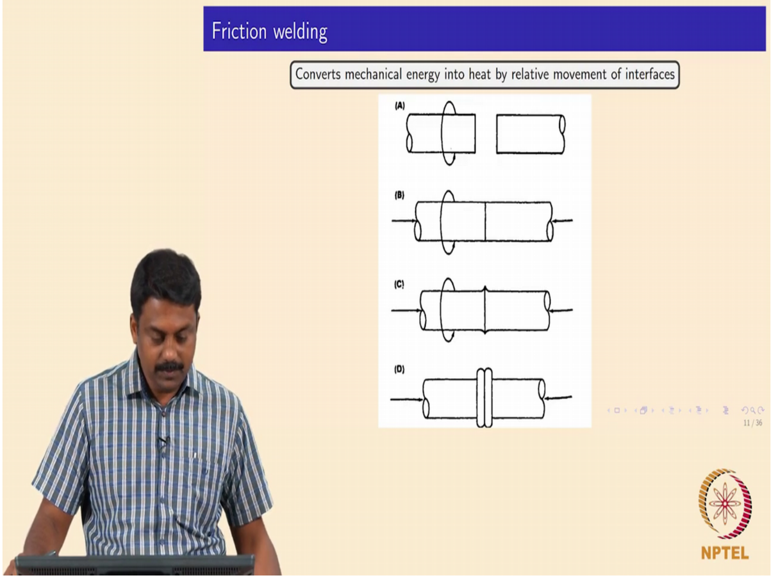

The first process we are going to look at is friction welding, right.

So the basic principle, the friction heats up, right. So. so we already feel that when the winter is coming so we rub our palms to warm ourselves. We do not warm that much. It is just a psychological, Ok.

So whereas if you rub 2 metal objects, obviously at the interface heat up, right because you are converting mechanical energy into, or kinetic energy into heat energy.

And apart from that you also have a local deformation of the interface because no surface is flat. Ok, unless you are really making atomically flat surfaces, Ok so then you may reduce the friction or heat really generated.

So obviously if you have surface asperities

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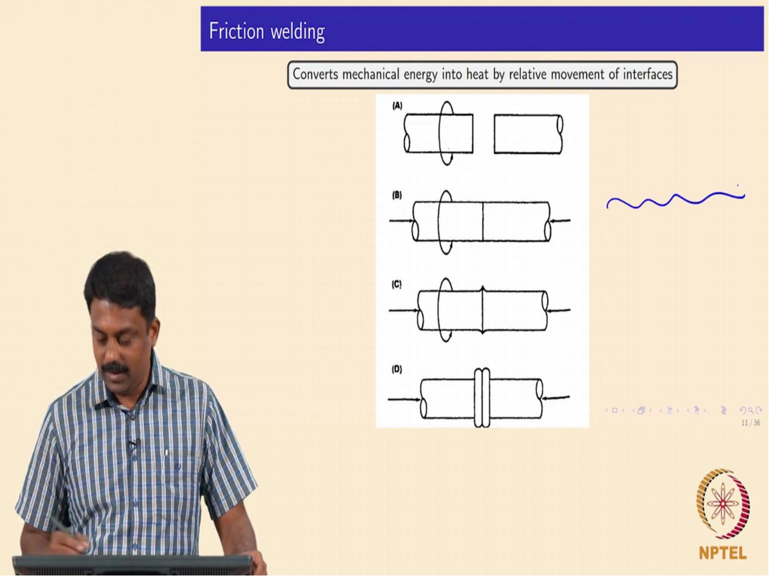

and when you are rashly rubbing, I mean you are rashly moving the interfaces with respect each other so obviously you will also have a mechanical deformation

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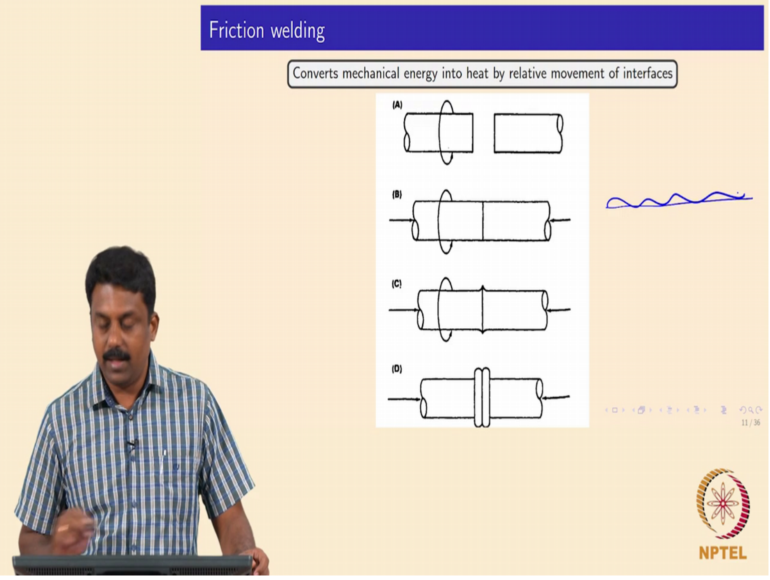

happening at the interface.

This mechanical deformation would also cause the adiabatic heating, right. So you may, you also have breakage of bonds and the bond energy can be converted into heat energy, Ok.

You can also feel when you take a pin and then deform it, continuously in cyclic load, right and you touch the bent region it warms, it warms up, right. Because you have locally plastic deformation. So some energy is converted into heat energy, right.

So apart from the conversion of kinetic energy into heat energy you also have mechanical deformation inducing heat at the interface, right. So the process is very simple. Honestly I do not like any processes which does not have arc because I love arc, Ok. So if it does not have any arc and plasma, I hate. Ok

For me any process which does not involve arc and plasma is very nasty, very dirty. Ok but we can live with that. Because some of the applications we need friction welding, Ok.

So one of the most common welds that are made using friction is the turbine blisk for the combustion, for the turbine. So turbine of aircraft engines for example, the turbines, the blisk and the blades are welded using linear friction welding.

We will see when we are looking at in subsequent slides. So some of the applications and this is very unique process Ok, for welding of aluminum plates, friction stir welding is the most suitable process, Ok.

Because welding of aluminum using arc welding is also very difficult because of the hot cracking issues, various issues.

So friction stir welding is very commonly used nowadays to weld aluminum plates for aircraft applications, aircraft bodies. They are all welded with friction stir. Again we will see the videos of making (()) (17:16) using friction stir.

So the process of friction welding is very simple. So you have two jobs here, isn't it? So these two jobs should be welded to each other. So in this case either you can rotate both the jobs or you fix one job, Ok you rotate the other job and simultaneously during rotation you also apply some compressive force.

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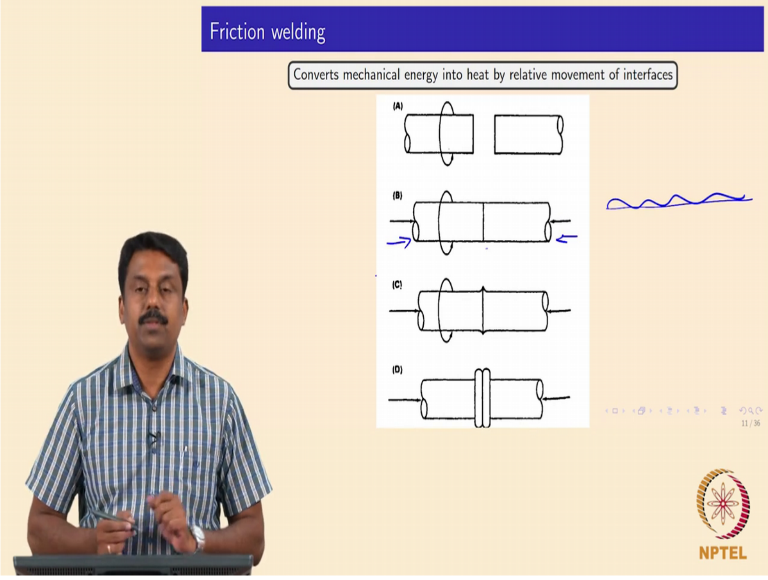

So this interface is going to heat up, isn't it? So once it heats up because of the upsetting force you are supplying you will have a mechanical deformation at the interface.

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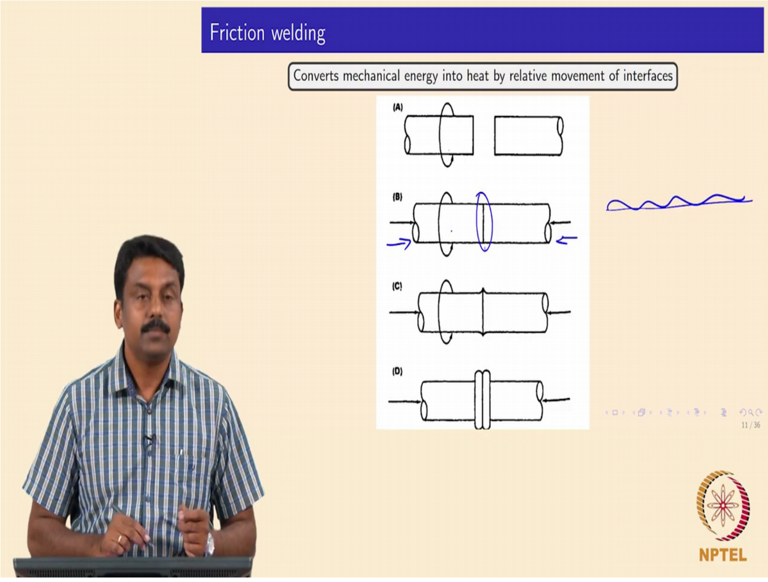

So there will be coalescence due to the mechanical deformation. So

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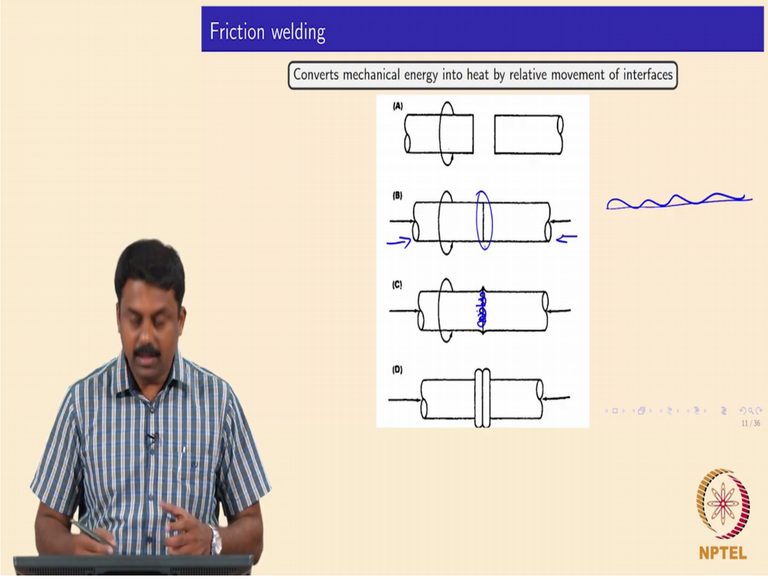

the inner interface is going to coalesce to form a joint, isn't it?

So the (()) (18:06) is very simple. We generate heat by friction and then subsequently apply a compressive force which will cause mechanical deformation at the interface.

The material flow can take place from one interface to other interface causing the interface to coalesce and form a joint, right. We will see video and come back to that.

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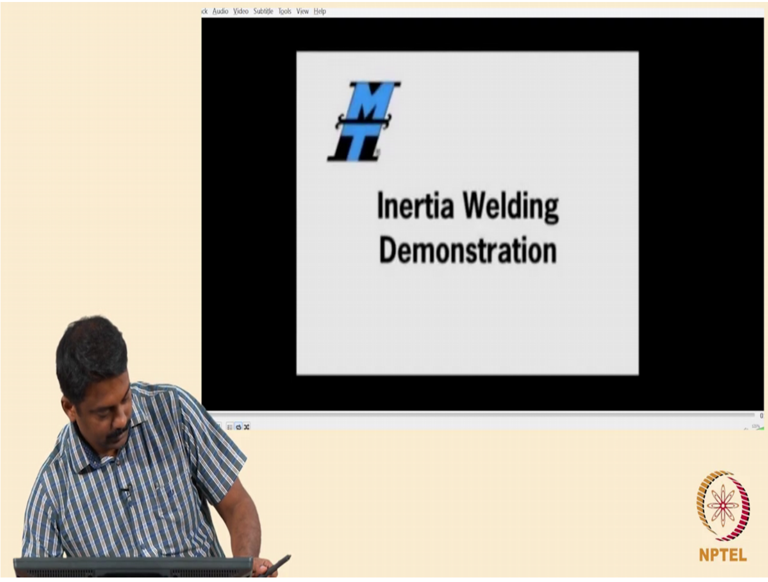

So this is the, yeah rotational welding or, yeah inertia friction welding. So this is what happens, no. So you have an initial interface, Ok

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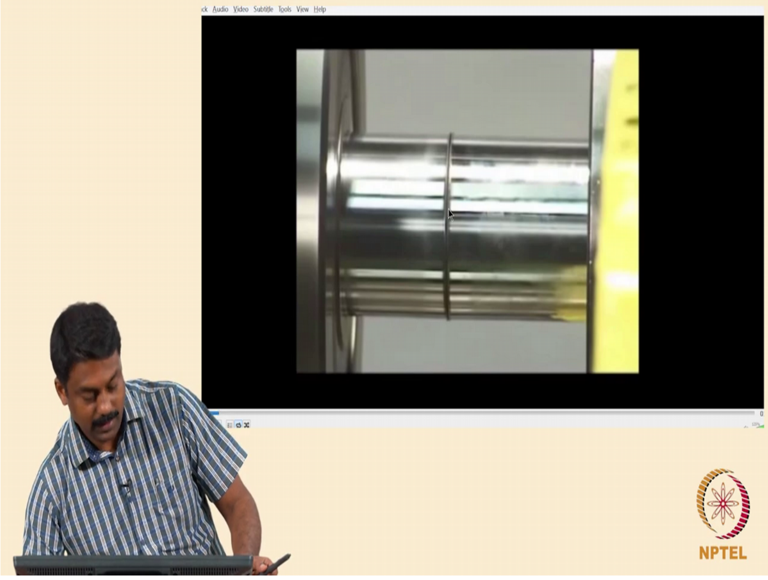

and then, so in this case this is fixed and this is rotating. Ok. You can see from beginning.

So I will, so we will start from this man, Ok from here.

18:59 demo video start

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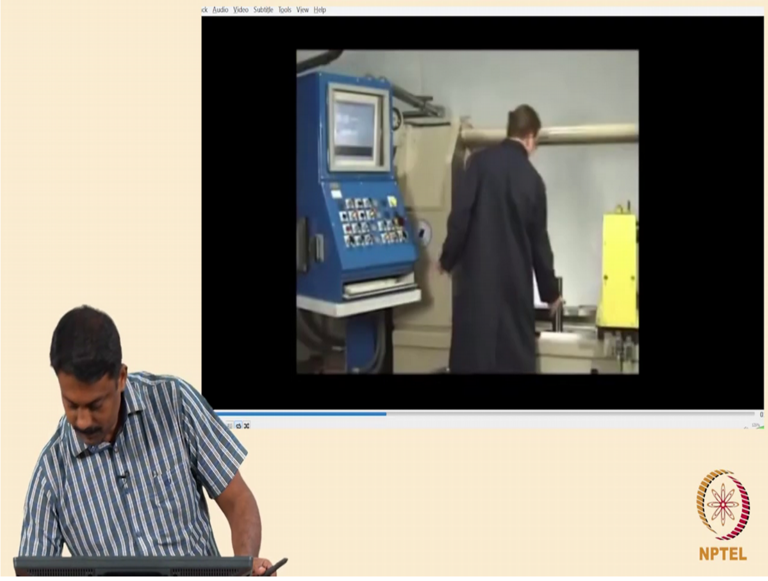

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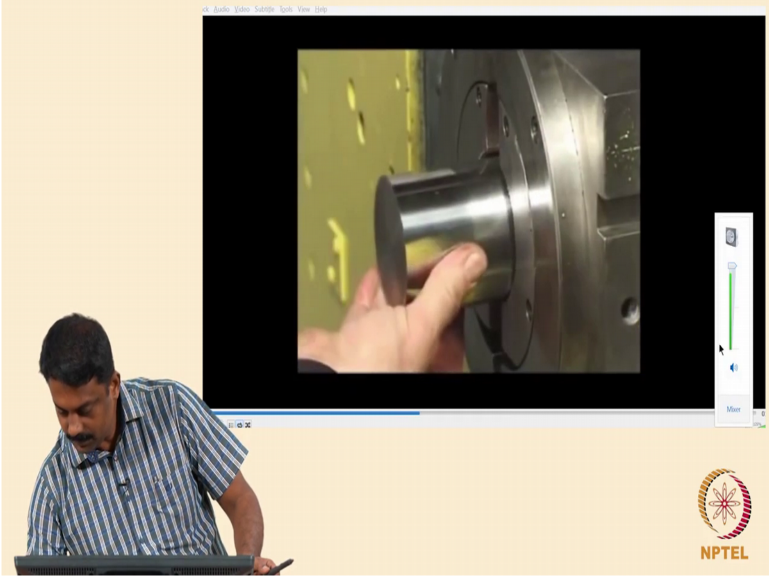

Some music is there so we will stop it. Ok so this is the

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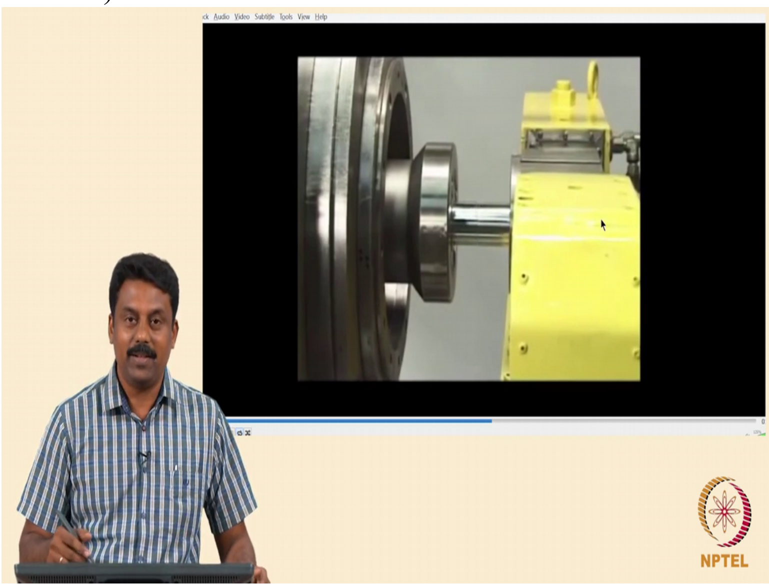

tooling requirement, Ok. So it has to withstand the force of

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rotation and the friction. So the other tool is rotating and this is fixed.

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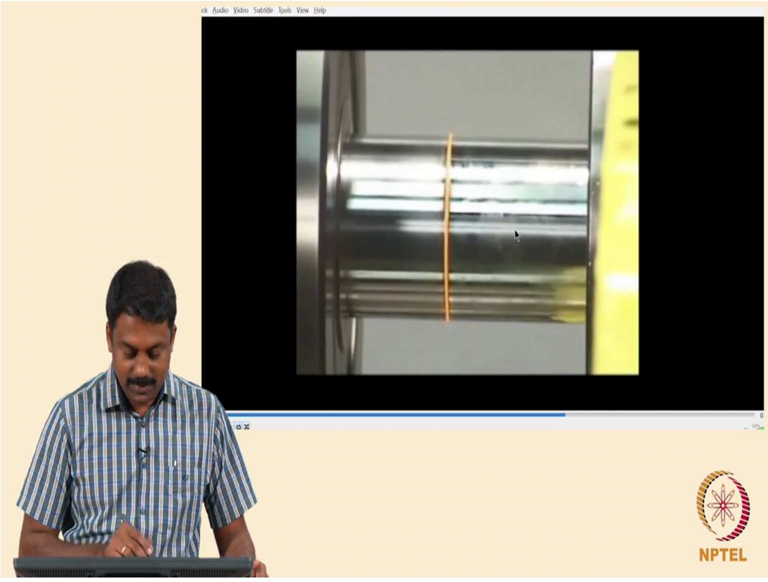

So if you see over here we are not applying pressure as we like. There are some process steps

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involved. So this is getting moved and this is rotating.

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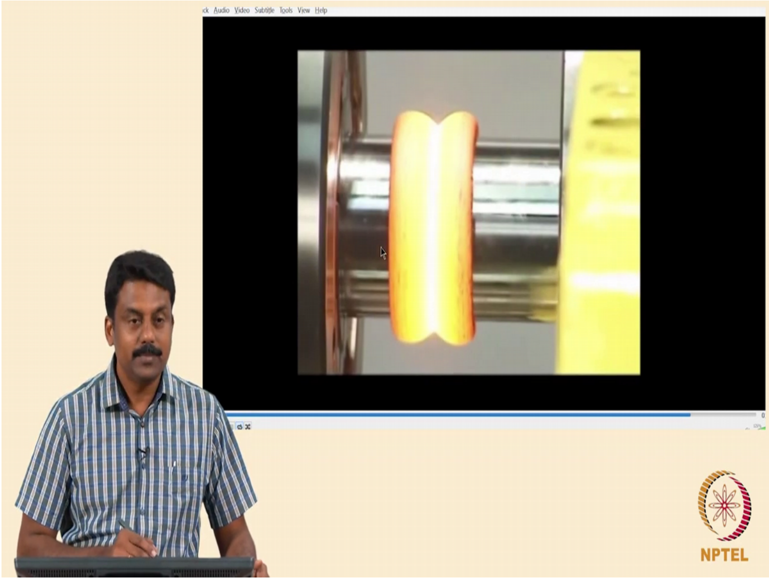

Ultimately material deforms and forms a splash.

So we will do it again.

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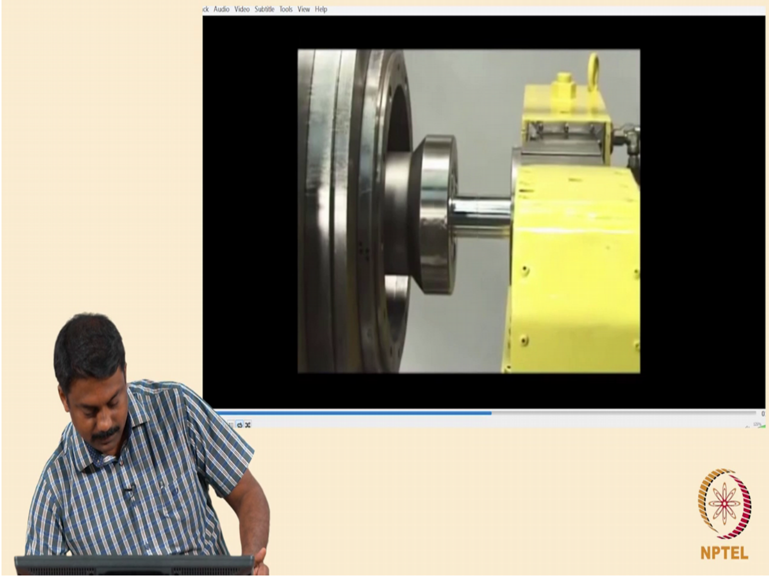

So it is the

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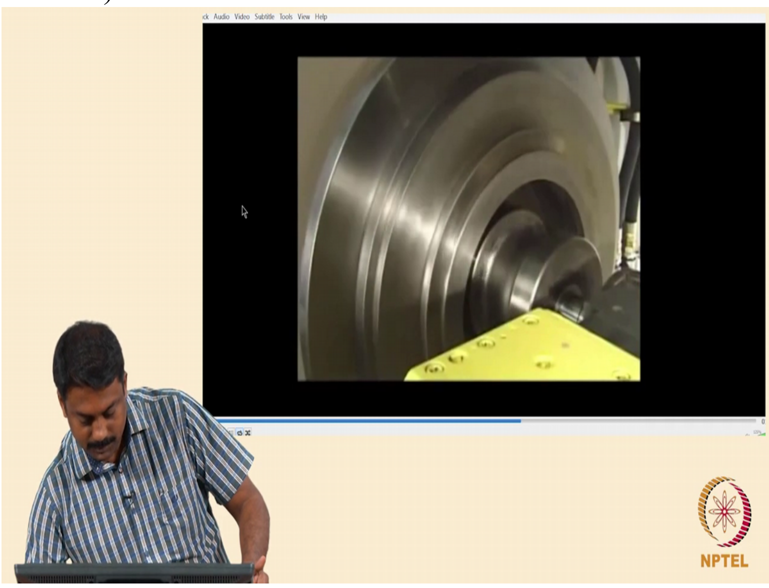

other tool is rotating.

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So there is initial, pre-upsetting force and then subsequently

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burn-off length made by

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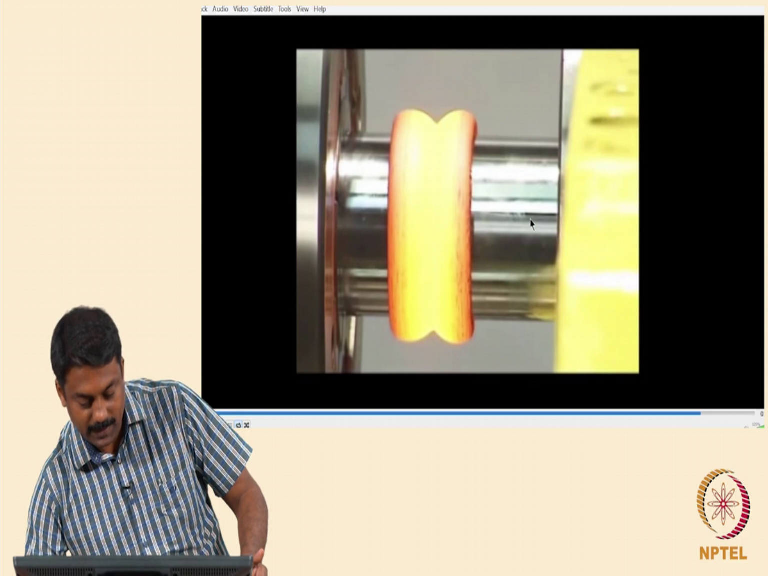

moving the non-rotating tool. And then once the temperature is reached, so increase of force so there will be mechanical deformation.

20:27 demo video end

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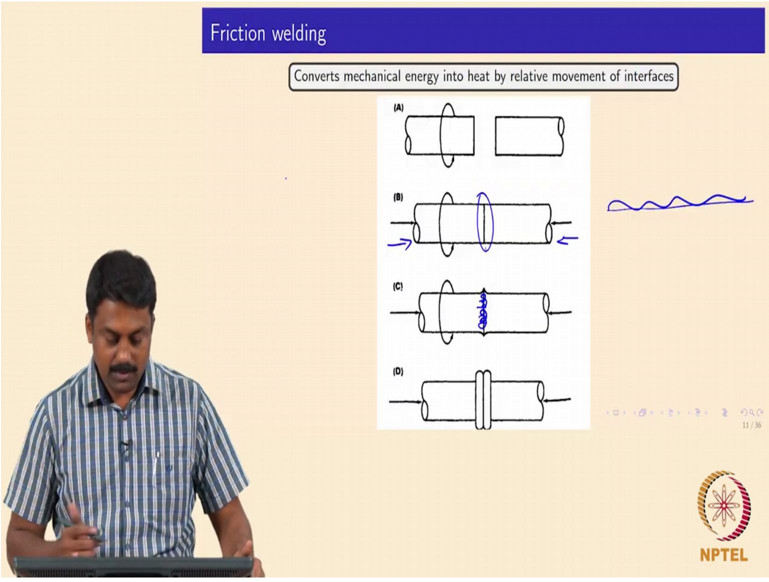

So whatever I have shown in the video it is actually given here. So this is fixed and you have rotation of the other interface and during these rotations you give the compression force and you also have burn-off moment.

And then subsequently there will be mechanical deformation once the temperature reached a critical limit, so we can have a higher force applied to interface causing mechanical deformation.

Subsequently we will have to machine off this flash.

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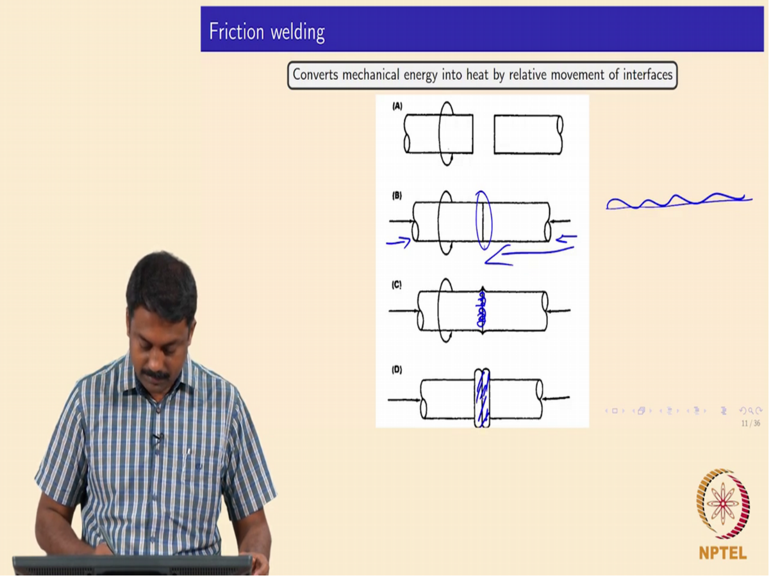

So once you machine it off, it will be a complete joint made. And the joint would have a much better mechanical properties than when you are doing in a fusion welding.

So fusion welding of such a rod is, it is impractical, isn't it? So if you are welding a rod of say 25 m m, 20 m m, and you have to weld with fusion weld it is very difficult.

So accessing for example, G M A W, you will have to make first level, Ok and then do a weld whereas in this case you can achieve the weld much more easily. Ok, therefore these kind of applications

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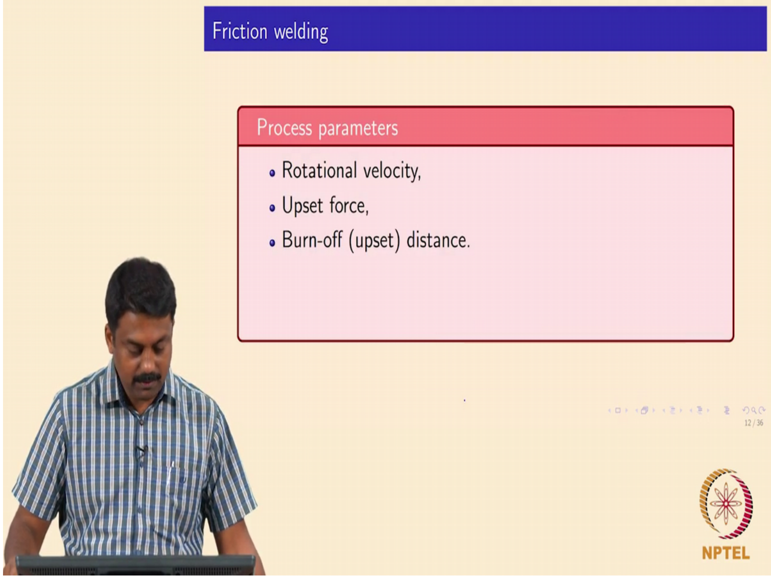

it is very, yeah very commonly, you know we use friction welding.

So what are the main parameters for friction welding which controls the weld integrity and weld formation is the rotation velocity, the r p ms, isn't it? How fast you rotate, then the heat is going to be generated based on the r p m, Ok.

And then the upset force and the distance of the upset, what you call the burn-off length, what you call burn-off distance. So these are 3 important parameters, controls the process stability.

Ok, so you cannot use a very small r p ms. When you do upsetting you will have cold deformation, OK, so the r p ms, the upset force and upset distance would all control the welding process by friction.

(Professor – student conversation starts)

Student: There will not be possible that one is welding at such a high speed that is stationary…?

Professor: Yeah, so that is why we need to make axis symmetric. So if we have force is not applied exactly at the axis of the rotation then you have those kind of wobbling problems, Ok. So the upset force would be applied exactly, in this case the axis of rotation.

(Professor – student conversation ends)

Ok so if the force is not exactly, for example you have the axis of rotation like this, the force is not at the axis of rotation and if it is, say at an angle you will have shearing. Ok that is why they mentioned about in previous slide the tooling, elaborate tooling is required.

And if tooling is not good, if tooling is not withstanding the pressure is generated it will wobble, Ok. So then instead of making a joint you may also have shear force at the interface that would cause the glide of the interface. The interface would glide. So then you cannot make joint, right, good.

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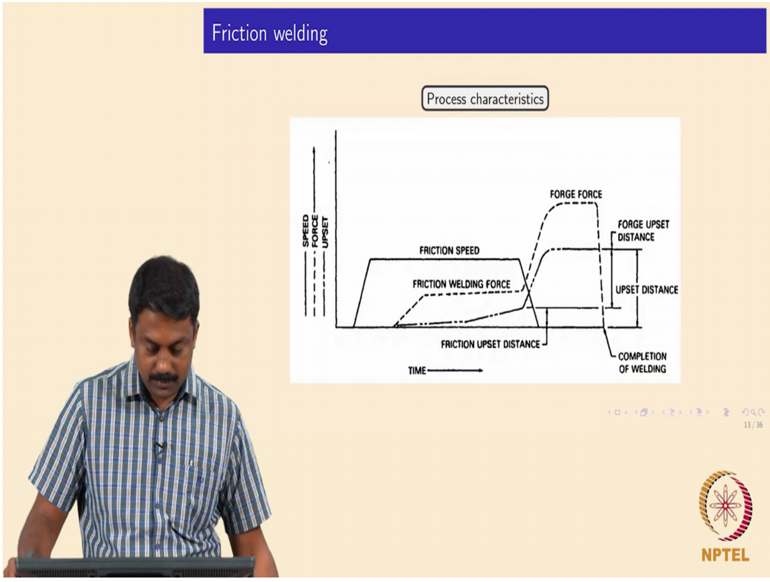

So if we look at you know, if you look at the video, the process happens, it is not, you know you just rotate and do an upset. We do the welding with various steps.

So for example so the typical friction welding process characteristics which involves the 3 forces, right, the speed which is r p m,

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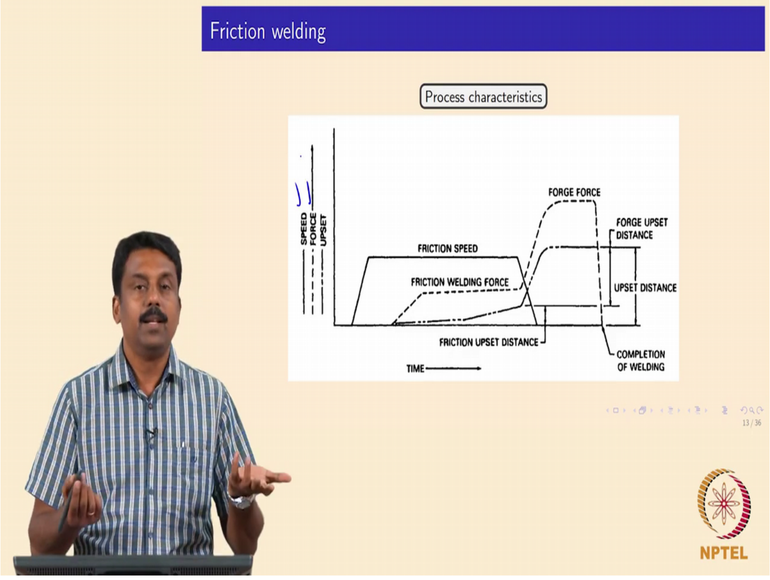

the force, right the upsetting force and

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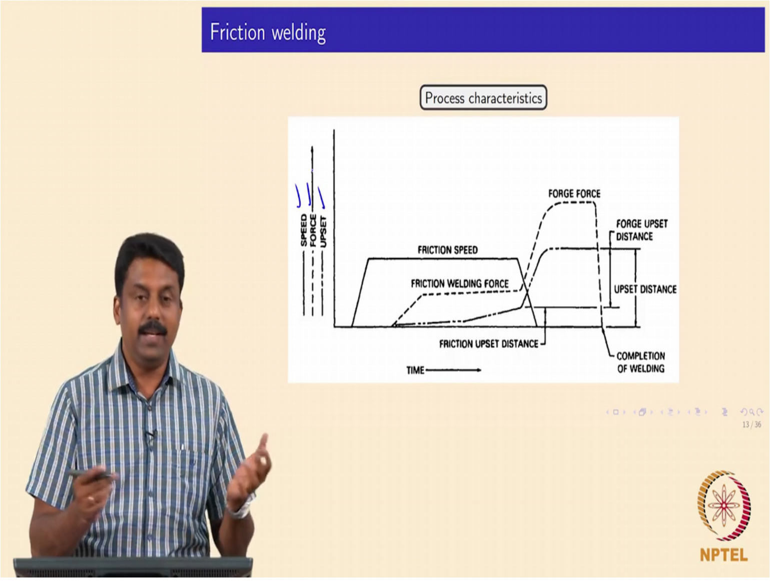

the upsetting distance or burn-off distance, right. So we vary these 3 things sequentially.

Ok so the first thing is the rotation. So we increase rotation gradually, first generate the preheat right and once you have the temperature reached and we also give some force so that we first smoothen the interface, Ok so the interface would be smoothened at the initial welding time.

So we give initial once the moment the r p m is reached, so we do one initial forcing so that the interface becomes smooth and then subsequently you maintain that force

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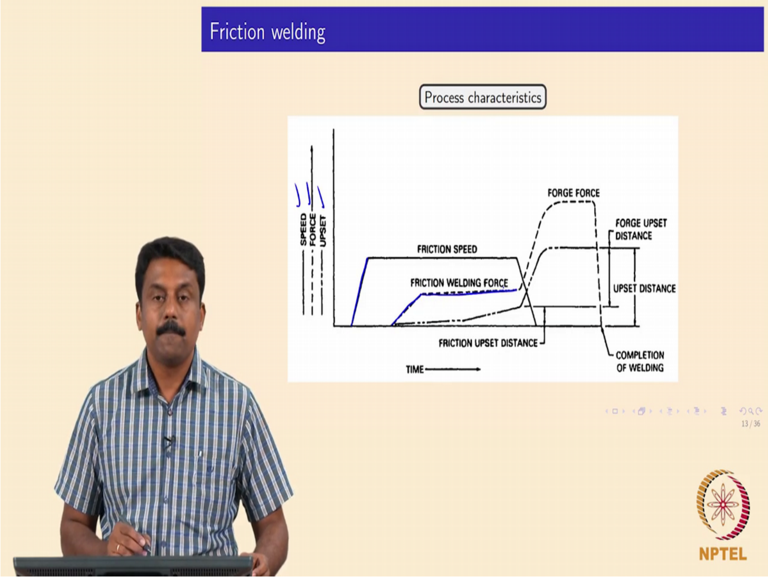

and then the moment the temperature is reached to required temperature, increase of force on the upset.

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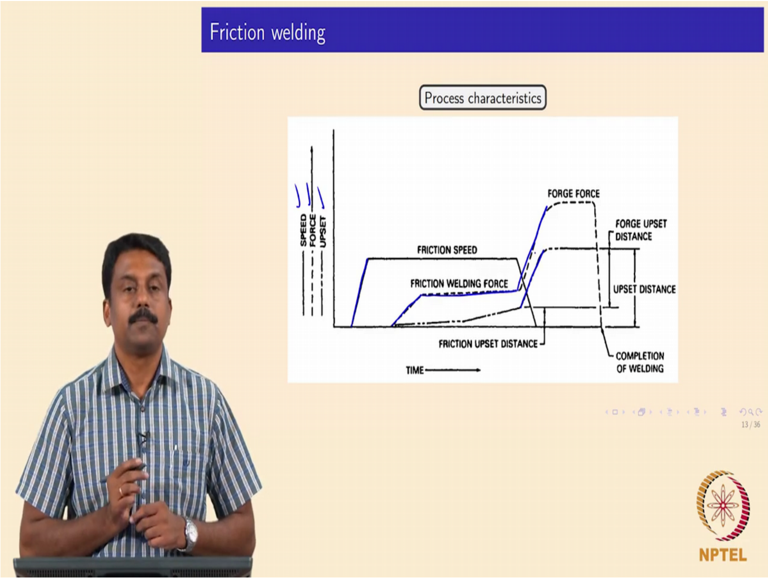

Yes, it is clear?

And then you maintain the force and the upsetting to time which we need, either based on the thickness or the diameter of the rods we can maintain and then obtain sound weld subsequently when you release the force and the job is removed. And you will have to remove the flash. The flash is removed.

Obviously you will have mechanical joint, right. In the video also you have seen so initially we were giving (()) (25:23) some r p m,

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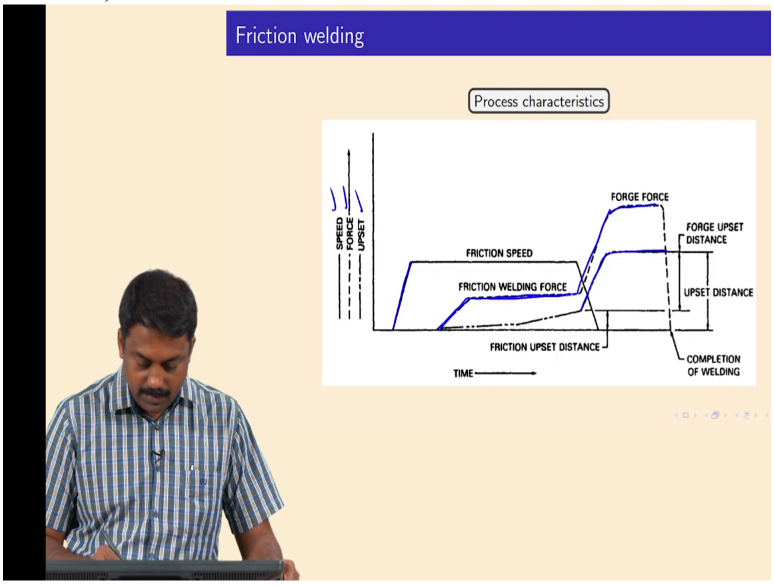

some force so that we can smoothen the interface. So that can be changed.

So that can be longer so if the interface is not prepared well, it will need some initial force to smoothen the interface

Subsequently once the heating is achieved we do increase the force in such a way that we will have a mechanical deformation causing the weld to happen. Yes it is clear? So this is typical process characteristic of the friction welding.

So three important parameters which control, is rotation speed, upset force, upset distance. Yes, it is clear? Good.

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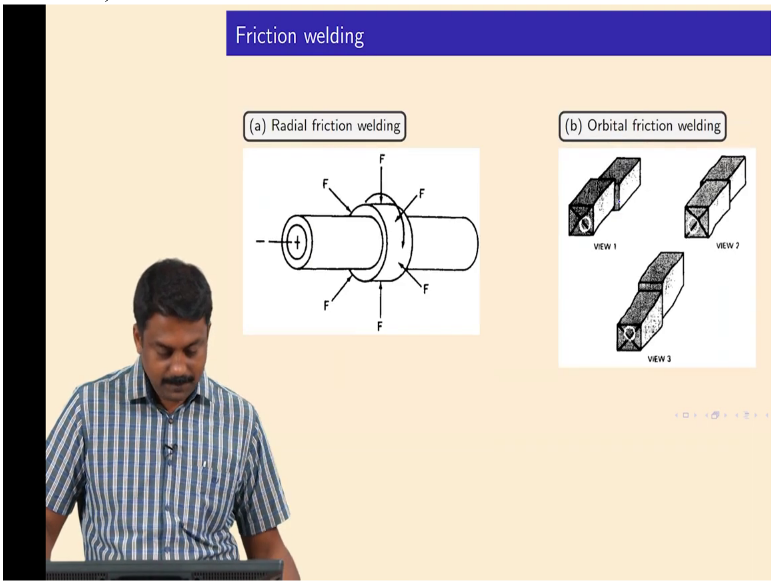

So based on the direction of the loading with respect the rotation we can classify this friction welding in various ways. Say for example in one case,

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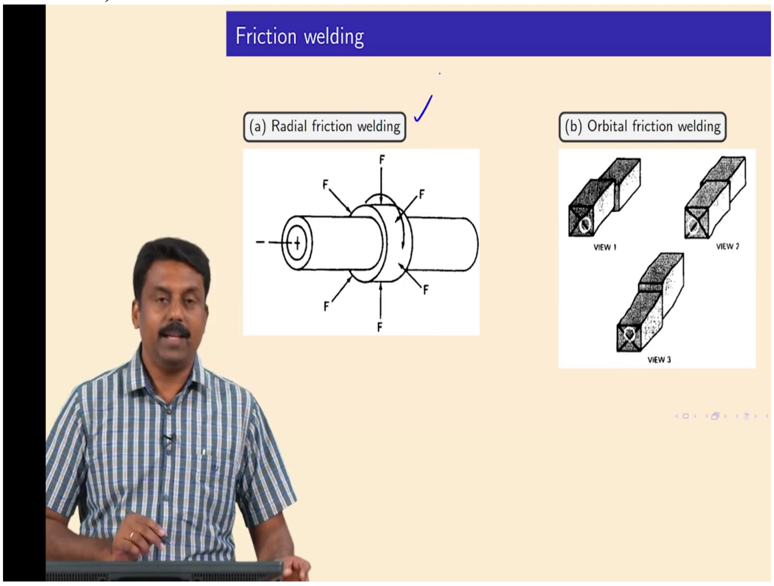

so in this case the force is applied perpendicular to the loading direction or rotation directions.

Ok so rotation direction is along

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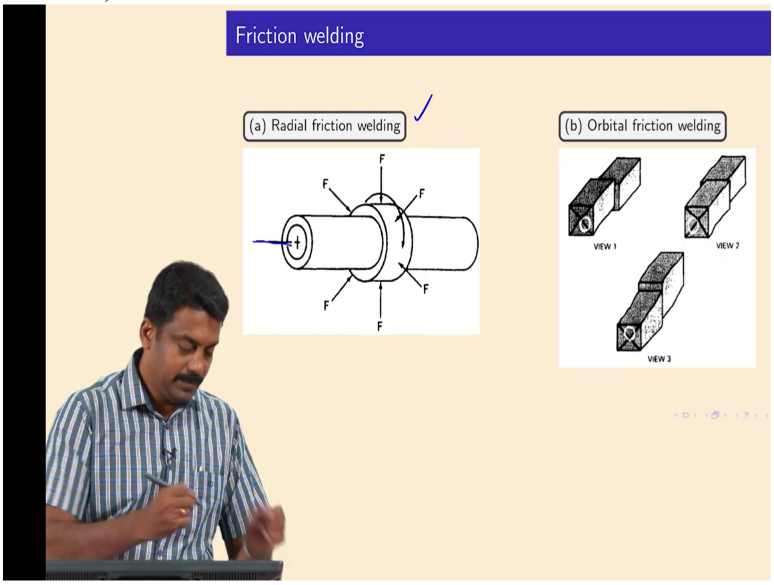

this axis and then you apply force in the radial direction. So how do you do that?

Suppose you have an infinitely long rod and two rods to be connected. It is very difficult to rotate them, right? What you do? We put a small cylindrical cup, right and then let the cup rotate at the interface, isn't it?

So in this case so we have the rods and we have upsetting force at the interface and then you let a cup rotate around the interface causing the friction heating. Yes, it is clear?

And subsequently the cup, the ring and the interface they are all to be welded, Ok and then you machine off same as you do in other case, the flash, in this case you machine off whatever is left at the ring. That would cause the interface to be welded. Yes, it is clear?

So in radial friction welding so we do not really rotate the jobs we put a ring at the interface, give some upsetting force and let the ring rotate, Ok. And we can also apply force radially using a clamp Ok and then the ring is rotated.

For example you have the ring and the ring is rotated continuously at high speed with an r p m and we can also apply a radial force and we can also apply a longitudinal force of the bars interface to be welded (()) (28:13).

And this kind of welding is known as radial friction welding, Ok. Or you can also do orbital friction welding.

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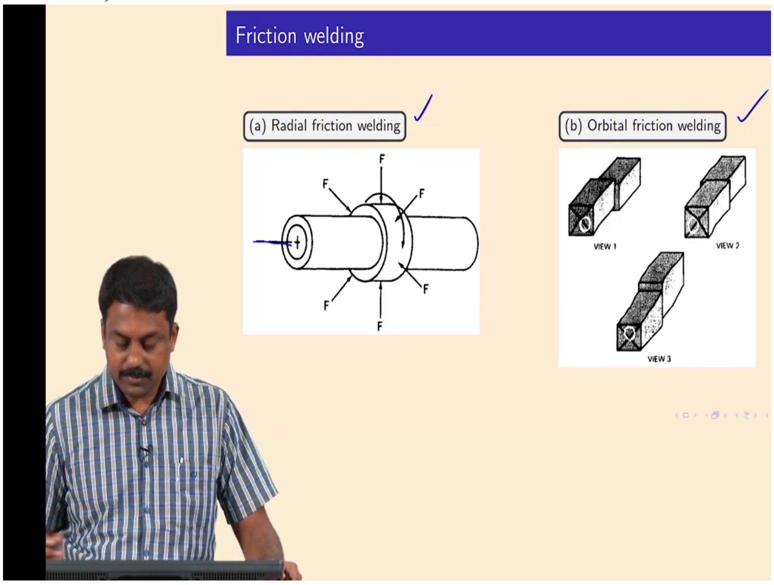

So in this case we do not use any ring or cup.

So the interface is rotated, Ok so if you have square cross-section so they are being rotated. Ok so in this case you will have the rotation happens in orbital manner.

So one interface can be fixed and the other interface can be made rotational. And ultimately the moment the heat is generated, you have upsetting force leading to joint formation.

So in both the cases the direction of the loading is different. Here it is perpendicular, and this is in the direction of rotation, right. It is clear? Good.

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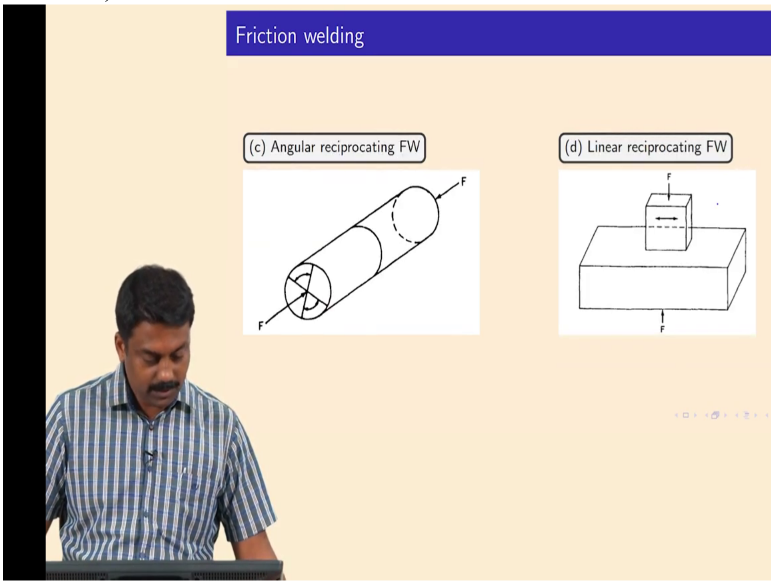

And we can also make it in a, in the heat generated, friction generated in various ways isn't it? For example we can also make it angle reciprocating friction welding. So instead of doing continuous rotation we can also do reciprocating motion, right.

And because in some cases we cannot rotate the job continuously if we have bigger jobs. So it is easy to do an angle reciprocating motion. So that can also be made. Then your tooling should be very elaborate and that can also generate heat.

Very commonly used friction welding uses simple linear reciprocating motion. And this is very commonly used

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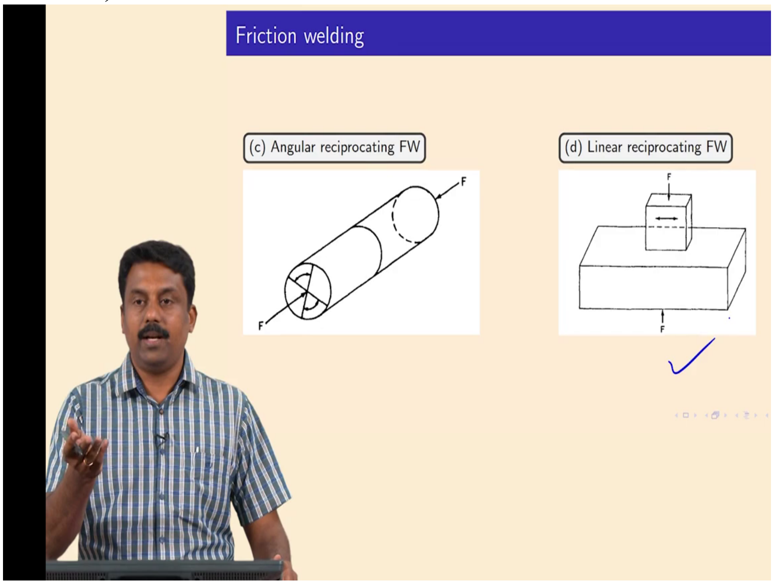

in the application that we talked about to weld turbine blades to the blisk or to the turbine shaft.

So those are welded with friction welding and again this is very, if you look at it, very what you call satisfying look at when the joint is made, Ok by using linear reciprocating friction. Ok

So I have video also.

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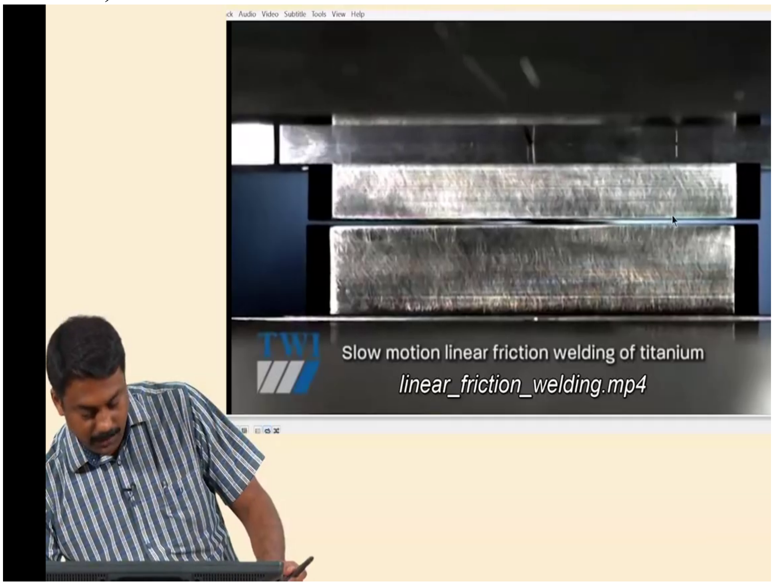

30:18 demo video start

So this video is actually from T W I. So what you see over here, two interfaces, (()) (30:27) thick. So thickness is more than 20 m m. Ok so what you

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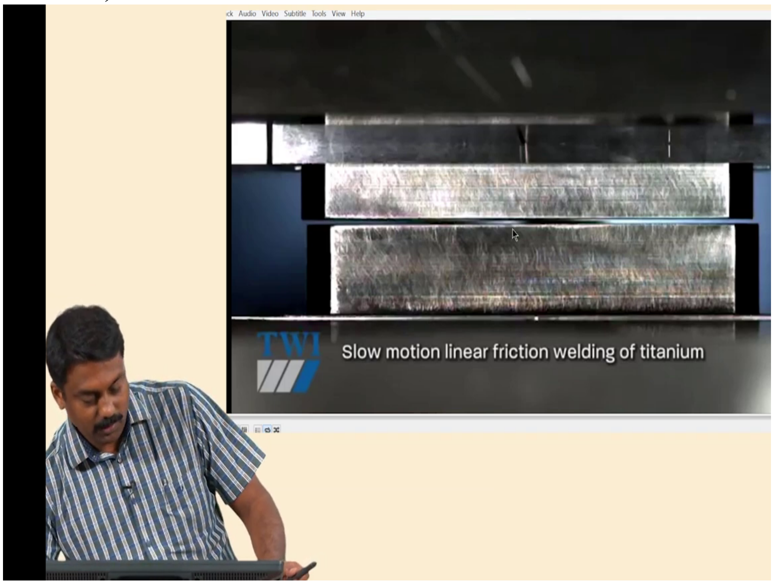

are doing over here is this, the top interface going to be welded with the bottom interface, Ok.

And so we are going to make linear reciprocating motion of the top interface. And subsequently we will apply the upsetting force perpendicular to the motion of the interface, right.

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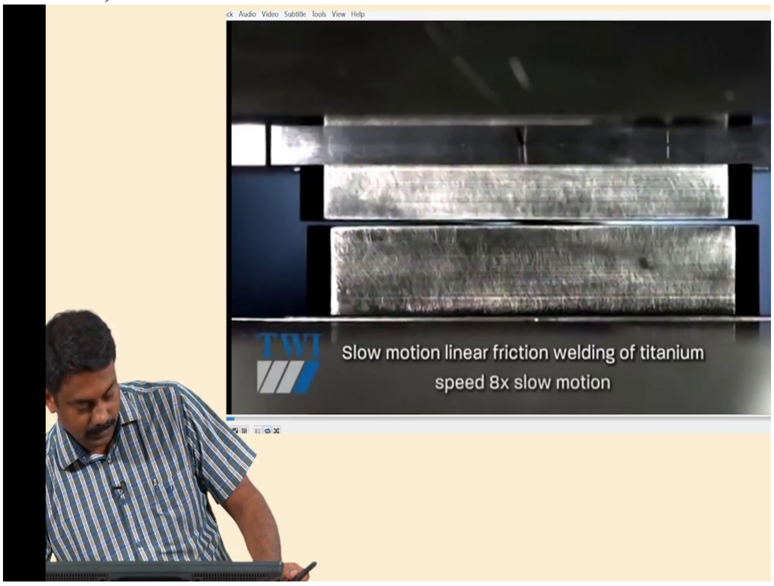

Nothing happens because the interface is not in contact, isn't it?

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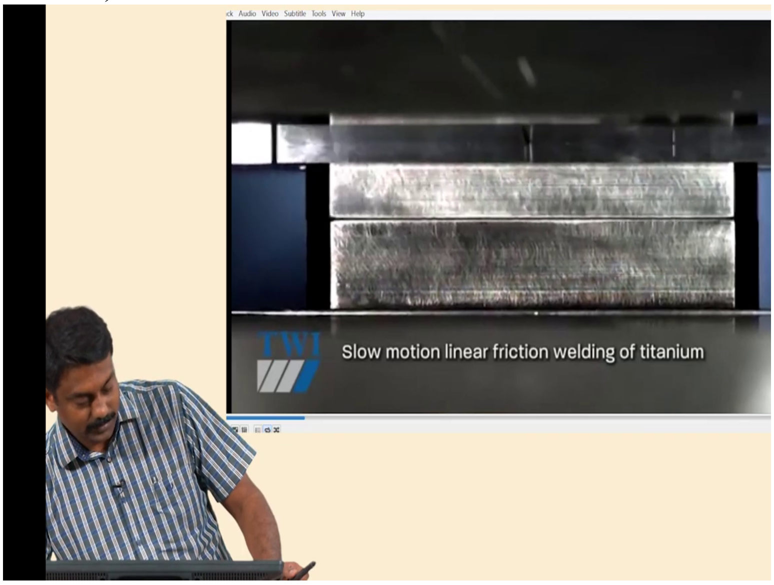

So slowly it has moved.

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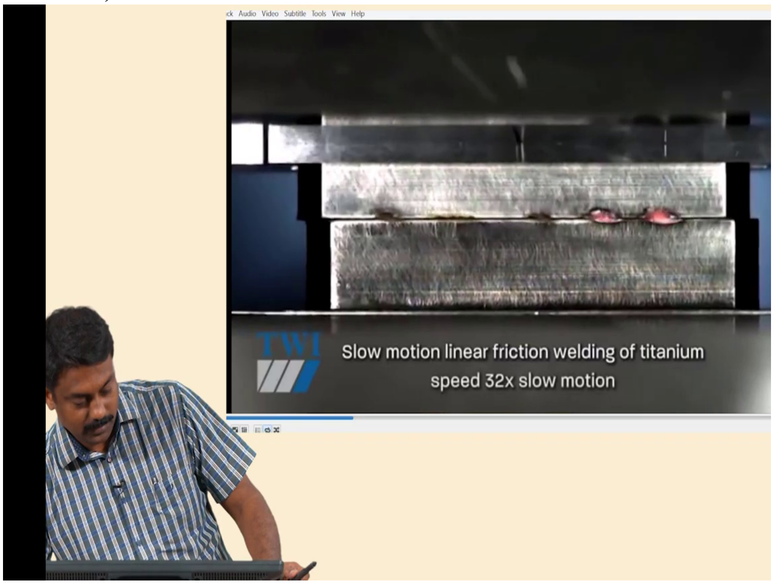

So again the process characteristics Ok,

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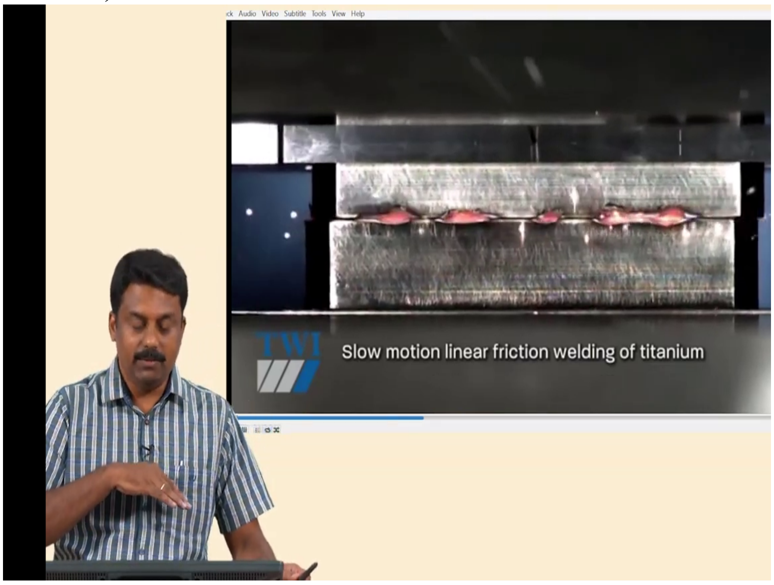

you steadily increase the force and then we also control the amplitude of reciprocating motion. So the interface heats up by the friction heat. So you have mechanical deformation.

And once the temperature is increased you can increase

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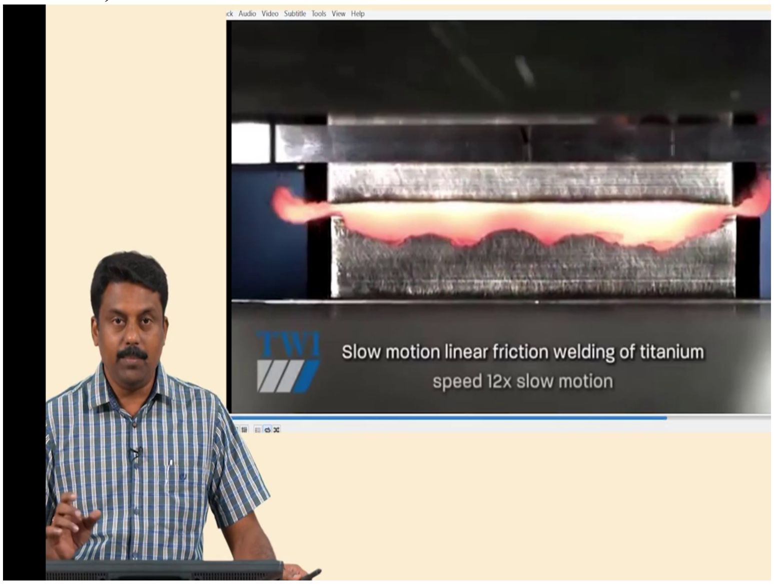

the orbital motion so that you can heat up much faster. And then upon increase in temperature you keep it for some time with the pressure so that the weld would be completed. Yes, it is clear?

And this process

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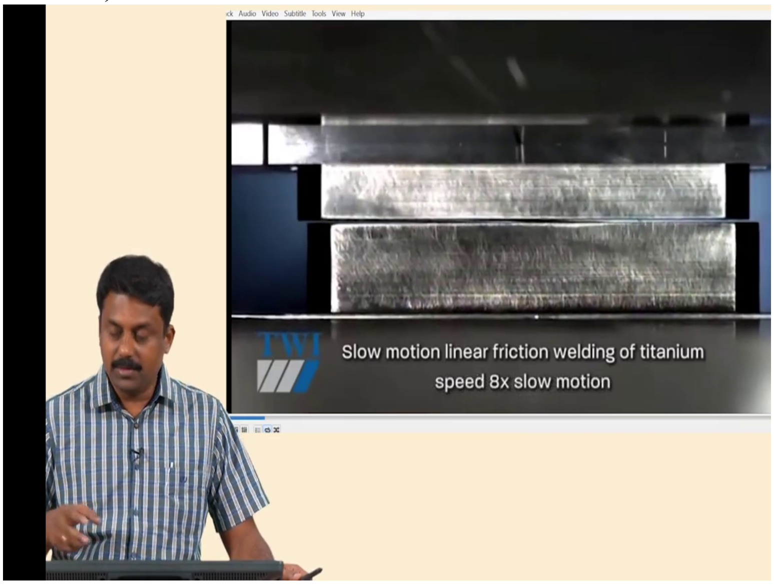

as we said, is very commonly used for welding superalloys and (()) (31:59) titanium blades to the blisk

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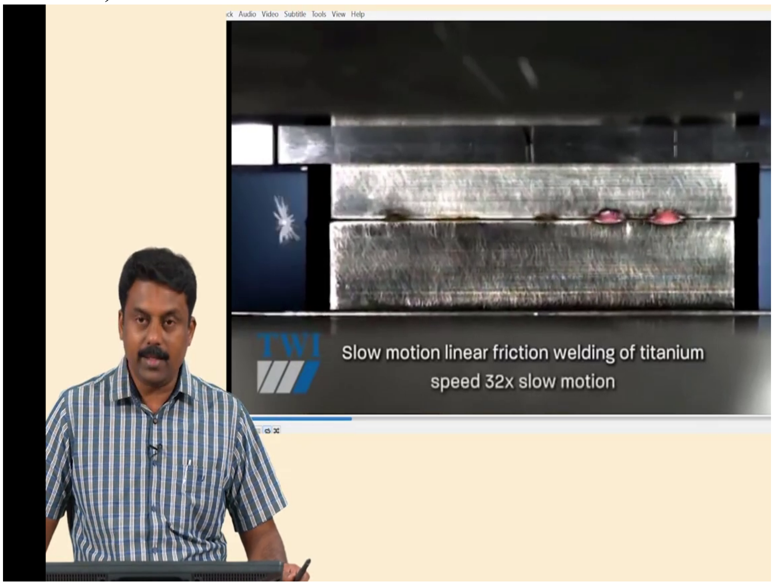

in aircraft engines, and yeah, power plant turbines as well. Any questions in this process? So we can use, we can generate heat by various ways.

So how the force is applied with respect to the rotational motion. So we can classify

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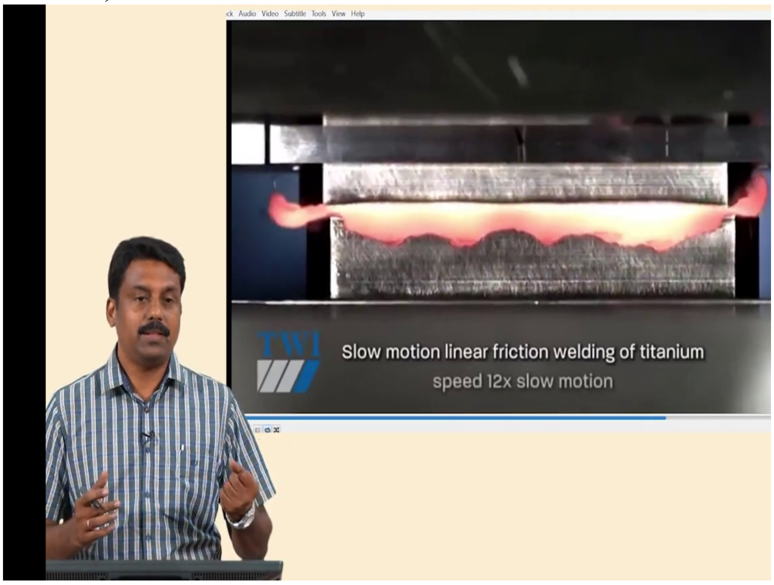

welding process into radial friction welding, so radial friction welding or orbital friction welding.

32:41 demo video end

Yes?

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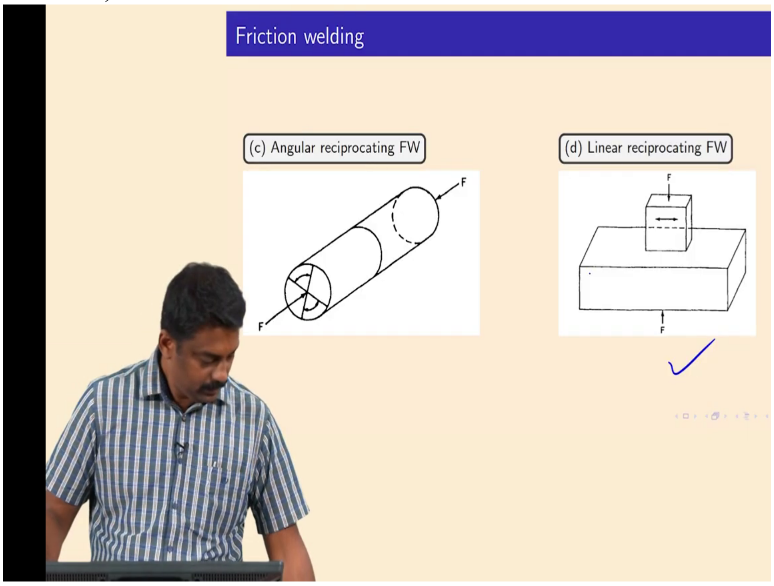

And we can also make reciprocating motion and that is known as angular reciprocating friction welding.