Theory of Production Processes
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Lecture – 49
Principle of Solid State Welding Processes

Welcome to the lecture on Principle of Solid State Welding Processes. Now, in this lecture we are going to discuss about some of the solid state welding processes principles. Many a times you know when we talk about the solid state welding processes in that case there is no apparent fusion what we see in the case of arc welding or even you have a lot of requirement of the electricity in the case of use of resistance welding.

So, the principle of solid state welding processes overcomes some of the difficulties or in many cases because of the nature of the work which is to be joined the use of the solid state welding principles or in practice so that welding takes place with minimum of heat affected zones and maximum of optimized properties.

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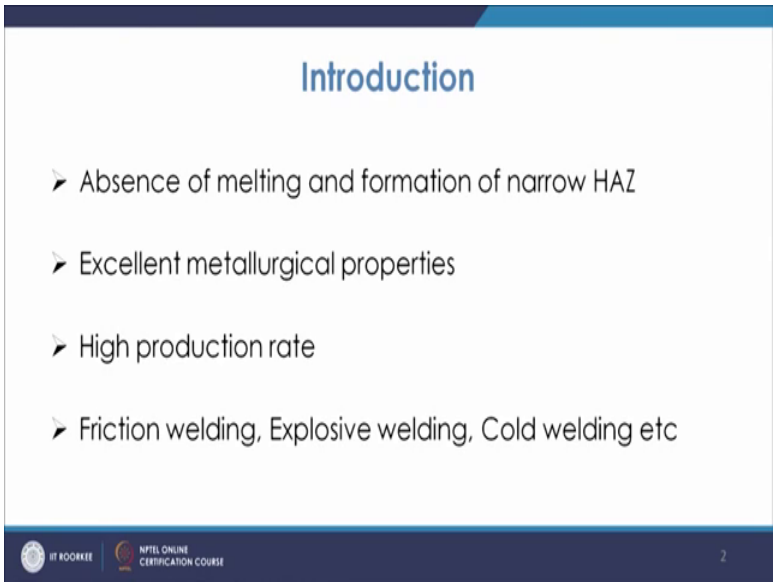

So, what happens in the case of solid state welding processes now, the thing is that in this case in the case of solid state welding processes you have absence of melting and formation of narrow heat affected zone. So, solid state welding means the parent materials which are the ones like mostly the bars or tubes.

So, when they are to be added in a butt shape then in that case there is a lot of difficulty how will you weld it maybe you can have some means of welding by even the submerged arc welding or so in, but what they will have to do a lot of you know there are many problems in welding and then also in when we talk about the arc welding or. So, in those cases you have the heat affected zones. So, if you are using it for the applications where the heat affected zones requirement is not there or it should be very minimal in those cases those processes will not be the suitable ones.

So, in this case what happens that the both the materials which are to be joined they will be basically rubbed against each other normally and basically the welding is taking place because of the collisions of metal and mostly because of the rubbing mostly because of the heating which is caused because of the rubbing or because of the friction and in that case the heat generated is quite enough to do the melting.

So, in these cases normally the heat affected zones are quite narrow. So, only at the very localized place there will be just localized melting will take place and then the joining will take place. So, there will be very narrow heat affected zones.

Now, the thing is that while doing this while going on in this exercise the surface oxides are basically driven off the impurities are driven off and there is a good bound between the two materials which are to be added. So, basically the metallurgical properties are quite improved in such cases these processes are having quite a good productivity the production rate is quite high and that is why they are they preferred methods of welding.

The varieties of these solid state welding processes are available and among them the very popular ones are the friction welding explosion welding or cold welding or. So, so we will discuss about a few and we will try to understand the underlying principle of one of one or two of these processes.

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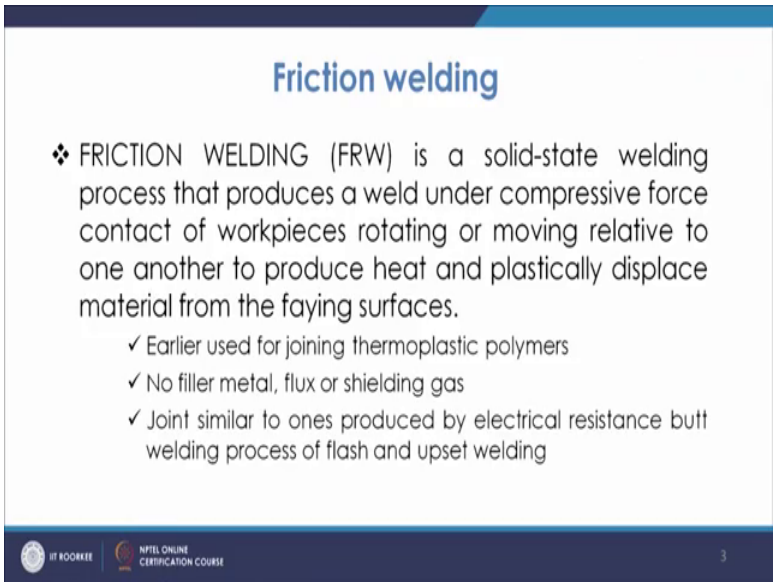

So, coming to the friction welding now, if you go by the definition it is a solid state welding process that produces a weld under compressive force contact of workpieces rotating or moving relative to one another to produce heat and plastically displace material from the faying surfaces. So, you know you have the compressive force contact you have two materials or two specimen which are basically brought in contact and then there is friction generated. So, the friction will be generated because of the relative motion between the two. So, one may be stationary another may rotate and then that may be brought in touch with the next one.

So, once you have the relative motion between them then at that surface the friction will be generated now because of this friction the heat will be generated. So, depending upon the friction the heat will be generated. Now, at that point slowly the when the temperature is so high then the plastic deformation may start and that at that time we this basically bounding takes place because of the force which is applied on the 2 you know material.

. So, this way you know these you know the two elements is added and. In this basically normally it was earlier started for the thermoplastic polymers initially before 1950 and then I after 1950 close to 1956 the a invention was even tried for the process was even tried for metals and it was seen that there is successful join even in the metals using this friction welding.

Now, in case the some of the traits of this friction welding are like this that in this there is no filler metal. So, as we discussed that you have two elements. So, there will be two you know maybe rods or bars or so. And then they will be just touched in butt. So, as we seen have seen that in resistance welding normally when we pass the resistance you go for lapped type of joints here normally we go for the butt type of placing. So, there is no filler metal which is there at the interface. So, you are just touching the two surfaces which are to be joined there is no flux or shielding gas.

So, these are the advantages as we have discussed also in the case of a resistance welding. So, once you have you do not have the use of flux it means the chances of entrapment of these fluxes in that interface will be minimum. So, that with any bad effect or ill effect of these fluxes entrapment you can divide off be dividing off and also there is no shielding gas requirement, so that it will be cheaper.

Joint is basically similar to the ones which is produced by electrical resistance butt welding process of flash and upset welding. So, it is something similar to that. So, where you have you know go to a state and then you apply the pressure and then that way you have the joining process taking place.

So, in the case of resistance welding you apply the current. So, you must have a proper current source a large amount of current is required in those cases, but here that requirement is less here you have you need the current may be for the movement of the parts. So, that way your requirement of current may come into picture. So, that way you have the good quality of weld is produced in the case of friction welding.

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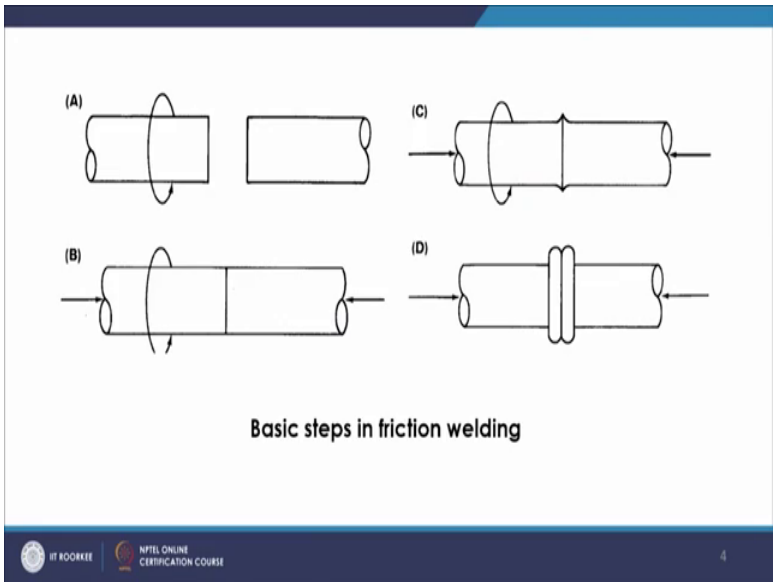

Now we will discuss about the sequence of the different steps which occur in the friction welding. So, as we see that you have steps A, B, C and D. Now, what happens that initially this is you see that there is rotation of A. So, A is rotated and B is stationary A is rotated and so this part is rotated another part is stationary. So, slowly, that will be brought together.

So, in the stage step B it has been brought together here it was you know it is this part is only rotating and this is stationary and this part is moved to this side and then it is brought in and touched to this point. So, at this interface you they have a common interface now. So, they will be touching and during the touching after the touching you have the. So, then you are applying the pressure also. So, you are applying pressure.

Now, what happens that once you apply the pressure in that case you have the generation of friction at here? So, at this point the friction will be generated and slowly you will have you know the at this point the forging and breaking takes place. So, once you have slowly it will come in and then it will stop. So, you apply the pressure and then it gets stopped and as you see that this motion is now stopped. So, once you reach there at that point where it is and showed that it has melted.

Then you apply the pressure and that is a breaking process and as well as the forging processes both the processes work here in this case and then in that case it is being joined. So, once it stops then it while stopping it gets joined because of the localized

melting of the material in this case. So, these are the sequence of the different I mean different steps in the case of friction welding.

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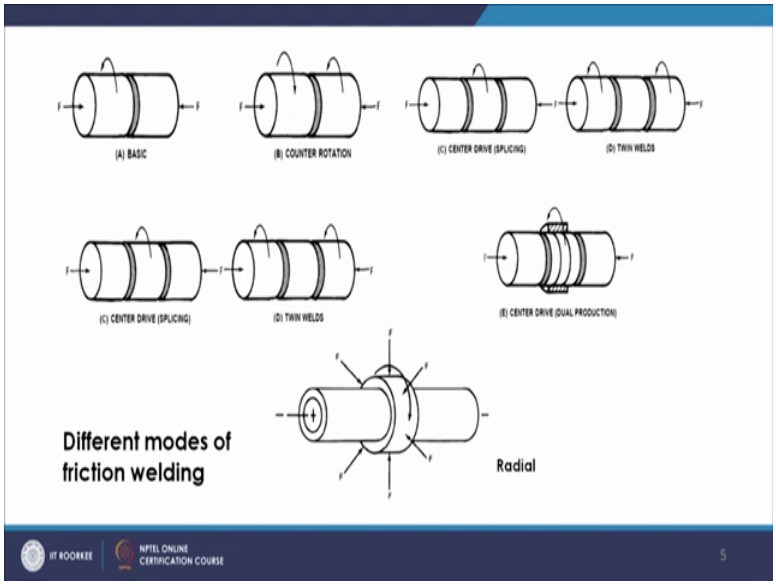

Now, what happens that normally you try to you know weld the cylindrical type of pieces like rods or tubes that also can be welded you know using this friction welding process.

Now, let us see the different modes of these frictions welding process. So, you can have the different modes in different in this way. So, this is known as the basic mode and this is the simplest mode where you see that you have the left part is I am being rotated and the right part is not rotated and basically the pressure will be there applied from both the sides the temperature will go if you take the steels suppose then it may go as high as about 900 to 1300 degree centigrade where the where after the when the pressure is applied then that case the joining takes place.

So, that is why because of the friction this joining takes place because of the heat generated that is why is known as solid state welding because both the parts are in solid state and they are getting joined now the next part is the one where you see the counter rotation. So, this part you know when you require high relative velocities in that case one part will be rotating in suppose clockwise. So, another part we have will have to be reporte rotated in the anticlockwise direction.

. So, they have sense of direction will be opposite to each other in that case you will have larger you know relative velocity and normally it is required for the you know low diameter specimen. So, what happens that in the case of low diameter specimen the chances of otherwise will be otherwise joining because the at you know normal speeds the you know chances of joining will be smaller, so because the heat generation will be maybe not be adequate enough.

. So, what you do is that in these that case you rotate them in opposite direction so that the larger amount of relative velocity is maintained. And so the heat is generated in those cases. If you look at the third point that is center drive for splicing it is known as now in this case you are able to get twin welds. So, you have the possibility of getting the weld at these two places. So, suppose you have one part in the middle so, there are two you know pipes on both the sides and in between you have to add to these two parts once itself.

So, in that case this kind of mechanism is adopted. So, because you have two very long type of pieces which are very difficult to be rotated in those cases, they are stationary. So, these two long pieces which are there on this side and this side, so they will be a stationary, but then the in the middle you will have a shorter piece which can be rotated at a very high speed and then apply the pressure from the both the directions.

So, this way you can have the joint to join of these two long pieces with this intermediate piece. So, that you have twin weld production in this case twin weld is also produced here in this case where you are rotating these two left and right pieces and middle part is not rotating. So, this way you see that you have different mechanism of rotation and then you get the different kinds of welds.

Similarly, you have center drive so, splicing in this case you have twin welds again here I think it is they are the same ones then you have the center drive that is dual production now here this is one center drive dual production and this is known as the radial ones.

Now, here in this case in these cases what you see is that the axis of rotation and the application of force they are basically same in all these cases, but you know in this case the point of the these direction of the force basically is perpendicular to the axis of rotation. So, in the case of this radial welding as you see that you have the application of

force in the perpendicular direction to the axis of rotation. So, that way you know you make the weld.

So, basically one you have to put a collar on the shaft so, this is how you put the collar you try to give the rotation to this collar component and then the inside this shaft is rotating and then you apply. So, because of the friction they will be welded to it. So, this is the example of the radial mode of friction welding.

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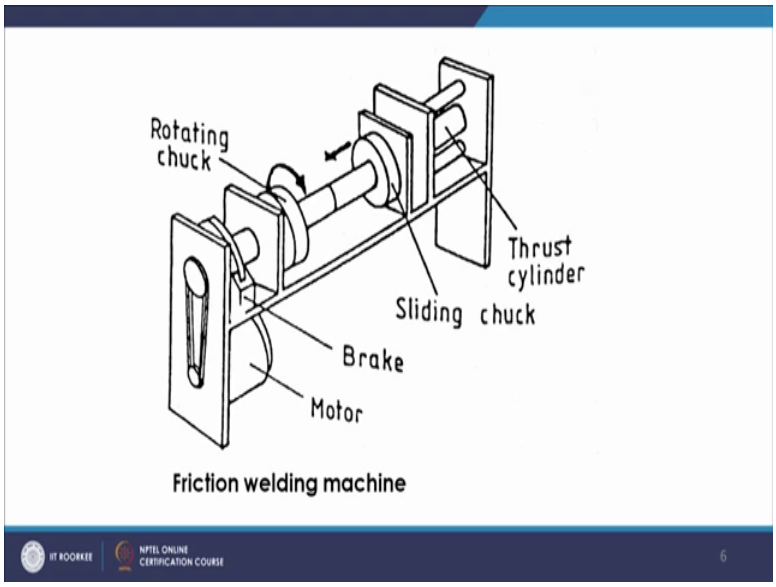

This is the typical friction welding machine where you will have a rotating chuck this side and that will be sliding. So, you can slide from this side and then you have the thrust cylinder that will be you know used for giving the thrust of pressure or axial pressure so that you have the adequate pressure weld then you have the brake mechanism here. So, that it gets rotated I mean stopped in the end and so that the after that the two parts are joined. So, this is the typical friction welding machine.

Now, if you generally try to analyze a friction welding process. So, what we see is that we know that the frictional force is nothing, but F is mu into l. So, F if L is the normal load in that case the frictional force will be mu into L. So, that is utilized. So, as you apply the normal load as you apply the load on this the frictional force will go on being more and more.

There has been many you know researchers and many scientists and some of the findings are like some people have because it also depends upon the contact area. So, sometimes fictional that force is you know taken as that a constant times the you know area of contact plus a constant times the you know normal load so, that constant. So, alpha into a plus beta into L, so, alpha and beta suppose there are two constants.

So, in that case you can define like alpha. So, F will be alpha into a plus beta into L. So, L is the normal load a is the area. So, beta will be nothing, but close to the mu and that way you know because alpha a is normally small. So, that is; what is F equal to mu L we have that value coming up.

If you look at the stages which occur in the case of friction welding normally it occurs in the case you know in four stages in the case of friction stir welding you have four stages in the. In the first stage you have the drive friction when they are just touching each other. So, there will be drive friction that is generated and the torque will at the towards the end of the first phase the torque will somewhat increase.

Now, once you go to the second stage now in the success of second stage that is a stage of seizure and rupture so that occurs in that second stage and towards the second stage your torque value towards the end of the second stage it goes to a high value.

Then after that you have the plastic deformation starting because there. So, once the plastic deformation starts the torque value goes on decreasing slowly. So, the torque value will decrease from there and in the end when you do the breaking and forging again some torque value will go on little bit increase and then further it will decrease.

So, there is a variation of the torque value and that is seen normally in the case of there is friction welding, so initially if you take this as torque and then the torque is basically changing with respect to time. So, if you take the time like this. So, initially it will go on that. So, this will be your first stage and then after that it will be going and then slowly once it will go on increasing in the second stage and then here it will be constant and then it is increasing to maximum in the second stage.

Now, in the second stage they are the seizure and rupture takes place after that the deformation will stars passing deformation will start. So, again it will come down.

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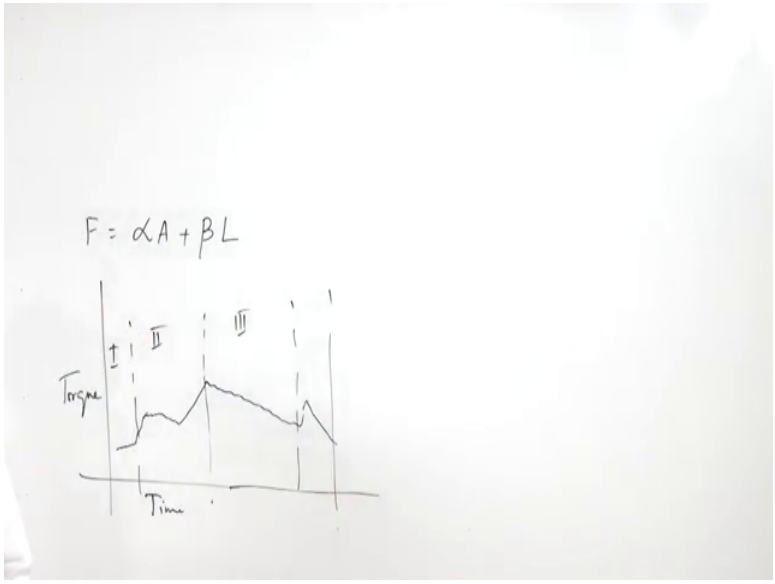

And, then after that this will be the third stage which; will where the plastic deformation takes place and then in the fourth stage again it will increase in and then it will be decreasing. So, that will be the final stage and in that final stage you are breaking and forging taking place. So, this way there are four stages in the case of friction welding taking place.

Now, there are different variants of friction welding. In the case of friction welding you have the variants like one is inertia welding another is friction stir welding. So, in the case of inertia welding the inertia is used by using the fly well. So, flywheel we will be attached and then the flywheel be. So, you will have the power attached to that section and then since we are using the inertia of that flywheel. So, you will have moment of inertia attached based on that you will have I omega square will be there I will be in a moment of inertia of your flywheel and then you will have a omega square that is based upon the rotational speed. So, based that concept is used for the inertia welding and then you have the friction stir welding.

So, in the case of friction stir welding basically you are stirring there is a stirring action in the zone where the basically the welding has to be carried out. So, you will have a tool and then that tool is going to rotate in that particular zone or in the joint which is there and then because of the plastic deformation the shearing action the bond will take place so, that is friction stir welding.

So, in the case of friction stir welding you have again varieties like hybrid friction stir welding, friction stir spot welding friction stir surfacing. So, these are the different varieties.

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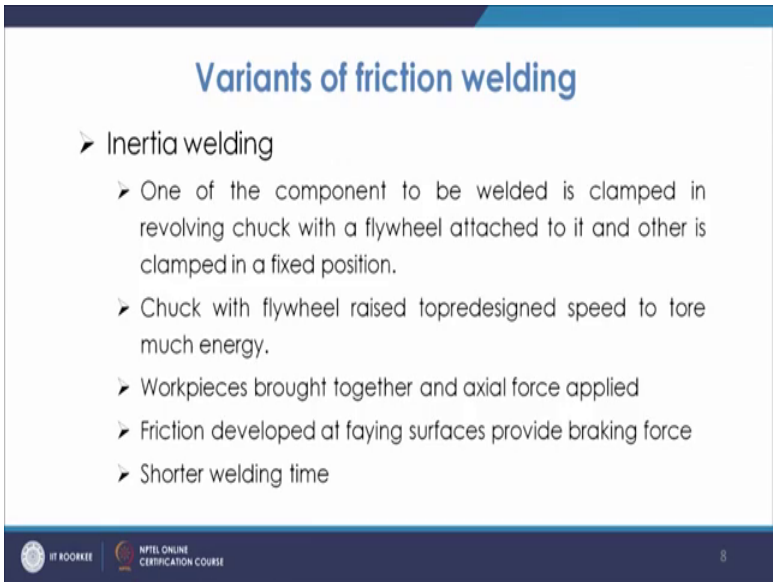

One of the component to be welded is clamped in revolving chuck with a flywheel attach to it in the case of you know inertia welding and other is clamped in a fixed position. So, that way you have that and then the chuck with flywheel is raised to pre design speed. So, that to store much more energy after that the work pieces are brought together and then axial force is applied and friction will be developed at the faying surfaces which provide the breaking force. So, that is how this welding is taking place.

So, there is normal is a shorter welding time, but then the application of pressure is also important in these cases this is the you know schematic of or setup of a inertia welding process.

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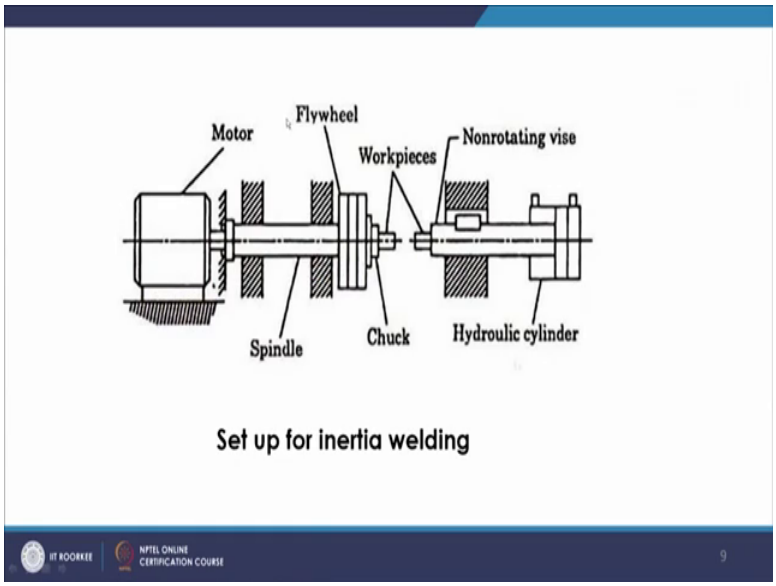

So, as you see that you have a flywheel attached here and then this is a spindle and then you will have nonrotating vise. So, that will be brought in contact with this and then that way since this is inertia of the flywheel is used that is why you we use this term known as inertia welding.

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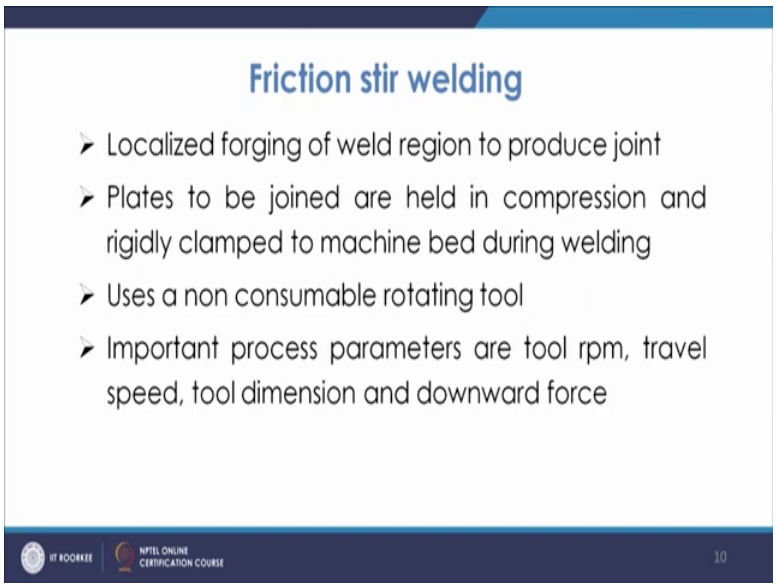

Now, in this case of inertia welding you have certain there are certain you know traits of this inertia welding the thing is that with the continuous drive friction there is certain difference in this case you know. In the case of continuous drive friction the welding is

carried out at constant spindle speed whereas, in the case of inertia welding the it starts at high speed and then slowly it decreases. So, you will have that is why you will have the shorter weld time in this case.

Now, in this case the heat will decrease and you know you will have the increase of torque also and there are certain welding variables like you have inertia of flywheel then you have speed of flywheel these are the variables which affect the quality of the weld. So, these are these parameters are to be seen.

As you know that the inertia of the flywheel can be used for finding the energy. So, that will be half of I omega square. So, I you know that I will be m into k square. So, depending upon k as the radius of gyration you will have mass of the flywheel and capabilities of gyration. So, based on that you can find I and then omega will be based on the number of rotations. So, 2 pi n by sixty. So, f n is the rpm.

So, based on that you can have the energy which is associated with such processes and also the velocity also is one of the factor. So, velocity normally has been seen that you will have 150 to 450 around per minute I mean meter per minute of the velocity is required for forging of the steel bars.

Similarly, you have the pressure heating pressure and that is 150 to 205 Newton per mm square. So, these are the operating variables in such cases there are even other variables which need to be looked into as you go to the higher studies or in a higher and you know other courses you can study specifically for such processes.

The very important process among them is the friction stir welding also um. So, as you know that in this friction stir welding you have localized forging of weld reason to produce joint plates to be joined are held in compression and rigidly complex to clamp to machine bed during welding then using a non consumable rotating tool and process parameters are 2 rpm travel speed tool dimension and down force.

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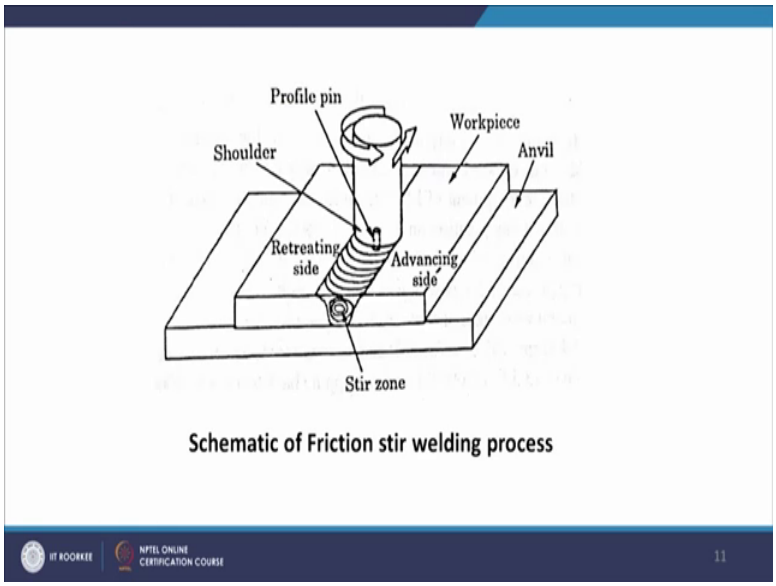

Now, this is the schematic of a friction stir welding as you know. in this case you will have a tool here this is in terms of a pin and then you will have this is as the profile surface. So, this is the shoulder cone known as and this pin basically goes into this recess and then it rotates and rotates and progresses along this the along this length.

So, this way what happens it deforms plastically the material which is in contact with it. So, the shearing is carried out you will have two sides advancing. So, once it is rotating in this direction as you see that this is rotating in this direction. So, this is rotating in this direction. So, this direction is known as advancing side and this is known as retreating side retreating side. So, you will have two sides and they will be rotating. So, these are the basically based on that you will have the change of microstructure or so.

Then, you will have the formation of different zones in this case like heat and deformation affected zone as DAHZ then you have the thermo mechanically affected zone TMAZ. So, you will have different kinds of structures you will be getting in such cases you will have plastic deformation as well as heating going on in this case.

So, coming to this FSW now, in this case what happens that first you plunge the tool then the tool is plunged? So, that this shoulder surface touches the shoulder is touch touching that that surface to be joined and then it is basically given a feed in this direction it is given this is rotated and also given your feed in and the direction of welding.

So, that way you know studying will be taking out and that stirring will produce the bound between the surfaces. So, normally aluminum alloy aluminum copper or aluminum copper lithium alloys are mostly on aluminum alloy it has been proved to be very successful very small you know energy requirement is there in this case only for so, the movement and some clamping pressure or so.

So, very very energy efficient process this is as compared to other joining processes related to arc welding or even that resistance welding. There are many advantages no need of filler then you have a minimum of the joint edge preparation you know no embedded oxide formation possibilities then you have good joint strength and all that. The only limitation is that you have to have the clamping facilities.

And, it is varieties are many like hybrid where you heat the person ahead of the ahead when you are going to weld. So, at the front point you can heat it so that the requirement of the force to move will be smaller and you will be better you know welding properties then you have a spot also spot spotting spot welding can you also be carried out by having some attachment and you can do the spot welding. So, it is a said that it is about 99 percent more efficient then in the case of a resistance a spot welding. So, like that.

Then one of the other type of solid state welding process is the explosive welding where the pieces of metal are basically joined under impact. So, you apply the impact what happens that when the impact velocity is less then you have the smooth or flat surface because of that the bonding will not be good, but when it is becomes to more it has a high impact velocity in that case the surface is wavy and so, joining takes place.

So, between similar or dissimilar materials large size components can be and difficult to weld components can be welded for critical components it is used. So, as you see that when it is quite you know explosion is done heavily then in that case you have a wavy interface and then in that case you are the attachment takes place because of some projecting type of motion. So, you will have the explosion taking place and then at that localized point you will have the welding taking place.

. So, these are the different examples these are the different you know processes based on solid state welding there are other than that also called cold welding cold forge welding or so, hot forge welding is there. So, all these are based on the concept that you will have the proper you know condition of such a condition that you have the attainment of

temperature or you may have some cases like you have diffusion bounding also occurs where the because of the diffusion at some temperature the diffusion bounding takes place.

So, these are the different other processes which are based on the solid state welding which can be studied and you can have more understanding about such processes.

Thank you very much.