Finite Element Modeling of Welding Processes
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Lecture – 04
Soldering, Brazing, Solid-state welding processes

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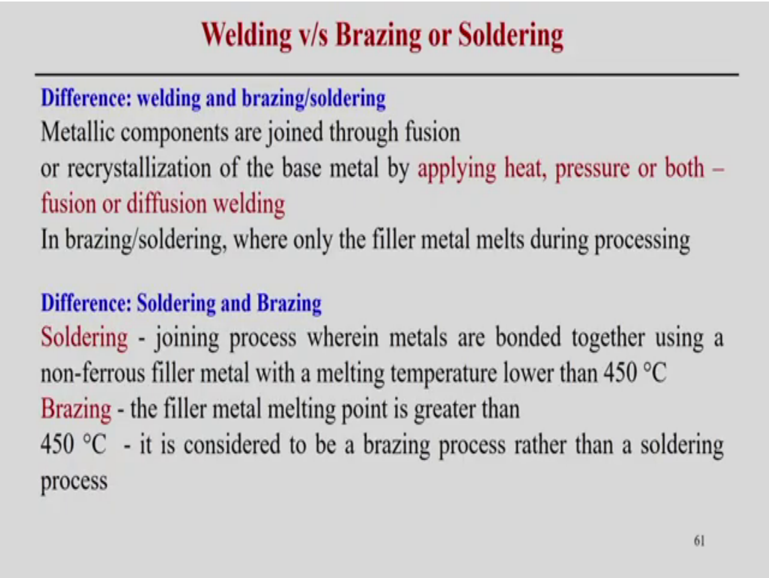

Hello everybody. Now, I will start the other part of the module 1 which we will try to cover the Solid state welding processes and brazing and soldering process. So, try you understand the basics of the what is the brazing and soldering process.

So, difference between the welding and the brazing and soldering process is that in the metallic components are joined through fusion in case of fusion welding process or recrystallization of the base material by applying some kind of the heat pressure or both together and that is the principle of the diffusion welding process.

So, or we can say the solid welding process there is some mixing of the metal is there some mechanical motion is required and such that plasticizers of the metal is sometimes necessary to join these two components. But in case of the soldering brazing, some kind of the filler metal use within the parent metal during the processing. So, in this case, the we need to melt the filler material and that will join the two components by the capillary action between these two between the narrow gap of this component.

And therefore, it is different from the fusion welding process from that prospect because fusion welding process we melt the parent material, but in brazing a soldering process, we melt the filler material, but not the parent material. Then, filler metal is fill the gap by capillary action and having the it should have very good wettability property such that it can join the parent metal. So, this way it is different from the welding process.

Now, what we can difference between the soldering and brazing process? Its say nothing, but the joining process in the in term of the temperature. In case of soldering, we have seen the soldering process there are a wide application in the electronics industry, the joining of the electronic circuit there we can find out the application of this soldering process.

But what we can define the soldering process is that joining process were the metals are bonded together using a non-ferrous filler material and, but the filler material having the melting point temperature below 450 degrees centigrade so that means, it is a little bit low temperature zone.

But brazing also we can use the same principle filler metal is used melting the filler metal, but the melting temperature of the filler meters should be more than that of 450 degrees centigrade. So, then, it is considered as a brazing process as compared to the soldering process. So, these are the differences between them mainly the soldering, brazing process.

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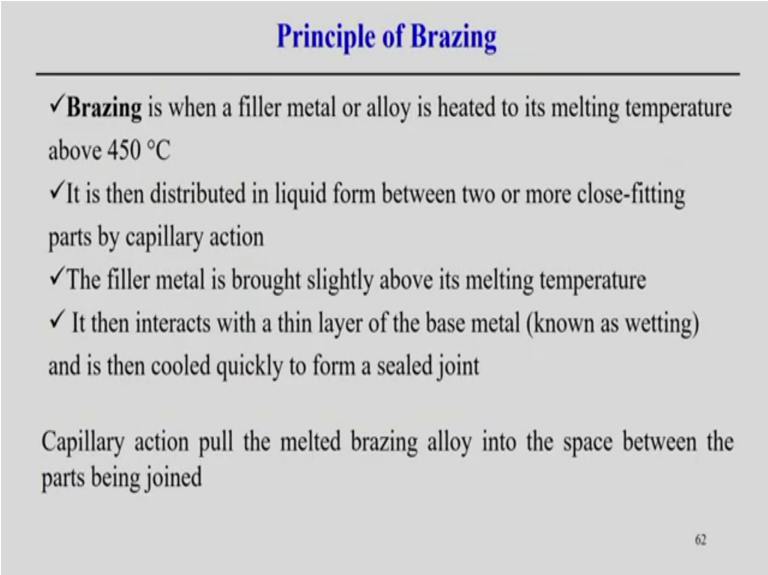

Now, what is the principle of the brazing process is that are definitely the alloy choose in such a way that we join the two metals such that melting point is below the 450 degrees centigrade. And once is the filler material is melt, then it is distributed in the liquid form between the two close fitting surfaces and by the capillary action, but it depends on the joint strength is actually depends on the gap between these two components which we supposed to join by using the braze soldering brazing process.

Now, the metal is brought together slightly above the melting temperature that means, filler material which is just above the melting point temperature the bring together and fill the gap between these two and that it interacts make a layer, thin layer of the base material which is know the wetting. That is why telling the good wettability properties is such that the filler material, filler molten material should have good wettability property with the parent material.

And such that it can quickly join these two components, but the filler can be done by the capillary action and between the space because if the gap is too high between these two-parent material, the joint state is basically reduces. So, some optimum gap is required such that it is possible to achieve the maximum joint state in a brazing process. The same thing also happening, same principle it can be followed in case of the soldering process so, that sub principle in this case.

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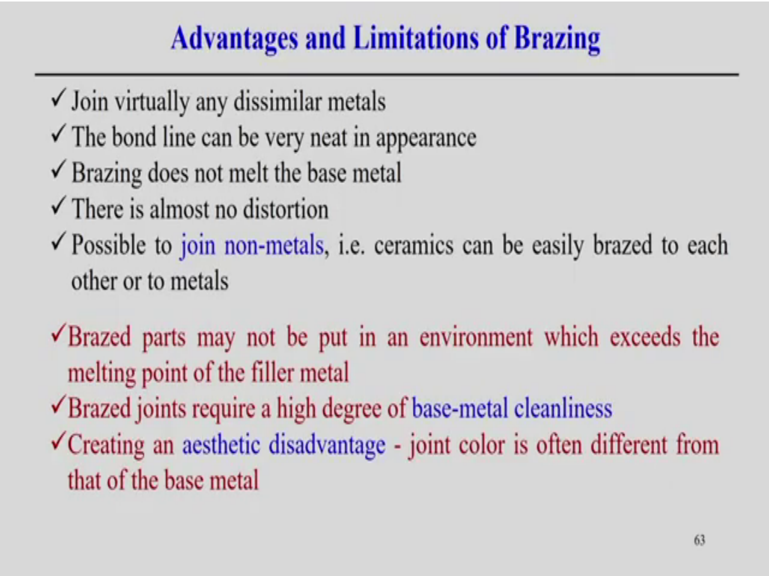

Now, advantage and limitation of the brazing processing in we can present in that way that joint virtually is basically dissimilar material. Maybe fusion welding of dissimilar metals sometimes difficult because it creates some kind the inter-metallic compound, but in other way since the filler material in the brazing and soldering process does not melt the base material.

So, dissimilar material combination of the material can be joined in a brazing or soldering process. But thing is that the joint strength can be less than that of the fusion welded structure for dissimilar material. The bond lines can be very neat in appearance that means, the bonding line is the very neat appearance, in a very clear appearance this is smooth in the I am talking about the in the terms of the smoothness.

Brazing does not melt the base metal that is true and there is almost no distortion because it does not melt the base material so, it is almost free from the distortion in this particular joining process. Even possible to join the non-metals, ceramics can easily brazed to each other to metals because some it is difficult to joining the ceramics just simply using the conventional arc welding processes.

So, in that cases, brazing can be hand pulled to join the ceramic components also. Now, difficulties that or maybe disadvantage in the sense that the braze parts cannot be put in an environment where the maximum temperature is above the melting point temperature of the filler material that has to be very careful. So, it cannot work at that particular very high temperature this particular joint.

Brazed joint requires a high degree of base-metal cleanliness that means, surface preference is on important on the parent metal so, very good surface preparation is required of the parent metal to get successfully or very good well joint by using the soldering or brazing process. But one disadvantage is the aesthetic disadvantages is that joint color can be sometimes different from the base material that is a one of the disadvantage in particular to the brazing or soldering process.

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Now, we come to this point the solid-state welding processes, we will try to discuss the different solid state welding processes, we will look at the overview the basic principle of the solid-state welding process or physical aspect associated with the solid state welding process.

In solid state welding process, definitely when you try to join the sometimes-fictional heat generation is required, fictional heat generation is there such that metal can be plasticized together and some heat, but it limited to the below the melting point temperature, then frictional heat helps to join the two coalescence of the two parent metal components.

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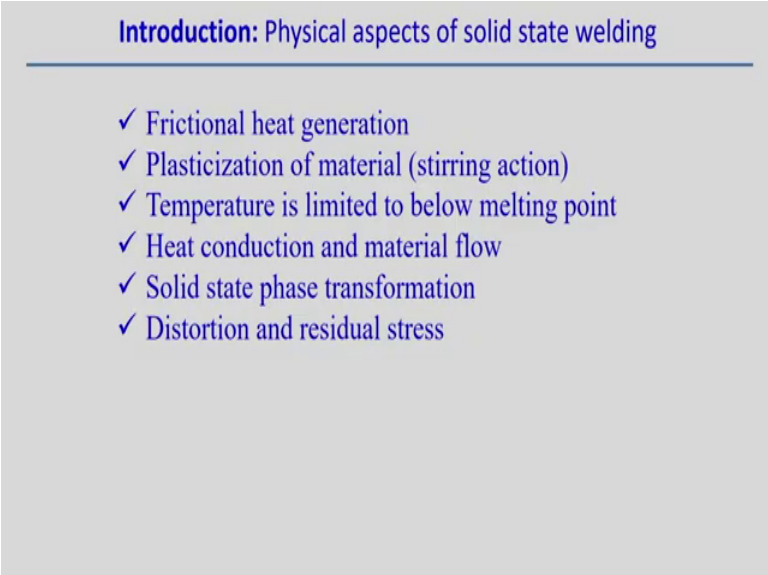

Along the plasticizers of the metal is just frictional heat generations is there at the same time the stirring of the metal is sometimes required that means, plasticization of the material is required to join the two components, but temperature is below the melting point that is true and heat conduction and material flow is always there.

That means, if we that associated that means, one is the frictional heat generation is there. So, similar way what we model this fusion welding process so, here also some kind of the heat flux can be applied. So, heat generation is there. So, it can be applied in the form of the heat flux.

And material flow also happens, but assuming that most of the cases are visco-plastic material flow specific to the friction stir welding process. We can do also flow analysis here, but material behaves the visco-plastic material flow as compared to the only viscous flow of the molten material in case of the fusion welding process.

Now, it is also associated with the solid-state phase transformation so, some kind of the metallurgical phenomena can be associated also here, some metallurgical model constitution can be utilized for the stress analysis even for the solid-state welding process. So, it is also associated with some amount of the distortion and residual stress generation in the solid-state welding process, but we will look into that mechanism for this thing.

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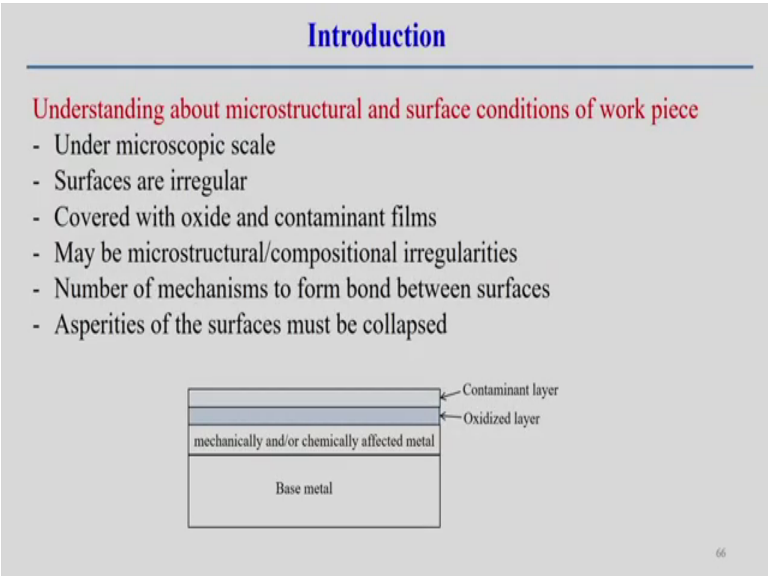

So, we start with these things understanding the microstructural and the surface condition of the work piece we start with these things. You can see under the microscopic scale surface not exactly flat so, it becomes irregular and it is mostly covered with the two; one is the contaminated layer another is the oxide layer. So, this layer associated with these things.

Maybe microstructural composition irregularities maybe there. So, microstructural and compositional irregularities may exist in the structure itself. And there are number of mechanism to form the bond between the surfaces, but the main thing is that few things are there if you want to join the these particular two components there which surfaces characterize in this way.

The typical characteristic of a surface is the having contaminant layer, oxidize layer and some asperities in the microscopic scale that can be joined between these two components one is that what way we can remove this oxide layer or what is the reaction happens, what happens to the oxide layers.

If it is possible to remove the oxide layer, the separate out and then metal come in contact between these two surfaces without any kind of the this contaminant or oxide layers, then it will be easy to join covalence's between these two components.

By means, the several means by application of the heat, by application of the frictional heat generation, by stirring along with the sub stirring of these things or without application of the mechanical load just by make it the very good surface preparation. But at the same time making contact the surfaces with application of the small amount of the heat or with the load or pressure with these things and keep it for a long time and that is the principle of the diffusion welding.

So, there is to a what is the surface of a particular component that is more important to understand for the solid-state welding process.

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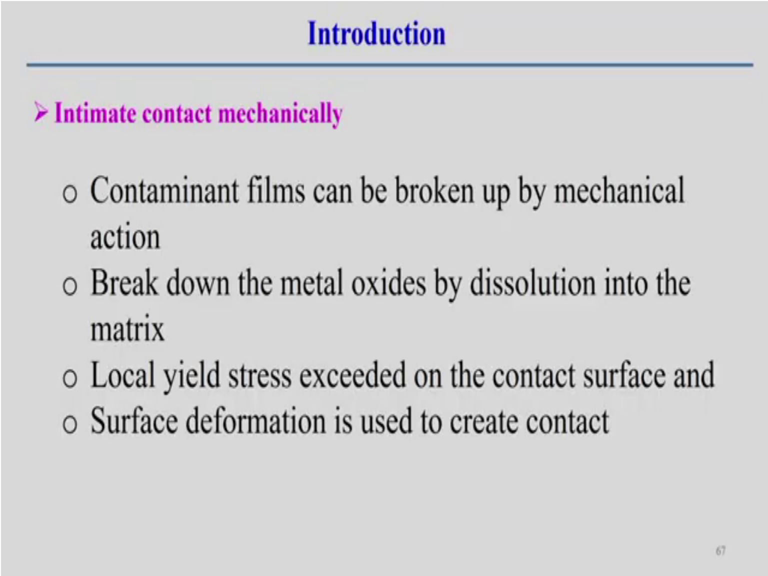

Now, intimate contact mechanically that means, once this things so, intimate contact between the surface mechanical is there. So, it is associated with the following steps. First is the contaminated films can be broken up by the mechanical action. So, some mechanical action is applied to this work piece surface first the contaminated films can be broken up and maybe break down the metal oxides by dissolution in the matrix. So, metal oxide can be dissolved in the matrix also. So, anyway broken of the metal oxides is required.

After that when the metal in contact, then local yielding may happens which may be exceeds exceeded on the contact surface. At the contact surface, local in may happens and the surface deformation is used to create the contact source, then surface deformation that interlocking of the surfaces, covalence's of the surfaces may happen all these things.

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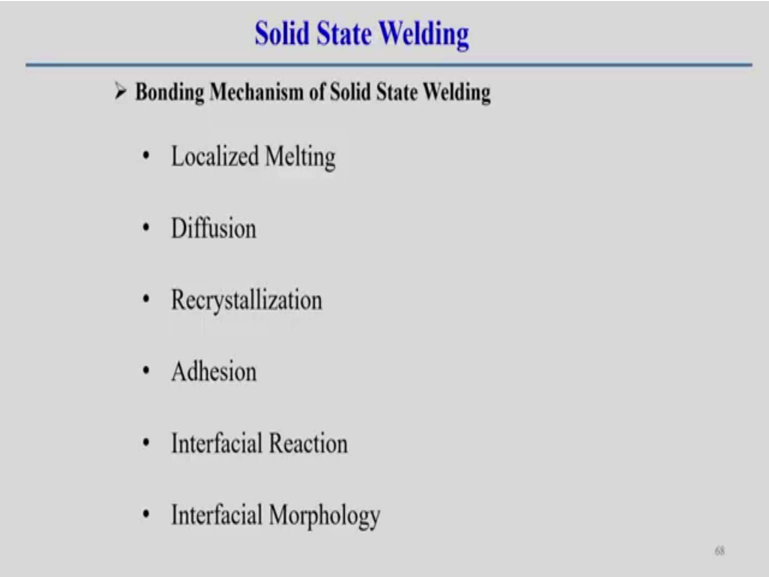

So, these are the phenomena is assisted with these thing solid state welding process, but bonding mechanism solid state welding process can be explained in this particular category; one is a localized melting is associated with this thing localized melting may happen is very localized zone, but overall bulk melting is not there not associated with this solid state welding process.

Then, diffusion may happens in the between the two surfaces that is also one mechanism. Recrystallization may also happen in these cases, the addition, interfacial reaction, interfacial morphology all are the typical bonding mechanism is associated with the solid state welding process.

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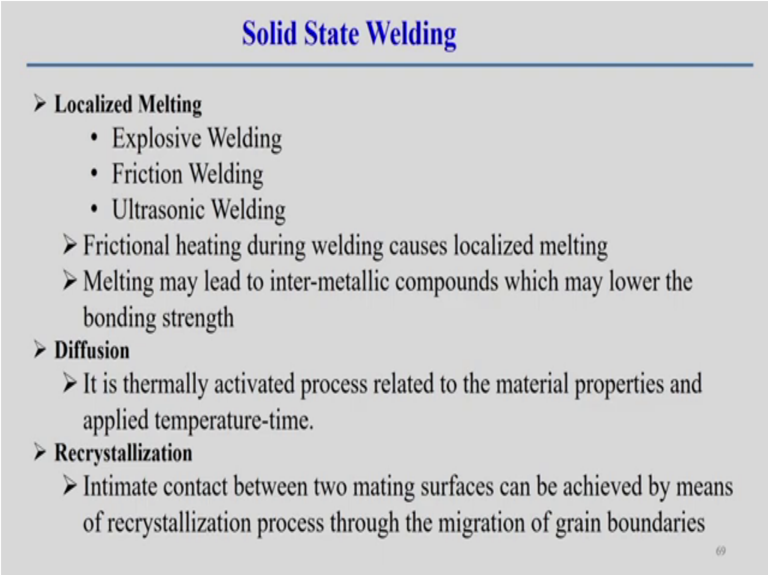

We will try to look into this typical mechanism for example, localized melting. The welding process is associated with the explosive welding, friction welding, ultrasonic welding this is all the welding process is associated with the very localized position the melting may happen and thus, coalescence of the component may happens.

Frictional heating during the welding causes the localized melting that is true and then, melting may lead to the inter-metallic compound formation that can be the one of the issues associated with this thing which may be lower the bonding. If there is a formation of the intermetallic if due to the localized welding particular zone, it basically intermetallic is normally brittle and that it reduces the bonding strength.

Then, diffusion may happen. It is a thermally activated process and which is related to the material properties and applied temperature time that means, in the diffusion process, first the surface preparation is required come in contact and then, keep it for a long time and then, what way the how fast the diffusion happens from one at the interface based on that diffusion welding is basically thing is define.

Now, recrystallization also this thing. Recrystallization there is a grain boundary what are the grain boundary between the two contact surfaces move by means of the recrystallization process through the basically grain boundary migration through the recrystallization process which is this mechanism is responsible for the bonding between these two (Refer Time: 13:09), but remember all these cases the surface preparation is one important aspect to consider.

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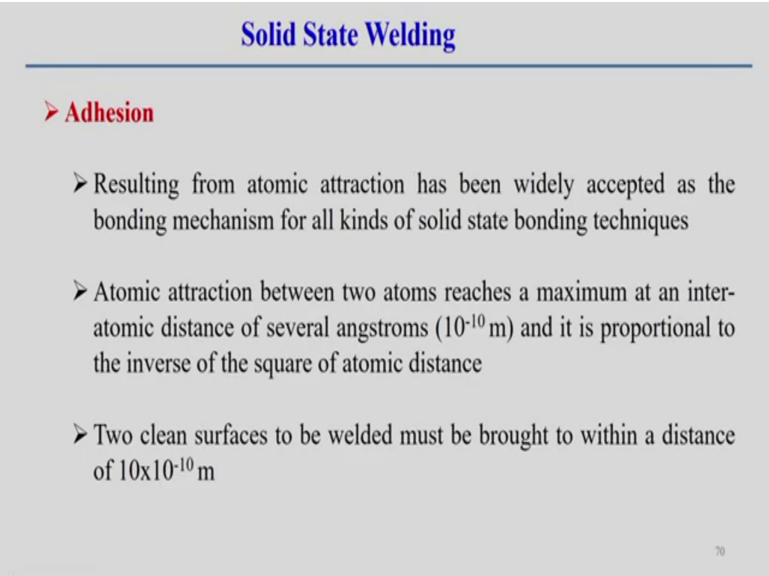

Adhesion means resulting from the atomic attraction has been widely accepted as the bonding mechanism for all kinds of the solid state bonding techniques. So, atomic attraction that means, we have to reach up to that point the two atoms can reach a maximum at a inter atomic distance of the several for the example 10 to the power minus 10 meter, it is possible to keep in contact with a very clean and flat surface, then it is possible to reach with this the two inter atomic distance, then they can bond using this mechanism.

Then, here it is two clean surfaces to be welded must be brought back within a distance of the 10 to the more than 10 into 10 to the power minus 10 meter in that range have to bring the distance so, then bonding is possible by the application of the addition mechanism.

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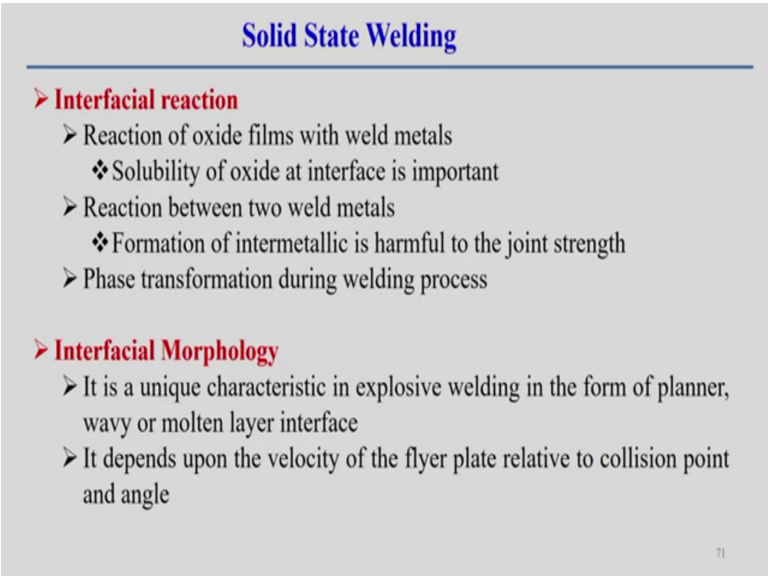

Similarly, interfacial reaction also associated with the reaction of the oxide film with the weld metals. Solubility of the oxide is one matter here in these cases, but solubility oxide at the interface is important to get this mechanism responsible for the joining of the in the solid state welding process in solid state phase.

So, reaction between the two metals can happen, the intermetallic formation may also happen, but that is not favour in the joining of the good weld joint strength. So, there at the same time phase transformers and D and D welding process is also associated at the interfacial reaction or so all these matters associated with the interfacial reaction. Interfacial morphologies nothing, but the unique characteristic for explosive welding. Now, what way the planar wavy or molten layer interface is actually formed?

It depends on the velocity of the flyer plate relative to the collision point that means, there is a jetting action what moves the flyer plate with a particular velocity at very high velocity, sometimes it is more than speed can be more than the velocity of sound. Then it gets some kind of that unique interfacial morphology and that is responsible the joining of the two components. We will see all these processes associated with the different mechanism.

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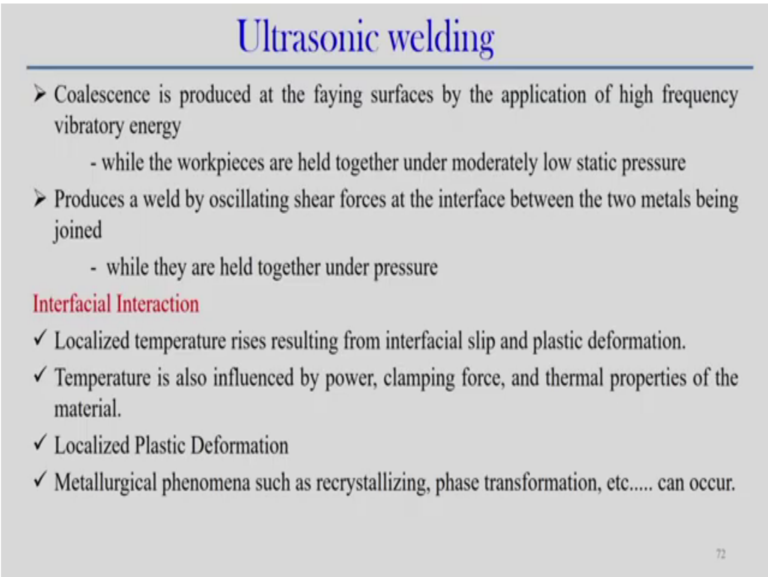

First, we start with the ultrasonic welding process. In this case, coalescence is produced at the faying surfaces by the application of the high frequency vibratory energy. So, in these cases, high frequency vibrator energy is the source of the energy to join the two components and normally the ultrasonic welding is basic confined with a very localized position and, but at the same time it is necessary to hold the work piece under certain pressure.

But if it is the pressure should be optimized such that vibratory motion the energy has to be transmitted at the interface. So, then at the interface, their coalescence of the shear force is responsible at the interface between the two metals when they are held together under pressure. So, vibratory energy transmits at the interface and the interface maybe with a very high frequency there is a shear force, oscillating shear forces associated at the interface.

And some frictional heat generation will be there and this with the under the pressure, then two components can be joined together, but all action is limited to very localized position. Similarly, interfacial interaction we can look into this thing, the different effect of the different parameters the localized temperature rise definitely where the interfacial slip and the plastic deformation happens at the zone.

Temperature is also influenced by power, clamping force and the thermal properties of the metal. Definitely, what temperature can be generated, what were the temperature diffused through this particular material the maximum temperature achieved during this process depend on that. Localized piece it is also associated localized plastic deformation. Metallurgical phenomena such as recrystallization, phase transformation is normally happens at the interface in the solid-state processes.

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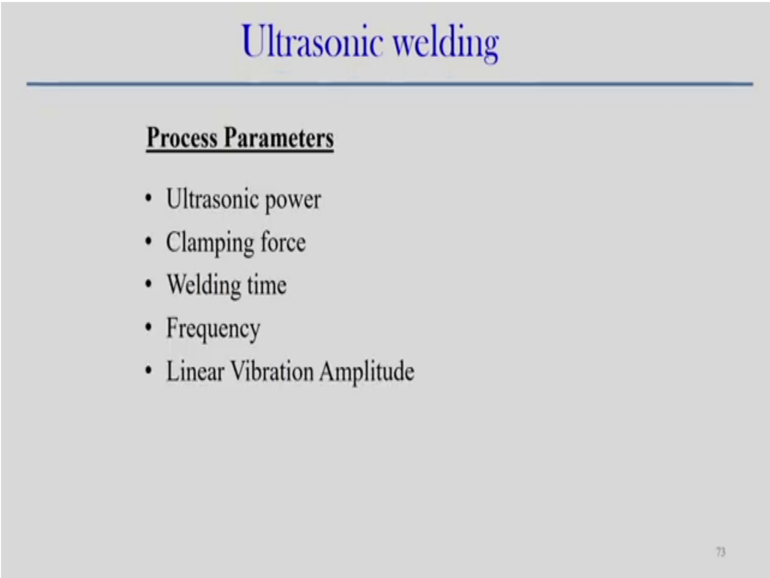

Process parameters for ultrasonic welding process is the ultrasonic power is one important parameter, then clamping forces, time welding time, frequency and amplitude of the vibration that all are the typical process parameters associated with the ultrasonic welding process.

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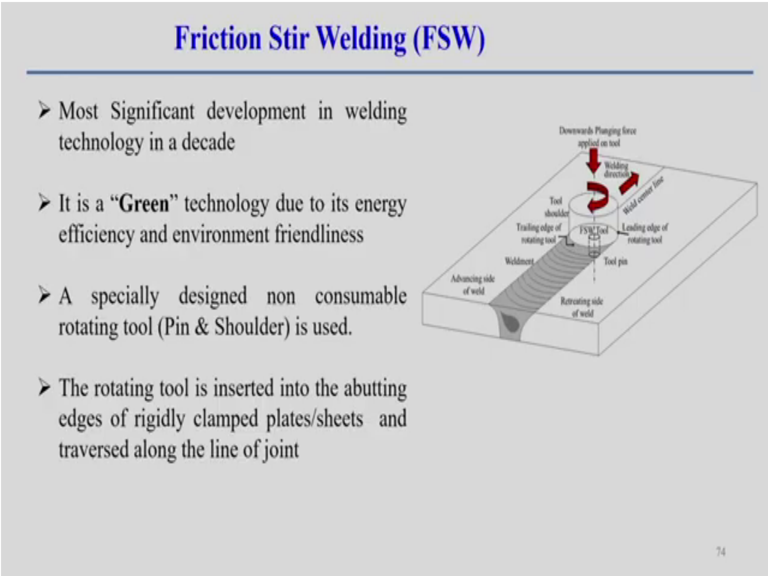

Now, one of the most widely used process in the solid-state welding process is the friction stir welding process. Here, you can see that what way we can works, and it is a most significant development in the welding technology in a decade. So, there are lots of work is going on a friction stir welding process, but what way you can define the friction stir welding process, how it works we can see.

But before that, we can say this is the friction stir welding process is a green technology because due to the energy efficiency and environment friendliness so, there is no fumes and kind of health hazard due to the presence of the shielding gas or uses of the gas in case of the fusion welding process.

So, that kind of things are not there in case of friction stir welding process because everything assets the solid state in the solid state means every or the joining happens below the melting point temperature. So, in this case, specifically designed tool is used that is inserted between the two work piece.

First two work piece in the butt joint configure so, we can keep at the interface with the inserting of the tool is required. Then, rotation of the tool, it generate the some frictional heat at the same time if you move the transverse movement, then its joining of the two components happens along that particular line, the direction over a length.

So, in this case, this joining happening that means, frictional heat generation is also there at the same time the stirring plasticization of the metals is also involved in this particular process. Now, if you look into this picture, here you can see that we define some advancing sign, rotating sign depending on the motion of this tool because tool is rotating on particular direction, at the same time the transversed motion is also given to the tool in a particular direction or it can be given to the work piece as well also.

So, here we can define the tools shoulder is basically is attach with the top surface and at the interface that means, between the two joint over the depth of the over the thickness of the work piece, the pin is inserted there. So, all part isin is basically generating the heat in these cases frictional heat and plasticization and then joining of these two metal.

But remember if you look into the cross section, the dimension, the nugget zone all this thing the heat affected zone all are the non-symmetric in nature not the symmetric because the relative motion with respect to relative motion. If you look into advancing site and retreating are different so, we cannot expect the symmetric profile and in this particular joining process. We will see what we can define the advancing and retreating side.

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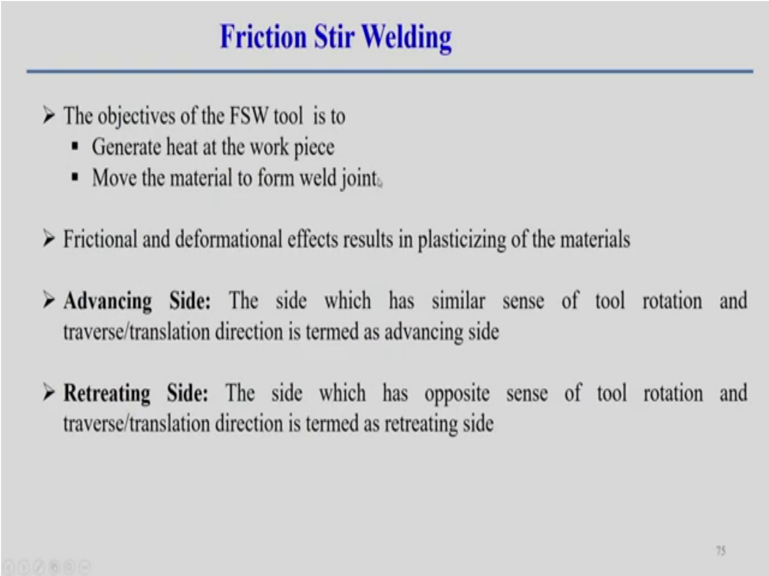

So, the objectives of the friction stir welding to leads to generate the heat of the work piece that is clear and the move the material to form the weld joint, but frictional in the deformation effects results in the plastic deformation of the metal that we can see from this process itself.

Now, advancing side is that side which is similar in sense of tool rotation the direction of the tool rotation and the transverse or translation direction is same that is the advancing side and retreating side that means, in these cases, the opposites of tool rotation speed direction of the tool rotation or transverse direction are different in this and that side is defined as the retreating side.

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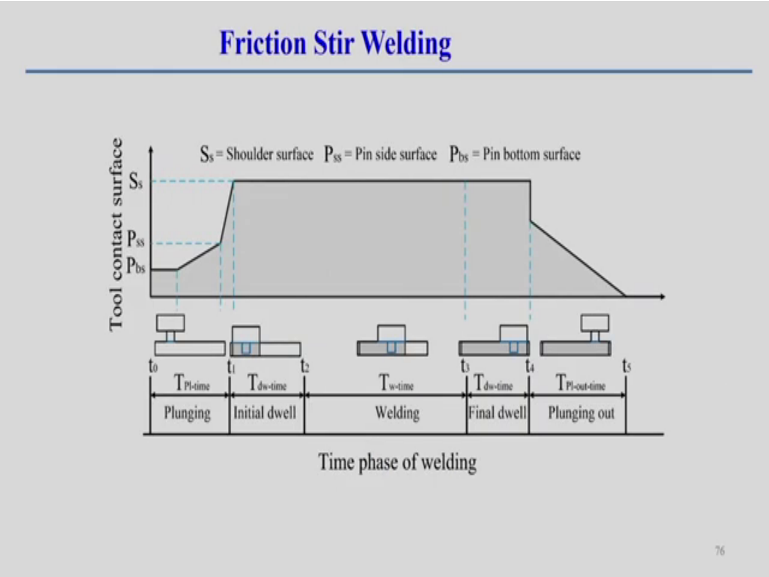

Now, friction stir welding happens in that several phase. There are several phases associated with this thing, first is the we can see the graphically the what are the different phases. Here, you can see the phases is called the plunging phase. Plunging phases means the work piece is there and the rotating tool is there.

So, rotating tool gradually penetrate to the workpiece and this is called the plunging phase and it follow some plunging velocity also that means, its penetrating to the particular workpiece and then in these cases, the transfers movement of the workpiece or tool kept as 0 that means, there is no transverse movement, only the rotational movement is associated with the tool.

Once we can follow plunging over that means, tool is inserting to the complete depth of workpiece, then the initial dwell phase is there. Initial dwell phase means simply keep on rotating the tool and the same position without giving any transverse motion to the tool.

Then initial once is sufficient time is given for the initial dwell phase and that means, sufficient heat is generated, then it start moving that tool, rotating tool along the transverse direction. The move some linear velocity have giving to the tool and that phase is called the welding phase.

So, once it is done, particular length welding is over, then we just remove the tool from that particular, but before removing this tool, we give the final dwell phase also because once it is nth position, we can keep on that position much more time after that we just gradually remove the tool from the workpiece that is called a plunging out pace. So, these are the typical time phase associated with the friction stir welding process.

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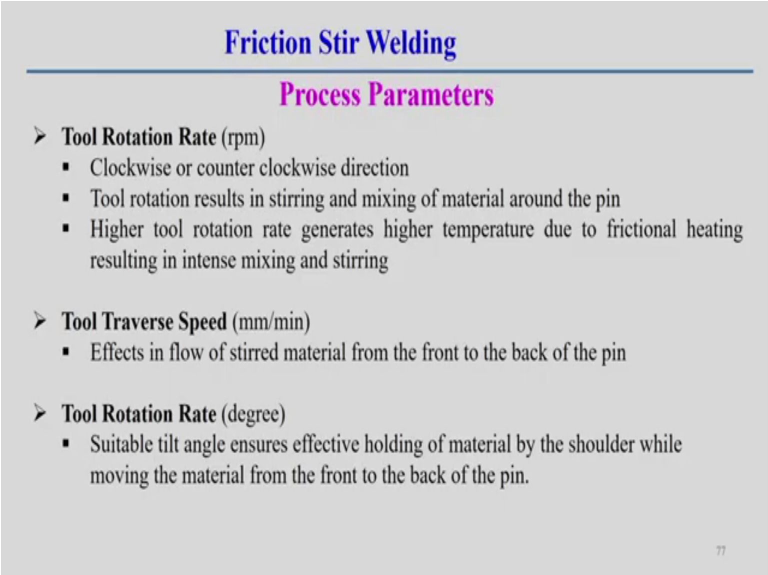

Now, what are the process parameters? Definitely that tool rotation speed rpm is one of the process parameter and we can give the clockwise, anti-clockwise direction and tool rotation is basically heat generation as well as the mixing or stirring of the material the pin. Higher tool rotation definitely generates higher temperature due to the frictional heating.

High heat generation maybe there and intense mixing or stirring is associated at the high rpm of the rotating tool. Similarly, tool transverse speed. Tool transverse speed is same as the welding velocity what we follow in the fusion welding process. What way the torch move a particular velocity same that equivalent here as the tool transfer speed in friction stir welding process.

So, in this case, effects in flow of the stirred material from the front to the back of the pin that means, profile can be changed with the motion of this things and optimum tool transverse is required such that proper mixing of the this particular zone is has to be ensure.

Now, tool rotation rate, I think this would be the tool angle basically the suitable tilt angle we normally use the effective holding of the material. So, it is not necessary tool will be always inserted at the vertical position. Sometimes they put the tilt of the tool such that effective holding of the material is required by the shoulder while the moving the metal from the front to the back of the pin. So, it is a better material mixing of the material is required in this particular situation.

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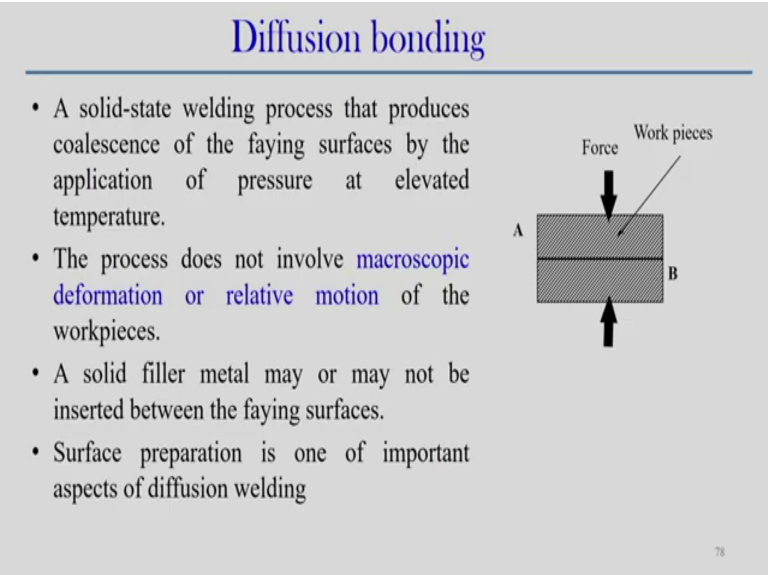

Now, we come to this point that diffusion bonding process. Diffusion bonding process you can see the two work piece is the held together with the application of the force and maybe added by the same temperature and at the interface sometimes may or may not necessary some kind of the external material.

We can see that this is a particular solid-state various old solid state welding process that produces the coalescence of the faying surface by the application of the pressure at elevated temperature at the because this sometime there is a diffusion bonding happens, that diffusion becomes more active if we along with the pressure we can add with the temperature.

So, the pressure does not involve the macroscopic deformation or relative motion of the workpiece, there is no need of that, but has to be in these cases surface preparation is one of the important aspect for the diffusion welding process to happen.

So, it is like that only two components has been kept for a long time and then at the interface, diffusion happens and then, it is responsible for the joining of these two component, but to get the success of these things, the surface preparation is one important aspect in these cases.

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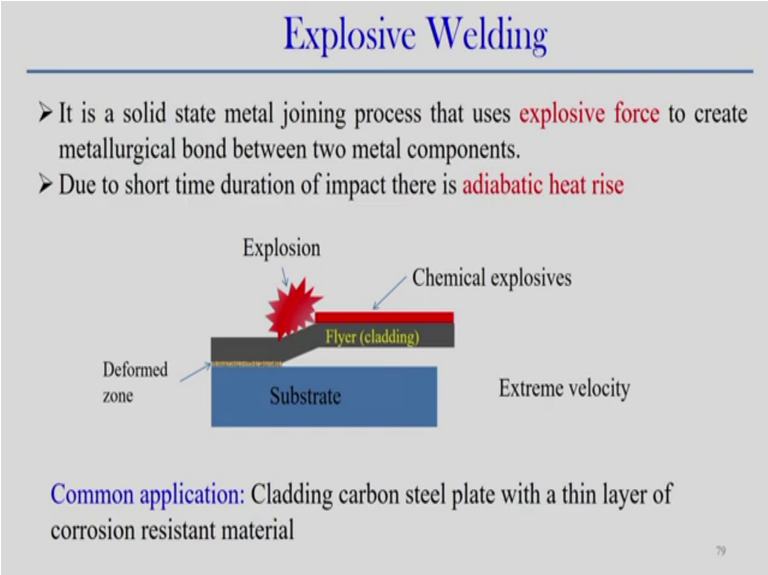

Now, we look into the what is explosive welding. See this is one kind of the solid-state welding process and you can see that uses the explosive force to create the metallurgical bonding between the two metal components. Now, see there is substrate material and the on the flyer material is has been used, but the flyer material has to be deposited by the using the explosion that have.

So, in this case, the we can use some chemical explosive on the top surface and then, once the explosive starts working on these things, the on very thin layer on the top surface is basically join the substrate material, but how it works we can see. So, due to the short time duration, the very short time it happens, very short time duration, the impact is basically impact of the layer and it is associated with the adiabatic heat rise, then there is no time to dissipate the during the process this in the impact process.

And it is associated this moves very fast for example, the deposition of that layer on the substrate metal is very fast and very extreme velocity. Sometimes, it can be more than that of the sonic velocity the velocity of the sound. Its common application we can find out the cladding carbon steel plate, very thin sit plate with a cladding of the carbon steel plate of the substrate material with a thin layer of the corrosion resistant materials that is the typical application very thin layer and suppose here the very big structure.

So, in this case, it will be easier to use the explosive welding, but you have to be used the explosive very controlled way. So, it is like that only over the substrate material, use the put the this layer cladding seat and then, we use the explosive that gradually the explosive due to the impact look by the explosive, the thin seat will be deposited on the substrate layer and that because of the some kind of the morphology, it will join between these two component.

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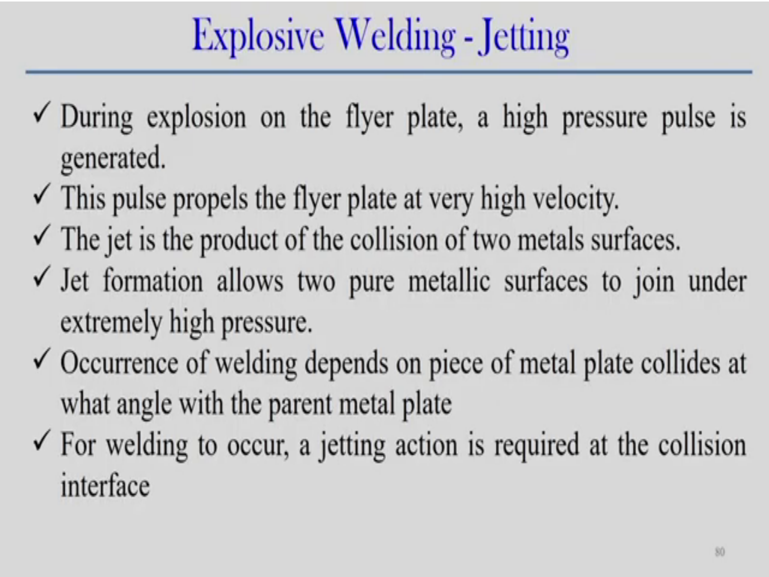

But in these cases, during explosive on the flyer plate, high pressure policies generated this is the principle of this thing and that pulse propels a flyer plate at very high velocity. And the jet is product of the collision between the two metals because two metal surface there is a creation of the jet and that jet propagate the to propagate in particular direction and allow the formation of the joint between the two pure metallic components under extremely high pressure.

Because in this case, the jetting of the flyer plate is normally happens and there is a occurrence of the welding depends on the metal plate collides at what angle with the parent metal that means, what angle we can keep the parent metal that is responsible the interfacial morphology in this particular case.

So, for welding to occur a jetting action is required at a collision interface where the collision interface a jetting action is there and its very high velocity move and then, the two surfaces join between by forming some kind of the interfacial morphology.

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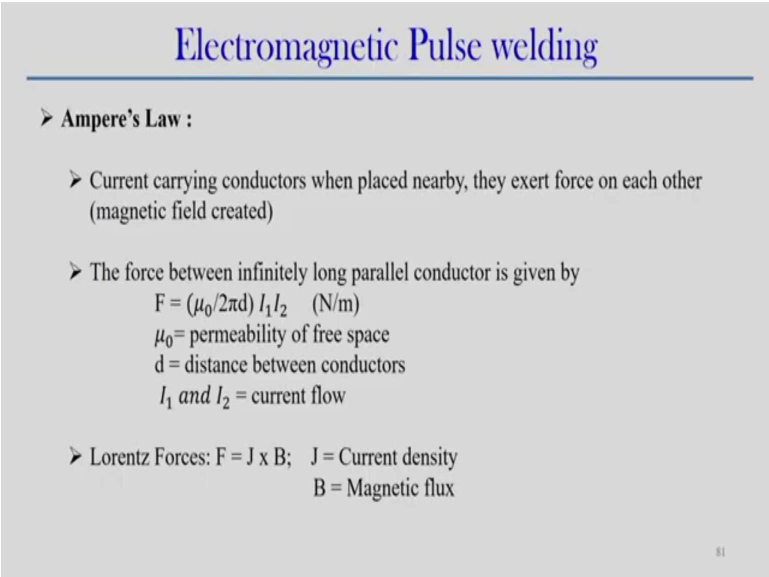

Next, we try to look into the electromagnetic pulse welding process. So, electromagnetic pulse welding that is the one of the welding process, we simply use the Ampere's law and we know that current carrying conductors when placed nearby, they exert some forces with respect to on each other and because of the magnetic field created and because of that magnetic field is created.

Now, force between the two infinitely long parallel conductor we can see that can be estimated, we can see here also F equal to is a function of I 1, I 2, I nu two is basically the current flow between these two conductors. So, using this principle, the electromagnetic pulse welding has been developed. We will see how it works.

So, then Lorentz force can be calculated this current density and magnetic flux also and during when there is a passage of the current between these two conductor. So, this Lorentz force is responsible here in associated with the electromagnetic pulse welding.

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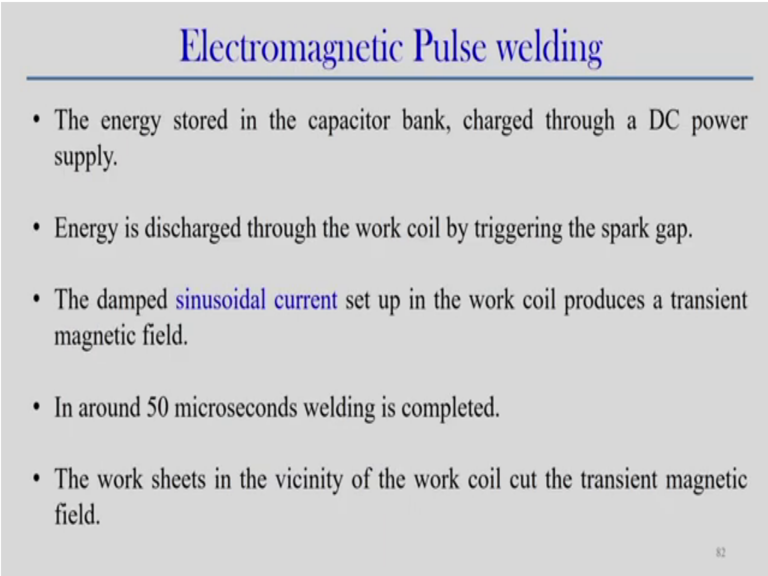

But how it works? It works like that only the energy stored in a capacitor bank and charged through a DC power supply. The ones the capacitor bank there is a sufficient charge is there, then energy actually discharge through the work coil by triggering the spark gap and that it discharged happened over a small period of time.

So, therefore, damped sinusoidal curve basically sign cup setup in the work coil, this actually produces the transient magnetic field so, that different particular current in this case the and the set up in the work coil that produces a transient magnetic field. So, transient magnetic field is important in the sense that it is basically created over a long very short period of time.

So, it around 50 microsecond welding is completed. So, in this case, the two worksheets in the vicinity of the work coil are cut the transient magnetic field and there is two components can be joined.

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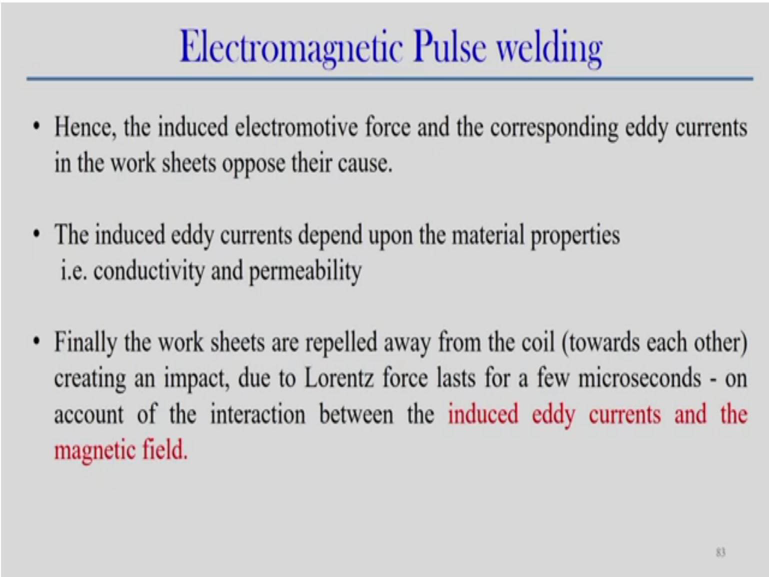

But in this case, that the induced electromagnetic force and the corresponding the eddy current the work sheet oppose their caused so, electromagnetic force and the eddy current is created. This induced eddy current depend upon the material properties and their conductivity and the permeability of this particular material.

But finally, the work sheets are repelled with respect to each other from the coil and towards with respect to each other move towards respect to each other creating an impact due to the Lorentz force last for a few microsecond one of the microsecond Lorentz force and on the account of the interaction between the induced eddy current and the magnetic field.

So, all are the induced eddy current and the magnetic field and they create some kind of the Lorentz force and then, it is we have designed in such a way that took place the coil with respect to each other and then, repel this will repel with respect to each other so that they move with respect to each other and that two components can be joined by the principle of the electromagnetic pulse welding.

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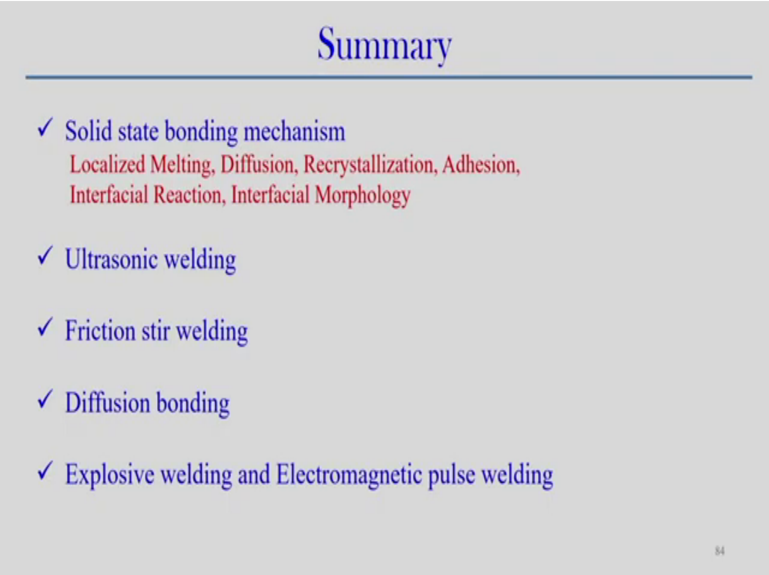

So, in summary of this particular sub section of the module, we have discussed the solid-state bonding mechanism that localized melting, diffusion, the recrystallization, adhesion, interfacial reaction, interfacial morphology all are the typical bonding mechanism associated with the solid state welding processes and different process follow the different bonding mechanism.

Then, we have discussed the ultrasonic welding process, friction stir welding process even diffusion bonding process and just explosive welding and electromagnetic pulse all these processes and their basic principle.

So, this principle will try to help our to understand that if you want to develop some kind of finite element of in a particular welding process that we should know that basic principle associated with this particular welding process, but we will try to look in detail of this finite element modeling of a particular welding process in the respective module also; so.

Thank you very much for your kind attention.