Advances in Welding and Joining Technologies

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Lecture: 08
Solid State Welding Processes Part I

Good morning everybody. Now, we will start the another module that is the Solid State Welding Processes.

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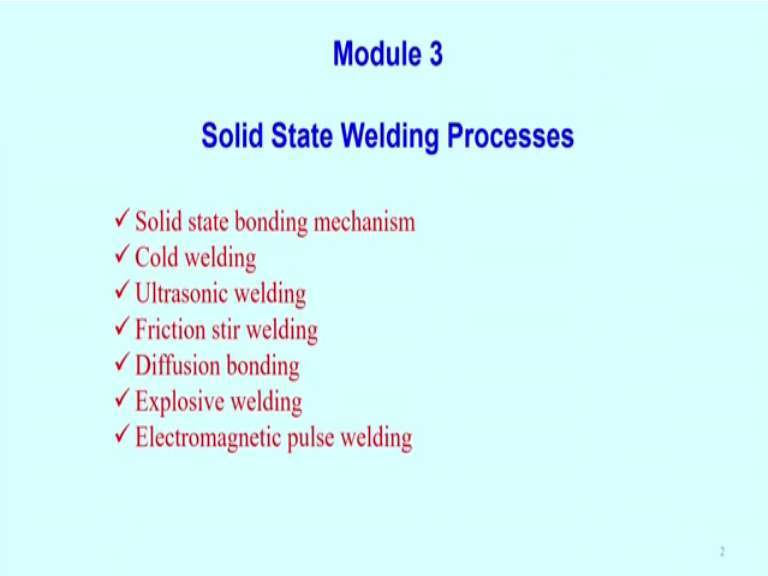

In this module, we will try to cover the different solid state welding processes and their bonding mechanism. So, first different cold welding process that comes under the solid state welding processes, ultrasonic welding, friction stir welding, diffusion bonding, explosive welding and finally, the electromagnetic pulse welding. So, these are the typical welding processes we will try to cover in this module.

Now, if we look into that solid state welding process; actually the solid state welding process is the very old process, but in principal is known to all of us, but the technology development using it, using the bond bonding mechanism of solid state welding process is still evolving, still, there are several development of the different welding technology based on the principal of the solid state bonding mechanism.

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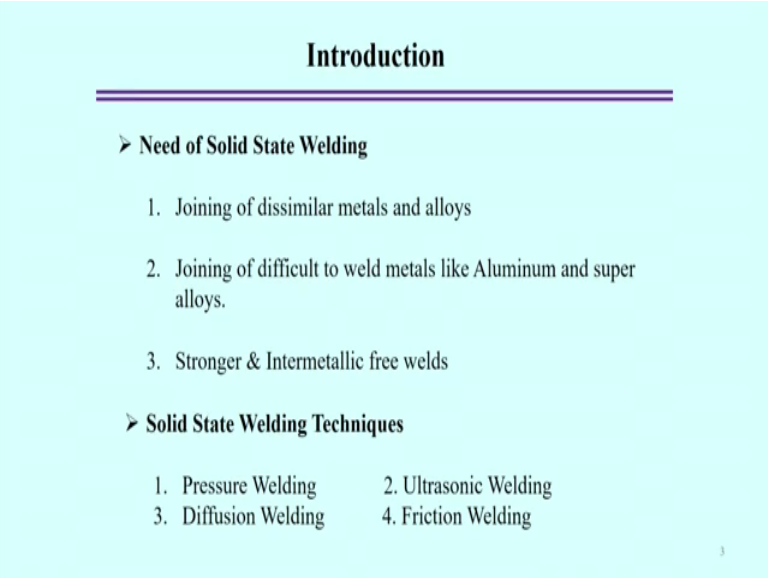

Of course, this solid state welding mechanism is very much advantageous in the case with respect to the fusion welding processes. So, in that point of view, the most advantage is that in fusion welding process, we can we can develop the basically, we need to melt the material and then specifically when you join two different types of the material. So, there may be the possibility of the intermetallic compounds formation.

So, in that sense solid mechanics, solid state welding solid state bonding mechanism is to some extent, it is advantageous that it will try to minimize the formation of the intermetallic and compound. So, most of the dissimilar materials and alloy combination is bonded by the solid state welding processes, of course, other cases for example, joining of the difficult weld materials like aluminium super alloy, they are extremely difficult using the conventional fusion welding processes.

So, in that way, the solid state welding process is more advantageous with respect to that type of material. Of course, the point third is the joint is becomes sufficient strength and intermetallic free welds can also be developed using the solid state welding process.

If we look into the; what are the different technologies or different techniques in solid state welding process that includes is the pressure welding first, second is the ultrasonic welding, diffusion welding and friction welding. So, of course, pressure welding means we need to apply some amount of the pressure then we can able to join, but of course, this pressure welding without the of any external heat. Next is the ultrasonic welding. So,

in this case probably, we can use the vibrated energy for the shearing of the tool layer and that it is a local localized deformation happens within that zone and we will try to join bond between these two metals.

An diffusion welding is also time dependent and normally it happens. It can be considered thermal thermally activated process. So, that happens at very high temperature at over a large period of the time, if we make to contact of the tool materials and if they are in contact then diffusion weld diffusion welding may also happen and of course, in this normally in this case the time requirement is very high and then friction welding.

So, in this case, the frictional heat is generated between the surfaces and that actually make the coalesces of the different material; suppose friction welding. Now, it is developed to the along with the friction the steering of the materials also happens and that also helps to plasticization of the material and from that point of view now the friction stir welding has been developed. So, all these four mechanism, we generally follow technology, we generally observe in the solid state welding process. We will try to discuss one by one.

But if we look into the basic understanding of this bonding mechanism, we need to look into the microstructural and the surface condition of the workpiece and the analysis or the knowledge of this is very much important to understand the solid state bonding mechanism. If we look into that the any surface under the microscope, then we will see, we find out the surfaces are the irregular, basically lot of asperities are there and they are irregular in shape may not be smooth.

So, that irregularity can be used advantageously that to form the solid state bonding. Of course, there is a one point that the surface, if we look into the characterise the metal surface, it is like that the base metal having specific crystal structure and then next layer of the base metal is either thermally or chemically activated affected layer. Then we found out the oxidise layer and then contaminated layer this is the typical characteristics of a metal surface.

Now, of course, in solid state bonding process, since, it is most of the metal surface covered by these two layers oxide and contaminated layer. So, to make the bonding between the two surfaces, it is very much necessary to remove the contaminated layer at

when the metal exactly directly come into contact with other by removing this contaminated layer and oxidize layer, then it is possible to make the bonding mechanism at the solid state.

So, in that case depending upon the microstructural compositional irregularities on the surface exists. So, different type of mechanism has been has been developed to form the to form the bond between the metals. So, practically mechanically; So, the irregularities asperities on the surface is basically generally collapsed and that helps to make the bonding.

Over all the bonding mechanism or when you try to bond the two surfaces the affected area is typically very small in case of the solid state bonding process or in case of the solid state welding process.

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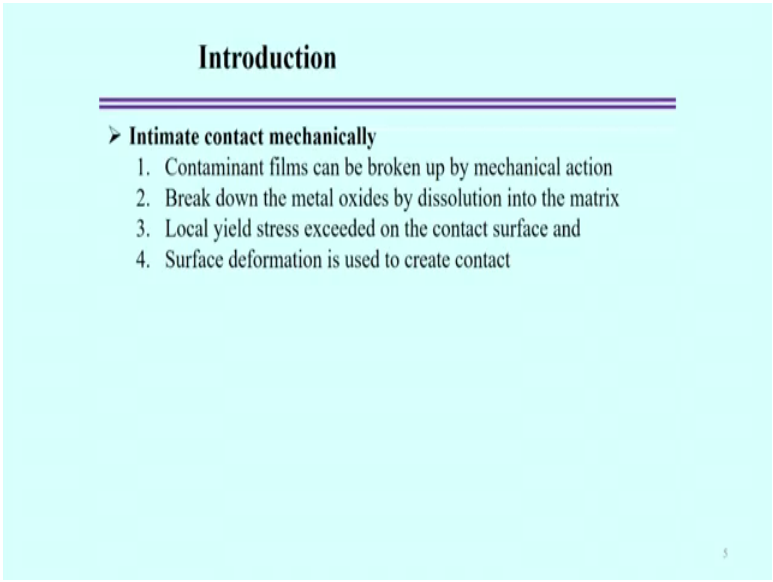

But if, we look in to the intimate contact mechanically between the two surfaces, one thing is that contaminated films can be broken by the mechanical action. So, by mechanical action contaminated films or layer can be removed or chemical using some chemical also, we can remove the contaminated layer.

Next break down of the oxide layer because if you see we have to remove the all the layers, contaminated layers, we can remove mechanically next we can break down the

oxide layers or dissolutions of the such that dissolution of the oxides can be dissolved within the matrix itself, then after that when actual metal in contact with the surface.

So, local yield stress in at the contact surface exceeded and then after that surface deformation, actually create the bond between the two metal when they are in when they are in contact. So, this is the that is why this is called the intimate contact can be done between the metals mechanically. So, that actually forms the bonding of the two metals.

But based on this bonding mechanism of solid state welding processes there are several types of the welding process welding process or mechanism for that bonding mechanism exists, one is the localized melting diffusion recrystallization adhesion interfacial reaction and the interfacial morphology all these typical mechanism is basic is involved in case of the solid state bonding process.

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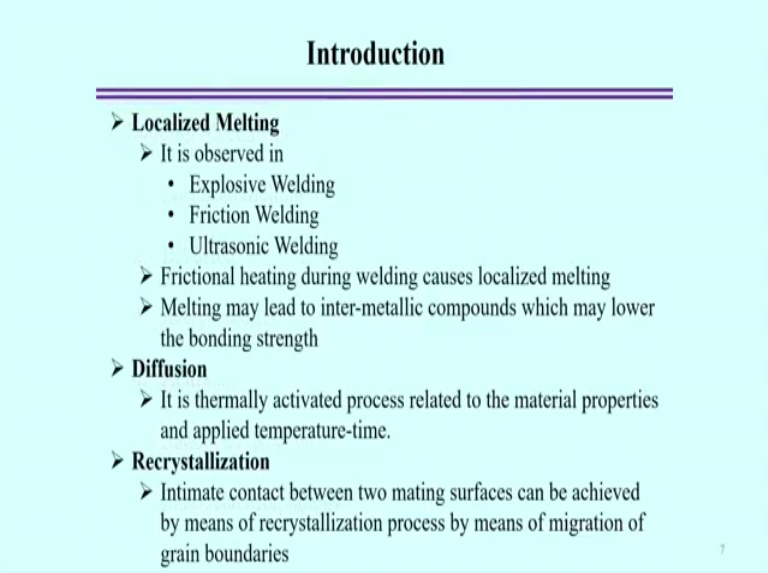

So, let us look into one by one. First is that localized melting localized melting normally observe in the explosive welding friction welding and ultrasonic welding. So, of course, normally the solid state welding process is the solid state welding process and normally that melting it never cross the melting point.

But in this cases, the explosive welding friction welding, sometimes, the very small the very localized area the melting may happen and that melting actually, but that localized melting is creates the bond between the two surfaces.

So, this mechanism observe that explosive welding process friction welding process and even in ultrasonic welding process also. So, here mainly the frictional heating during the welding frictional heating basically during the welding actually creates the localized welding.

But the other side of this thing, if there is a localized welding during the process also. So, it actually leads to the formation of the inter metallic compounds that actually lower down the bonding strength. So, therefore, this in this it is better to avoid the localized melting during the during the process itself.

Now, if we look into the other mechanism the diffusion mechanism diffusion mechanism is mainly thermally activated process related to the material properties and applied time also and sometimes we apply the some amount of the pressure also between the contact base surface. But in diffusion welding, it is very much important that the surface preparation because surface should be removed from any kind of contaminated layer and the oxide layer in if we completely remove the oxides layer and the contaminated layer and then to surface arrange contact over a large period of time even that we keep it a at elevated temperature.

And of course, also elevated temperature, but may be small application of the load between these two contacted surface. So, that bonding mechanism creates that is called the diffusion bonding. So, normally which materials has having the difficulty of joining using the conventional welding processes with that case we generally follow the diffusion bonding mechanism.

Recrystallization also helps to making the welding or joining in solid state that mechanism is like that the intimate contact between the two melting surface can be achieved by means of the recrystallization phenomena and of course, that recrystallization phenomena through the migration of the grain boundary.

So, in that grain scale, we if we look into the in grain scale grain boundary migration even in the contact surface, then that grain boundary migration is evolved through the recrystallization process and this is the that mechanism is called basically recrystallization.

And through that mechanism, the bonding between the two surfaces is possible, but it is extremely important the orientation of the grain at the contact surface is very much significant and of course, that may not should not be any kind of contaminated and the oxide layers and the contact surface.

So, contact is very perfect in this case and in the microscopic scale the irregularities or is the grain oriented in specific direction probably that actually favours this recrystallization mechanism to bond between the two solid components.

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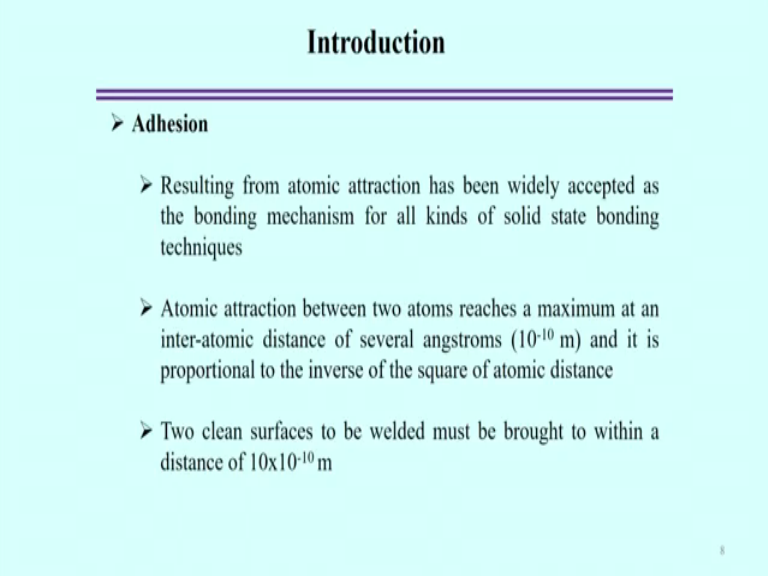

Adhesion also is another kind of mechanism. So, this mechanism can be explained like that it is a basically results from the atomic attraction and this is the one kind of the bonding mechanism and of course, it is we for all kinds of the solid state bounding techniques is generally follow this principle.

So, here atomic attraction between the two atoms reach at the maximum inter atomic distance. So, that physically you have to bring the two contact surface at the distance as a distance of the several angstroms distance; that means, is a order of 10 to the power minus 10 meter that distance the gap between the two contact surface can be maintained and this distance is actually proportional to the inverse of the square of the atomic distance.

So, definitely if it is possible physically possible to bring the two contact surface is that 10 to the power minus 10 meter in that order of distance, then there can be link through the atomic attraction and that mechanism is called the adhesion here, see two thin surfaces must be welded or must be brought to within the distance of 10 to the power minus 10 into 10 to the power minus 10 meter.

So, in that range and, but of course, the if you want to brings this, it is a cannot be possible using the if you follow any kind of formational welding processes.

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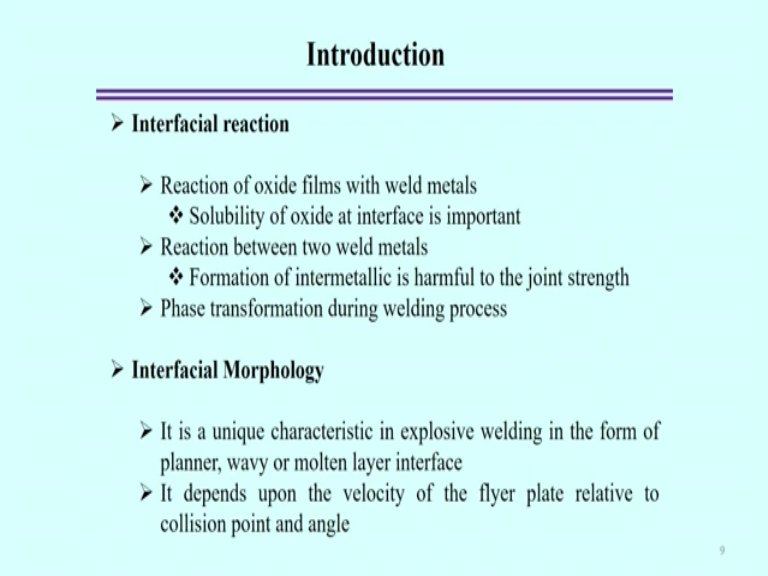

Interfacial reaction; if you see the reaction of the see within the metal surface we can easily remove the contaminated using some chemical or mechanical action, but the oxide layers is sometimes the intricate part of this surface. So, interfacial reaction what happens the oxide films basically oxide films with the weld metals; we try to remove the remove or we will try to dissolve the oxide layers within the weld metals.

So, therefore, solubility of the oxides and the interface is very much important to analyse and then reaction once the oxide metal either dissolve or remove then reaction between the two weld metals forms and there may be the formation of the inter metallic. If they form the intermetallic formation, then that is that intermetallic is actually harmful for the weld join and that actually brought down the strength of the weld join or may be the bonding between this two may not be very strong in presence of the inter metallic compounds.

So, it is better to avoid the formation of the inter metallic materials to forms that good bonding mechanism by interfacial reaction, of course, during this interfacial reaction, there may be the phase trans, there may be the formation of the; there may be the phase transformation may also occur. So, this is one mechanism.

Another mechanism is the interfacial morphology. So, this interfacial morphology is specifically we observe or it is a characteristic part in specific welding processes for example, explosive welding processes and that morphology is in the form of a kind of plane or a kind of wavy nature and that sometimes it is creates the local localized melting that molten layer interface, we observe this kind of morphology.

So, it basically depends on the velocity of the faying surface. So, that velocity actually decides the interfacial morphology specifically the in case of the explosive welding. Of course, apart from the velocity the flyer plate relative to the collision point and relative to the point and angle at which point basically location of this plain flyer plate is decides that this typical interfacial morphology explosive welding process.

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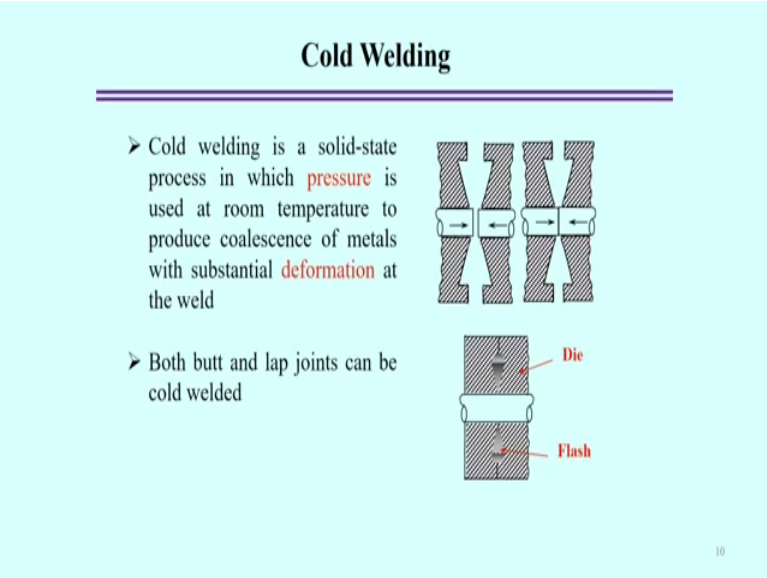

Now, apart from this different mechanism, now I will come back to the; what are the cold welding process. So, this is one kind of the solid state welding process if you see cold welding is a one kind of solid state welding process basic in this case there is a application of the pressure is used and that applied pressure. But that phenomena actually happens at the room temperature in this case the substantial deformation happens at the

contact interface and they finally, form the join in the either in terms of the butt join configuration or in terms of the lap joint configuration.

So, both possible here if you see from the figure that with the die we can fix the material and come in contact application of the pressure may be hold for a sufficient time and then they actually make a weld join without the application of any kind of the temperature. So, without the head of the temperature; So, that is why these type of solid state welding process is known as the cold welding process.

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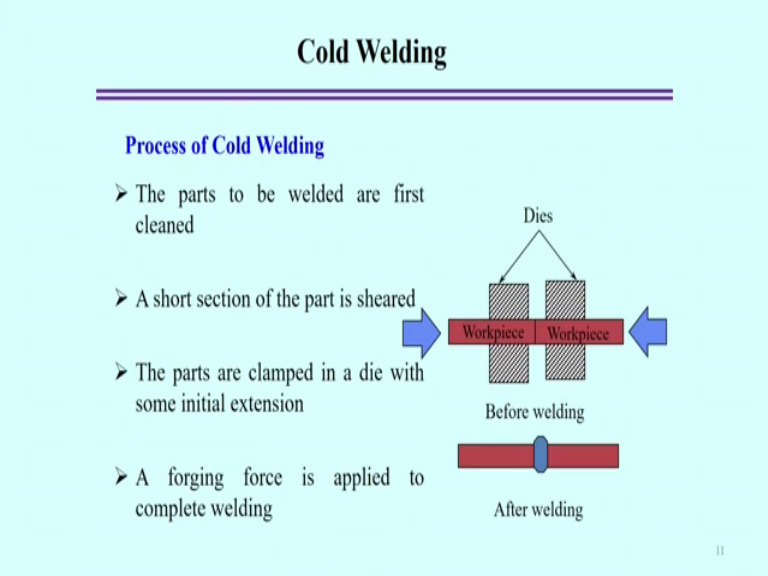

So, better way if we look into this figure that the parts of the welds to be joined first they have cleaned normally to remove the contaminated layer and then a short section of the parts basically shared and that parts are claimed with the die and some initial extension is fixed and then we apply the pressure force pressure. Basically, forging force we apply and then that actually forms the complete welding if we look into these two figures one is the before welding and that comes the after welding.

So, this is the more simplified welding process, even there is no only need to apply the forging force, but there is no need of the some external heat and that forms the weld joint, but all these solid state welding process the surface is the main issue.

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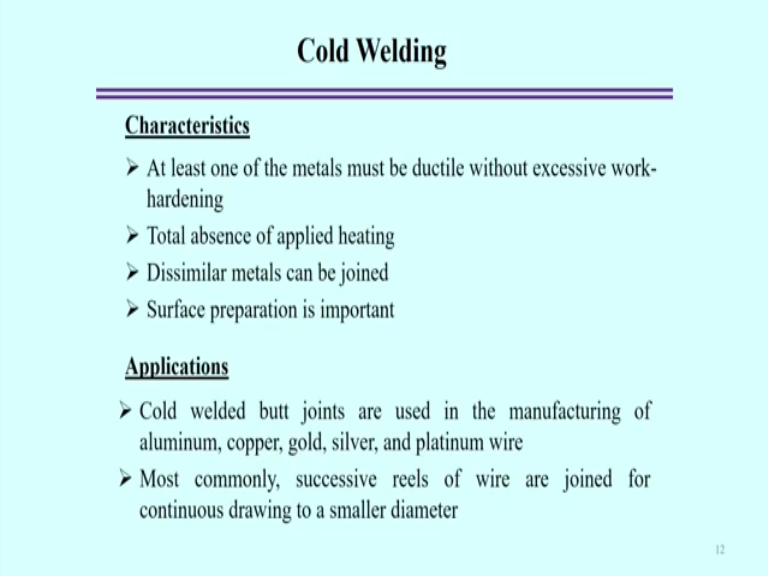

What are the typical characteristic of this cold welding process if you see at least one of the metals must be ductile. So, that it can deform at least during the application of the forging force, but of course, without excessive work hardening because if the metal is ductile. But if work hardening is very high; that means, during the deformation of the work material the strength level increment strength level increment will be very high if work hardening work hardening affect is very high.

So, in that case, moderate or low work hardening effect, but of course, having some ductility that is the more suitable for the cold welding process total absence of applied heating. So, this process has been done without application of any external heating dissimilar metals can be joined.

So, in case of dissimilar materials; that means, one of the materials will be at least having some ductility and low or moderate work hardening effect and of course, the surface preparation is very much important. So, normally the welding process will be very sound, if it is possible to remove the contaminated and oxides layer before the welding process.

If we find out the application of this cold welding process we can find out cold welding butt joint can be used in the manufacturing in case of aluminium, even copper gold silver and the platinum wire. So, if you see most of this metal is having good amount of ductility, but we find out most application of this successive reels of the wire reels of the

wire can be joined for continuous drawing to a smaller diameter this is a typical application, we find out the this type of typical application using the cold welding process.

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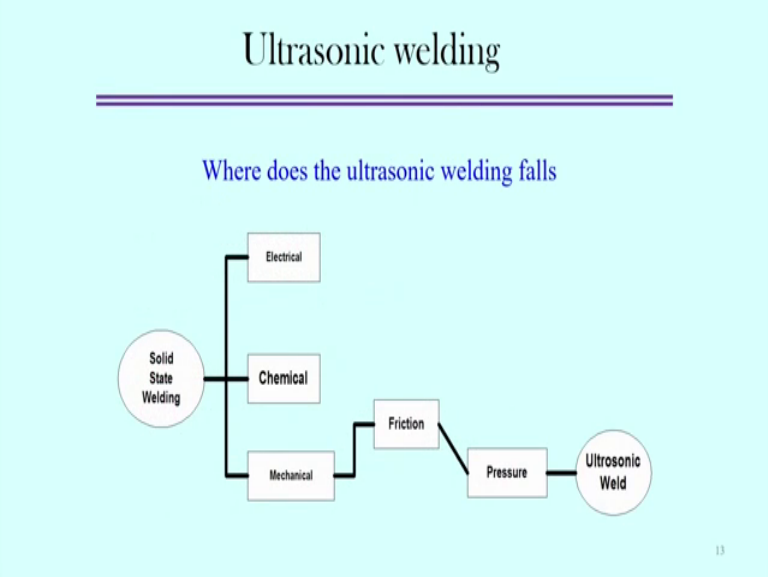

Now, we come to that another solid state welding process that is known as ultrasonic welding process. So, if we look into the stand of the ultrasonic welding process. So, first we start with the solid state welding process the solid state welding process the driving energy in all these cases can be electrical can be chemical can be mechanical.

But ultrasonic welding process will come under the mechanical energy requirement, but here the mechanical energy that friction is also involved that frictional heat generation will be there and then pressure is also required at the same time friction as well as pressure and that actually constitute to the basically ultrasonic weld.

So, now we look into that ultrasonic welding process that principle of this ultrasonic welding process. So, in this case coalescence is produces at the faying surface by the application of the high frequency vibratory energy so; that means, when the work piece are held together under the moderally low static pressure; that means, along with the application of the pressure the on the that high frequency vibrated energy is also differ in case of ultrasonic welding process this actually produces the weld by oscillating the shear forces at the interface between the two metals that is supposed to join.

So, therefore, during the application of the vibrated energy it should be hold by some amount of the along with the some amount of the pressure also.

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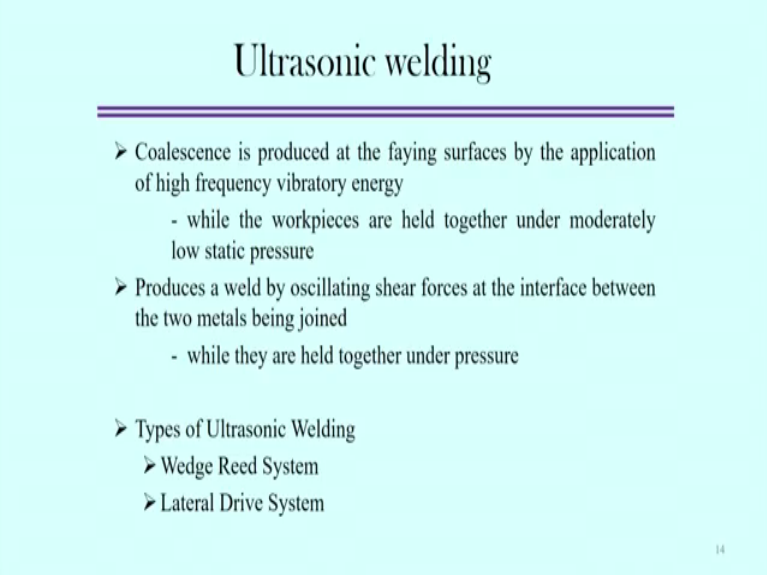

So, normally two types of the ultrasonic welding process, we observe that is the one is the wedge reed system another is the lateral drive system.

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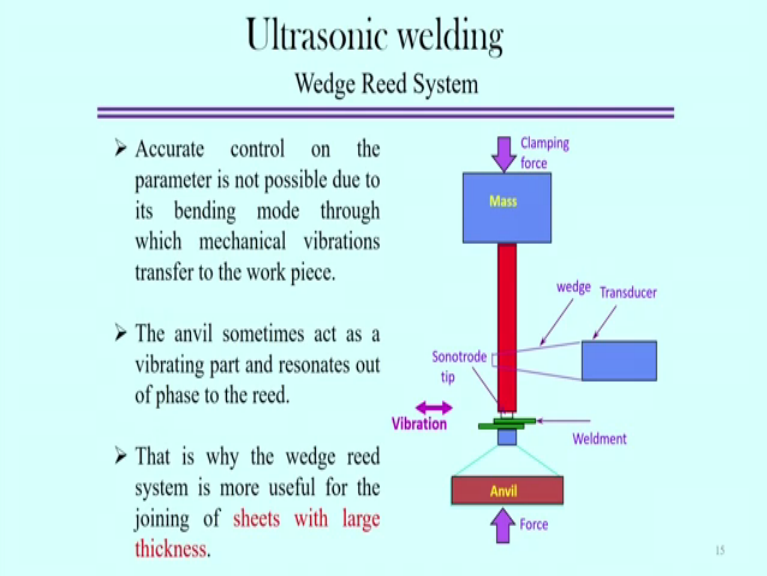

So, if you look into this thing the figure that a clamping force the accurate control on this parameter is possible due to its bending mode through which the mechanical vibratory vibrations actually transfer mechanical vibration is transfers to the work piece. So, this is

the typical wedge reed system. So, in this system, the clamping force is applied and sonotrode tip is basically creates some amount of the vibration on the workpiece, the weldment structure and at the interface that vibration energy basically the vibration vibrated energy actually released on the interface and then with the application along with the application of the some amount of the force or pressure that actually induce the joint in term that is called the that is the basic system of the ultrasonic welding process.

So, here the anvil in the bottom side if we look into that sometimes act as a vibrating part and resonate out the face of the reed. So, sometimes this anvils also helps in that way and here, if you see the vibration is actually on the horizontal, the vibration amplitude is that on this horizontal plain therefore, this is typical the wedge reed system and it is very much useful the relatively very high thickness material as compared to the other system now if you look into the other system also.

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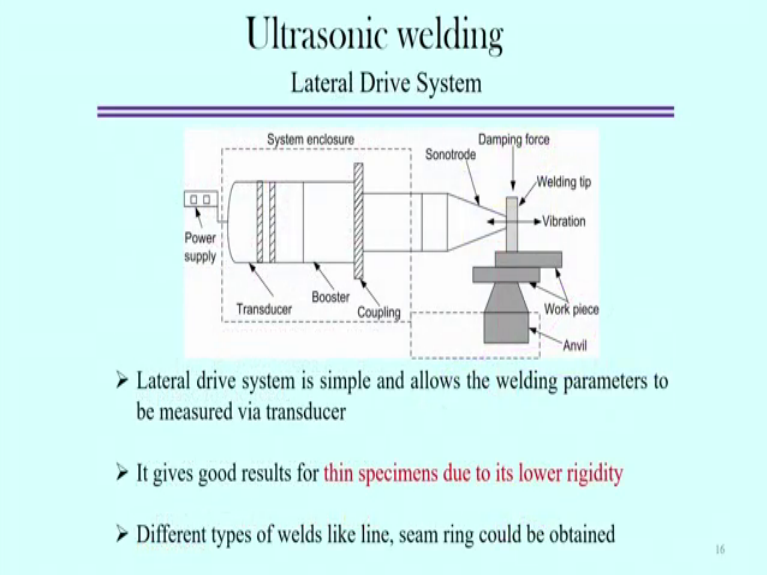

The lateral drive system here if you see the configuration of the system is little bit different from the wedge reed system. So, in this case that lateral drive is more simple and allows the welding parameters to be measured via transducer here if you see the above the anvil there is a work then settlement of the workpiece and then damping force is applied from the welding tip.

But the sonotrode is also in the on the horizontal plain and here the advantage is that the welding parameters actually can be measured by a transducer, but in other system reed;

that means, wedge reed system that in that case there is a difficult to control all the welding parameters; that means, measurement of the welding parameters was the difficulty there, but here you can easily do that you can measure the parameter.

So, this type of system is mostly suitable specifically very thin sheet. So, thin specimens and because overall system rigidity of the overall system is basically low as compared to the wedge reed system wedge reed system is more rigid as compared to the lateral drive system.

So, that is why wedge reed system is typically applied for the relatively higher thickness material, but in case of the lateral drive system, we generally use the very thin sheet. So, different types of the wedges like seam ring can be obtained using this welding process.

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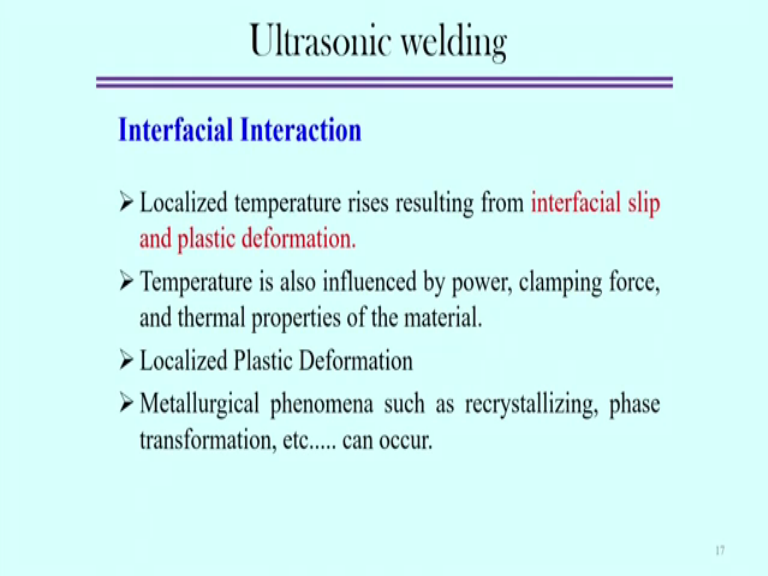

Now, the mechanism interfacial interaction how it happens in ultrasonic welding process; So, first is that localized melting is happens during this process rises resulting from the interfacial slip. So, at the interfacial slip as well as the plastic deformation because of that localized temperature basically increases and of course, this temperature rise is basically influenced by the power and the clamping force and of course, thermal properties of the material these are the these responsible for the increment of the temperature.

But definitely there must be some amount of the localized plastic deformation at the interface and it is also characterised by the some metallurgical phenomena such as recrystallization and phase transformation.

Of course, it depends on the composition of the alloying components of the material and temperature because temperature condition at the plastic deformation condition, deformation condition in terms of the stain standard temperature that actually influence the phase transformation as well as the recrystallization mechanism.

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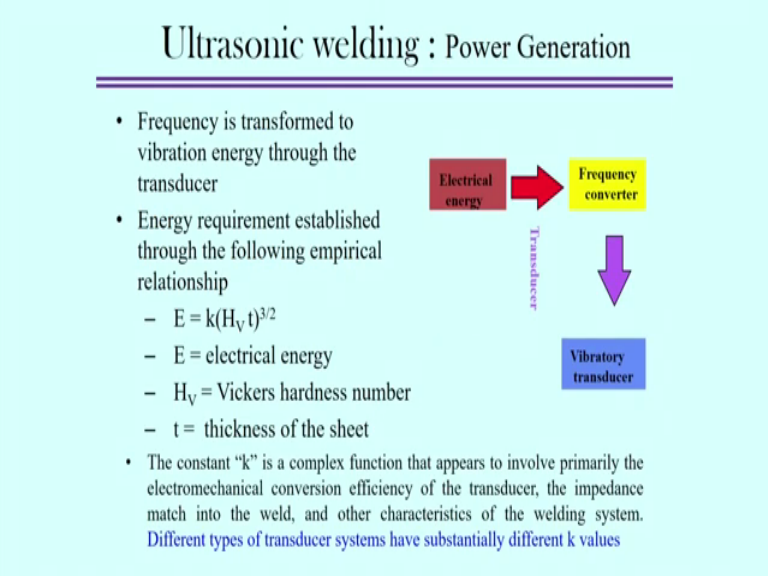

Now, power generation in ultrasonic welding process if we look into that; that actually in this case the frequency is basically transferred to the vibrated energy through the transducer; So, electrical energy source then frequency converter that actually that actually creates the vibrates that actually transfers to the vibrate through the transfer vibrate transducer is its actually creates the vibrating energy.

So, energy requirement in this systems; establish can be established through the some empirical relation if we look into this equation that E equal to that k H v t to the power 3 by 2. So, here E is the electrical energy amount of the electrical energy H v is the Vicker's hardness of the material and t equal to thickness of the sheet.

So, therefore, if you see this is purely empirical relation that is means that electrical energy is basically proportional to the amount of the hardness of the material and the

sheet thickness of the material and this also three by two to that power that power is also constant. So, here the k is the only constant term, but that k is the actual estimation of the k is very difficult because heat actually depends on the so many parameters. It is a complex function of the electro mechanical conversion efficiency of the transducer of the impedance mess impedance match into the weld and the other characteristics parameters that actually involve during the welding process.

So, therefore, different types of the transducer systems having the different values of the k.

So, once if you find out the k we can roughly estimate the amount of the electrical energy actually required for the ultrasonic welding process.

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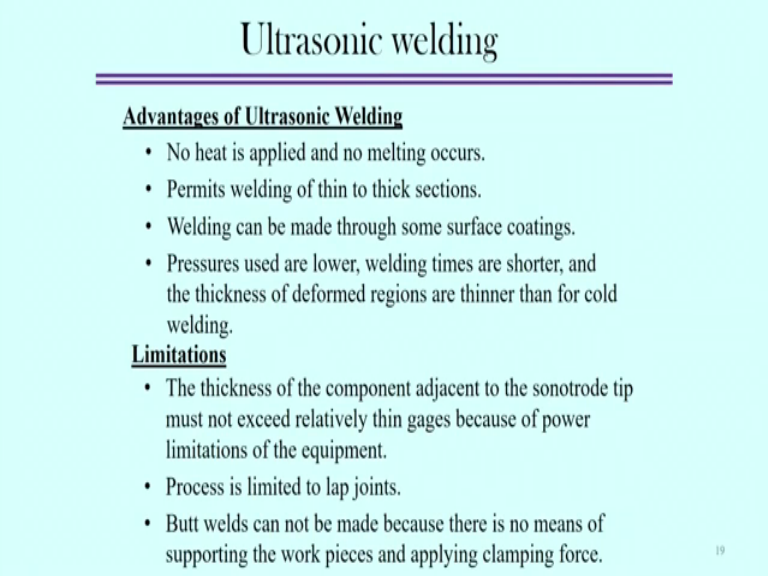

Now, if we look in overall advantages of this welding ultrasonic welding process. So, definitely there is no heat is applied and therefore, no melting occurs. So, that is the one advantage next advantage is that welding of a very thin to very thick section depending by changing the different welding parameters that can be done this is another advantage.

So, that another typical advantage of this process is that the welding can also be done even in material is also having some coating and pressure used normally not very high pressure lower welding types relatively less and the thickness of the deform regions are also thinner than of the cold welding process. So, therefore, the affected zone where the

bonding occurs between the two surfaces that effected zone is very small even with respect to the cold welding process. So, in that sense it is very advantageous process, but having some limitation.

So, of course, very high thickness of the component cannot be welded because there may be some limitation of the sonotrode tip design and that thin gages that there may be the power limitation of the equipment also that actually limits the thickness of the material to be joined using this technology processes limited to the normally lap jointed this process is not possible in case of the butt joint.

So, only lap kind of joint is possible using this technology butt weld can be made cannot be made because there is no means of the because on the supporting work pieces and the clamping forces applications and of course, the contact surface vibrated how this contacted surface is converting the vibrated energy that is also important. So, in that it is not basically possible in case of the butt joint configuration. So, this ultrasonic welding machine is mainly used for the lap join configuration.

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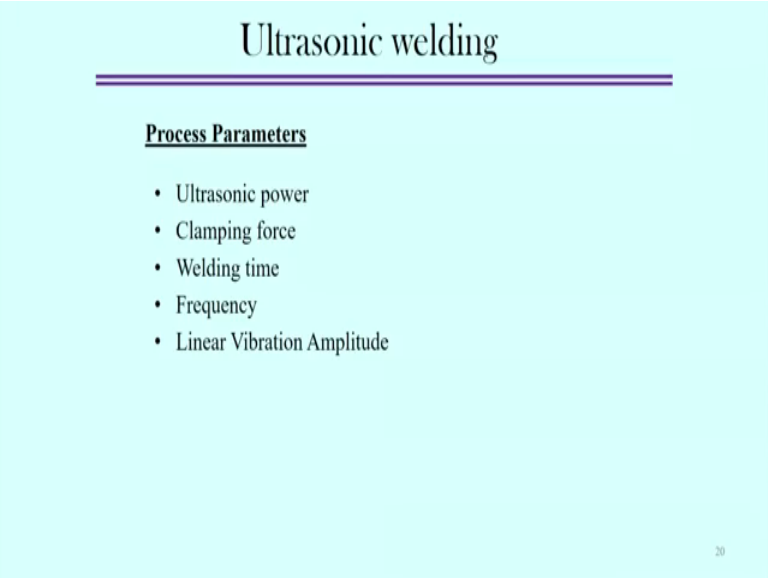

Now, if we look into the process parameters in case of the ultrasonic welding process; we see the process parameters. We can summarize that ultrasonic power, clamping force, welding time, frequency and the linear vib amplitude, linear vibration amplitude; So, amplitude of the vibration that is also parameters in case of typical ultrasonic welding process.

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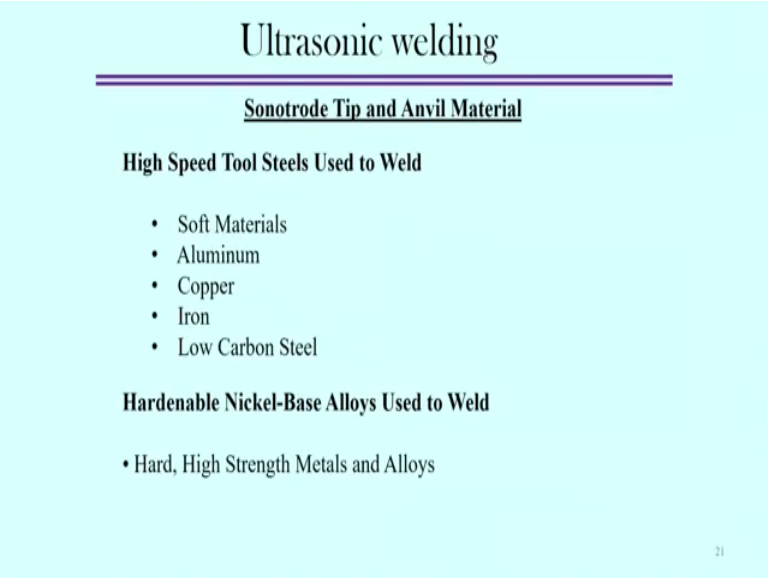

Now, if we look into that in other aspects of the ultrasonic welding process that what are the sonotrode tip and the anvil material we used in case of this welding process. We can see that high speed tool speed steels high speed tool steels; basically used the welding of the soft material other type of soft material apart from aluminium, copper, iron even for the low carbon steel. But if we want to very high strength material and alloy may be the sonotrode tip and the anvil material should be made of the hardenable nickel based alloy is basically used.

So, therefore, if we look into overall structure of the ultrasonic welding process that normally the ultrasonic welding process that in this case, the effected zone weld basically bonding occurs between the two surfaces is very small as compared to the cold welding and this type of welding process is basically mainly used for the lap join configuration, but it cannot be used for the butt join configuration.