Advances in Welding and Joining Technologies
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Lecture - 10
Solid State Welding Processes Part III

Hybrid friction stir welding; so, after conventional friction stir welding processes also having some advantage and disadvantage as well.

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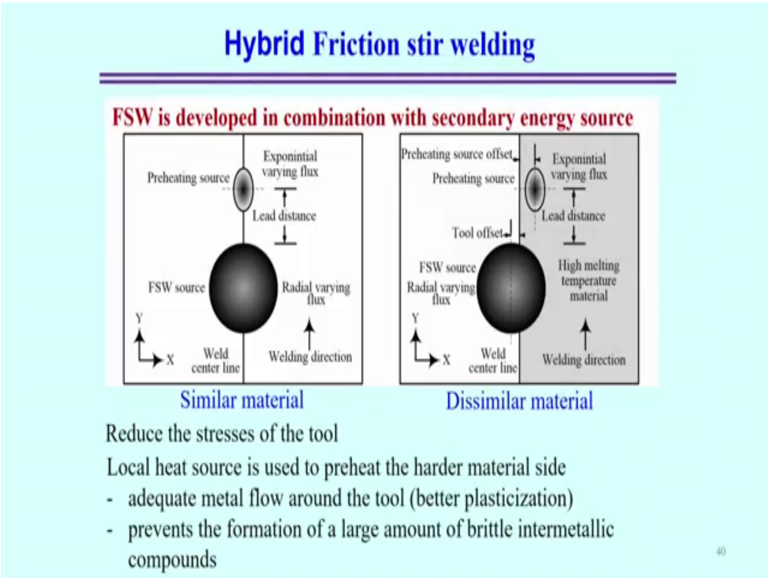

So, modifying the conventional friction stir welding process hybrid friction stir welding process has been developed. So, hybridization means which it is a simple way, by adding some extra heat source with the conventional friction stir welding process that actually brings some new dimensionality that is called the hybrid friction stir welding process.

So, in this case, the hybrid friction stir welding process normally comes into the picture in the by looking into the two different aspects, one is if the material workpiece material is very hard or if the workpiece material is thermal conductivity of the material is very high and both the cases using the conventional friction stir welding process little bit having some demerits of.

So, to overcome that kind of things; so, hybrid friction stir welding has been developed, but hybrid friction stir welding is advantageous specifically for joining of the dissimilar materials because here, there is a scope of controlling the inter metallic formation that is very much typical in case of conventional friction welding processes or maybe I can say the conventional friction stir welding process as well.

So, let us look into how this hybrid friction stir welding looks like? So, here if you see, the FSW is developed in combination with the secondary energy source and here it can be used both for similar as well as dissimilar materials. In similar materials the configuration like is like that, we use the conventional friction stir welding tool; that means, the tool shoulder is in contact with the workpiece surface as well as the pin in depth that is also in contact or steering action of the materials. But, if it is very hard, then if we use some extra heat source that actually basically sharpen the materials and make easier the plasticization of the material and can expect a very good edge joint.

So, in this case, the for joining of the similar kind of materials there is no need of using any kind of tooled offset or maybe offsetting of the energy source. We just straight forward along the weld center line, we can simply put that, secondary energy source and then it helps to joining of the similar materials, but relatively harder materials. Here relatively harder materials in the sense that, normally we define or maybe in general we use friction stir welding process is the softer material for example, aluminum or aluminum alloy and mainly based on welding of this alloy this process was developed and now, it has been advanced to application of relatively very hard material.

So, in this similar material, but if we want to get a very good weld joint in this case which we can reorient the position of the tool or may be this thing external heat source. So, dissimilar materials is problematic welding because of two different thermo physical properties are completely different in these two materials and if, we can reduce the thermo mechanical behavior of the material around the weld zone and with some optimum position of the friction stir welding tool as well as the secondary heat source, then it is possible to get a very good weld joints.

So, that can be done in this way, one it is possible to that friction stir weld tool to offset is any one of the side such that it can controls the volumetric mixing of the two materials and may be some impact on the control of the inter metallic formation. At the same time, since thermal conductivity are very different for this dissimilar combination of the materials, then it is possible to offsetting the secondary heat source or secondary energy source relatively towards the high conductive material for example, if we consider the dissimilar material joining between aluminum and copper, it is better to use the offsetting of the secondary heat source toward the copper side.

So, in general the advantages like that reduce the stresses of the tool, because external heat source actually makes the ease of material flow ahead of the FSW tool. So, that actually improves the stress on the tool or in indirectly the ware of the tool or maybe it improves the life of the tool. That is the main significant advantage of hybrid friction stir welding process. But if you look into that, local heat source is use to preheat the relatively harder material either in similar or dissimilar combination and prevents the formation of large amount of brittle intermitting compounds and specifically for joining of the dissimilar material that are the basic advantage of hybrid friction stir welding process.

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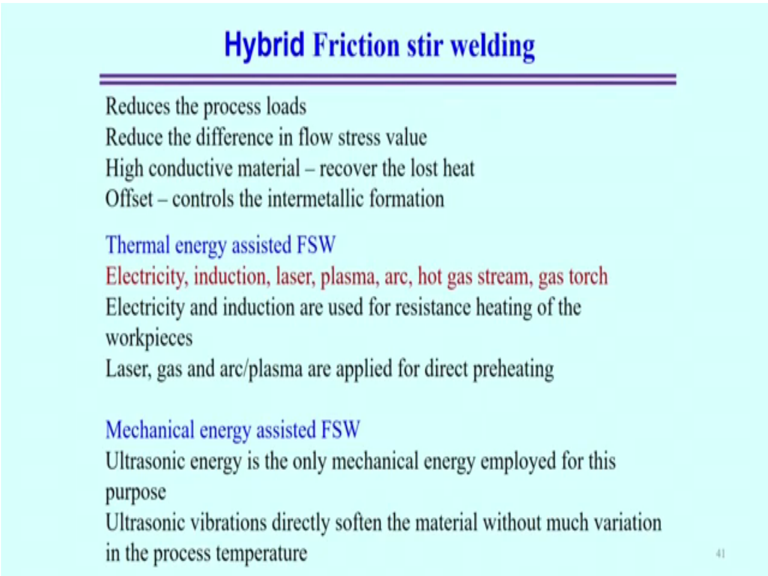

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So, if we look into that, that other what is the main impact of the hybridization of the friction stir welding process is that, it actually reduce the process loads. So, then axial force actually reduces because by use of the external heat source in case of hybrid friction FSW process and at the weld joint this external heat source of course, if we find the optimum combination of the offsetting in the tool offs tool as well as the secondary heat source that actually reduce the difference of the flow stress; that means, it basically makes ease of movement of the tool and in that way, it helps to making a better weld joint at the interface.

High conductive material, if one of the material is very high conductive for in case of dissimilar pair of materials in that case, recover heat; that means, whatever amount of the heat generated heat we will conducted air by the high conductive material that lost amount of the heat can be recovered by using the secondary heat source, that is another purpose of using secondary heat source in case of dissimilar welding process and offset actually controls offset for the FSW tool that actually controls the electronic material furnaces. So, these are the basic advantage of impact of the friction stir hybrid friction stir welding process.

But, the secondary energy source can comes from this from two different two different way, one is the thermal energy assisted FSW other is the mechanical energy assisted FSW. So, thermal energy FSO; FSW the secondary source can be using some electricity, some induction, some laser, plasma, arc, hot gas flow or stream or gas torch that can be used as a secondary heat source, but in this case, the optimization parameter is very much significant because finally, the maximum temperature within the system should not cross the melting point temperature.

So, therefore, carefully using of the secondary heat source helps in case of thermal assisted friction stir welding process. So, the electricity and induction are used for the for basically resistant heating of the sample, and laser gas or plasma source can be directly used to the substrate material for the preheating of the material. Mechanical energy assisted FSW that only the ultrasonic energy is only the source of. So, far has been developed for the mechanical energy employed for the purpose of the hybridization of the friction stir welding process. Actually ultrasonic vibration directly soften the material by converting the mechanical energy and without much variation in the process temperature. So, that is the basic advantage of using some ultrasonic source, ultrasonic energy in FSW processes.

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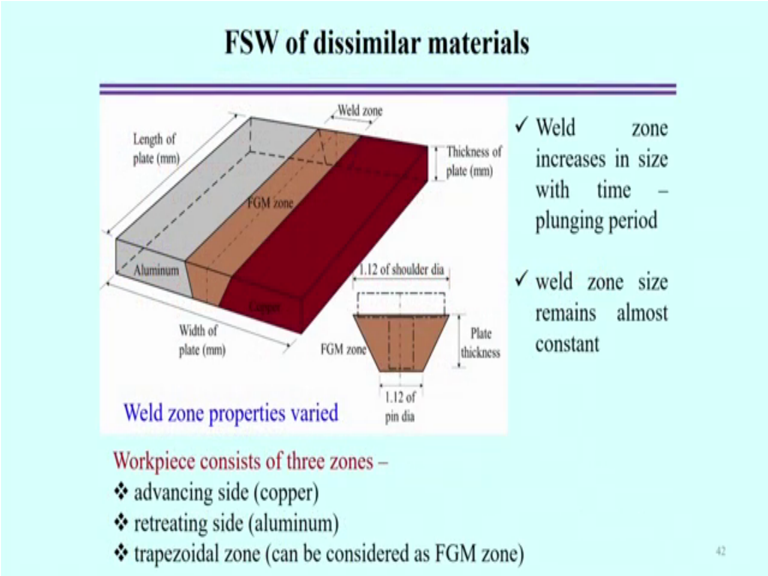

So, apart from the different technology or different FSW hybrid FSW process; so, now, if we look into that, specific to the friction stir welding of the dissimilar materials, what are the typical properties we observe and dissimilar welded materials? In this case, we considered an example of joining of aluminum and copper.

So, from the figure if we see that retreating advancing side is in copper and retreating side we generally put the aluminum and exactly there is another trapezoidal zone and that trapezoidal zone can also be considered that once that zone corresponds to the functionally graded material because at this point, there is a mixing of the aluminum and copper exists in between these two.

So, when we try to try to analyze the hybrid friction stir welding process, we can divide the three different zone and we can do the further analysis of that. So, here direct formation of the functionally graded zone actually depends, its actually transient in nature in the sense, because which if you look into the friction stir welding process the initially the plunging depth.

So, which start from time t equal to 0 and gradually put the along the dip direction the pin and that is in transient in nature and then after plunging then we put some dwell period also and during the dwelling in dwell period, the more or less the size of the functional engine can be decided and then after that, if we move forward ; that means, using some welding speed, then if it creates the weld zone, but that weld zone is more or less uniformly from; that means, at specific point, the cross section is uniform and it gradually moves along the y direction.

So, that’s why, where initial this transient in nature and weld zone almost remains constant during this process. So, here if we see, the typical that and the size of the functionally graded material zone is like that, 1.12 of the shoulder diameter in the upper side, the lower said 1.12 of the pin diameter; that means, just above the diameter of the pin spin size and diameter of the shoulder side and the and the upper side, that actually more or less creates that is the shape is like a triangular. So, this to analyze the hybridizations of the friction stir welding process specifically for dissimilar material. So, they create this kind of different kinds of the zone.

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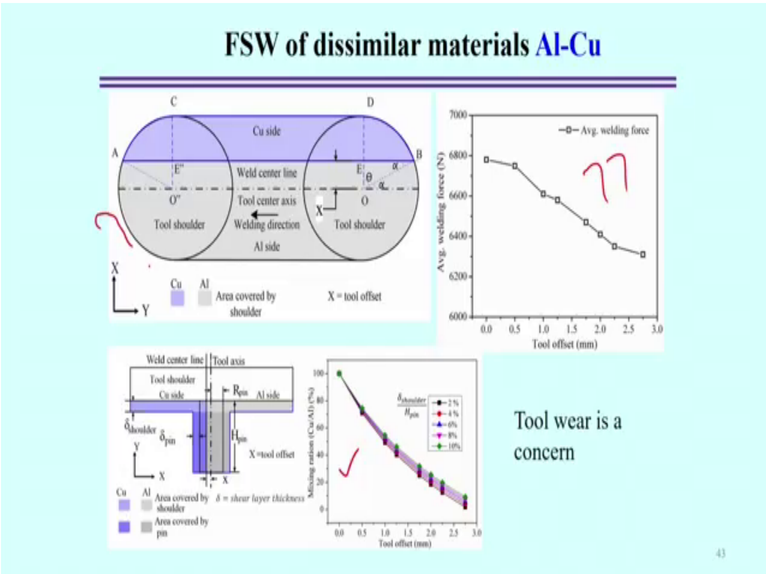

Now, we can we do in the further analysis of a FSW of dissimilar materials we can see that, first figure shows this figure shows, that highlighted part in the; that means, if we put the tool opposite towards copper site; that means, when this the mixing volume ratio during the friction stir welding process between copper and aluminum that actually as a function of the tool offset. So, if we increase the tool offset; that means, volume ratio of sorry volume of the aluminum is generally increases and, but as compared to the at the same at the same time, there is a reduction of the volume during at the mix at the mixture of copper reduces.

So, that actually in that control by the amount of the tool offset. So, this way, the looking into the volumetric mixing that mixing ratio if we look into this figure, that mixing ratio the copper by aluminum that actually at the when the tool offset equal to 0 ; that means, 100 percent; that means, ratio is 100 percent; that means, equal volume mixing exist at the tool offset of 0.

But, when the tool offset increases and it raised to around 2.5 tool offset 2.5 millimeter. So, the mixing ratio actually decreases; that means, there is a variation of the mixing ratio. So, this way, it is possible to control and roughly we can estimate, this volume mixing ratio and that that actually we can correlate the amount of the inter metallic compound formation just by simply controlling the amount of the tool offset. Also at the same time, here if you see, there at the same time with a increasing of the tool offset. So, here the tool offset is provided towards the copper side; that means, the tool is subjected to more resistance with the softer material as compared to the harder material.

So, in that sense, the amount of the axial force required decreases with increasing of the tool offset because at the high tool offset, very small a part of the copper side is in intact with the or contact with the tool as compared to the aluminum side. But, whatever the tool we can use in general the welding of the whether similar material or dissimilar material, the wear of the tool is the major concern and that is the main component of the main concern of the application of the FSW process.

So, of course, the in general, the hardness of the tool should be much higher as compared to the workpiece material and based on that, there is selection of the tool and then accordingly, the characterization or measurement of the wire during the friction during the FSW process that is, the one direction of work that is that needs to understand to completely find out the impact of the tool wire on the in general on the FSW process and their commercial use of that process.

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Even a like other welding processes, also friction stir welding process also can create some defects, but that defects comes from mainly the improper choice of the parameter. So, extensive experiments are required to find out the process map of a successful weld joint. But, if you look into that, FSW process also we can see that different type of a depicts can form, one is the due to the reason of that improper material flow and heat generation. If heat generation are not proper and crop the material is not very in certain part of the friction stir welding zone, if there is not sufficient material flow that also create some amount of the defect.

And that defect is also influenced by the tool rotational speed. So, mainly tool rotational speed is the one most significant parameter that directly impact on the formation of the defect. So, normally tool rotational speeds speed is very high to keep in ensure that the sufficient amount of the heat generation during the interaction of the tool pin and tool shoulder with the workpiece material.

Then tool traverse speeds, the welding speed is too high that also create some kind of the defect that's why, we can keep the very low traverse speed we can ensure the low welding peed can be ensure the chances of reducing of the defect in friction stir welding process.

Improper tool geometry selection; so, geometry is also another important parameter that actually impact on the formation of any defect. Sometimes, the straight lengthy colored tapered tool without any thread, can cause the material flow. So, in that sense, adding of the thread on the tool pin profile can increase the material flow or material mixing. So, in that sense, that geometry of the tool is also another important parameter and of course, that if their size of the pin optimum size of the pin is also required; so, that we will be able to plasticize the certain part of the zone. So, that it will be able to create some good zone weld bonding between the materials.

So, insufficient plunge depth is that that make a cause also welding defect. So, if plunge depth is not almost up to the end of the bottom of the tool, that can create some problem also and you can thickness of the joining material. So, when there is a two different thickness material in butt joint configuration edge joint. So, in that case, it difference the thickness are different. So, they are they the mixing of the and then finding the optimum size of the tool is a important parameter is an TDS job.

So, in that sense, they can create the defect if there is a improper size of the pin. So, that is also another difficulty of joining and there is a chances of produces some kind of the defect when you try to join the two different thickness material and gap between the plates also impact on the well the defect formation in the weld joint because, if gap between the plates is too high then the material flow may not cover up the gap. So, the if it is if it is possible the optimum gap or may be as close as possible to put the two material is helpful to produce the weld joint without any defect.

So, this with this, we can conclude that friction stir welding process it is a it is the one of the most significant development in resenders happens and so, much of work is going on friction stir welding process and now the list the direction of the work is going on. The joining of the review hard material using the friction stir welding process or the only reason behind this is that this since this is a solid state process, so chances of a formation of the other metrological or defects that normally happens in the fusion welding processes. But still, for the several material aluminum or other little softer material the this friction stir welding is an well established process.

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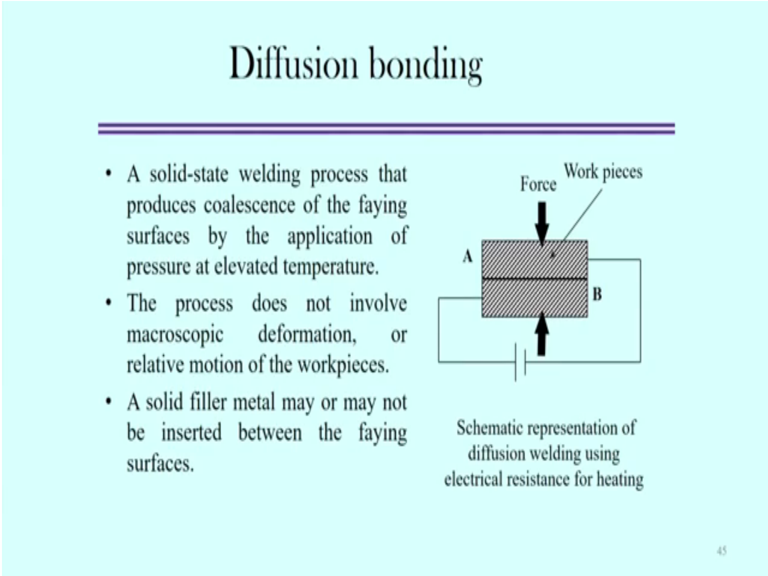

Now, come to the next topic that is the diffusion bonding. This is the another kind of bonding solid state bonding mechanism. So, diffusion bonding is a solid state welding process. So, in this it these cases, that coalesces of the two faying surface happen by the application of the temperature and pressure. By the application o pressure, but under the environment of elevated temperature that is a favorable condition to produce the a diffusion bonding between the two surfaces.

But the process, when you conduct this process, diffusion bonding between the two surfaces that actually does not produce any macroscopic deformation, but microscopic deformation deformations happens and there is there is not require any relative motion between the workpiece. So, these are the criteria based on that we can join the two surfaces. This technology or concept is very old, but till it is a very effective process. Sometimes, solid filler material can also be used may or may not used, between the faying surfaces. So, right hand side will show the schematic figure of the diffusion bonding, that we can see that two different materials A and B. There is the application of the force and at the interface it is necessary to produce some amount of the heat generation.

So, here electrical resistance can also be used to generate the heat at the thing surface so that two surfaces can be joined if you look into the bonding mechanism, in case of diffusion.

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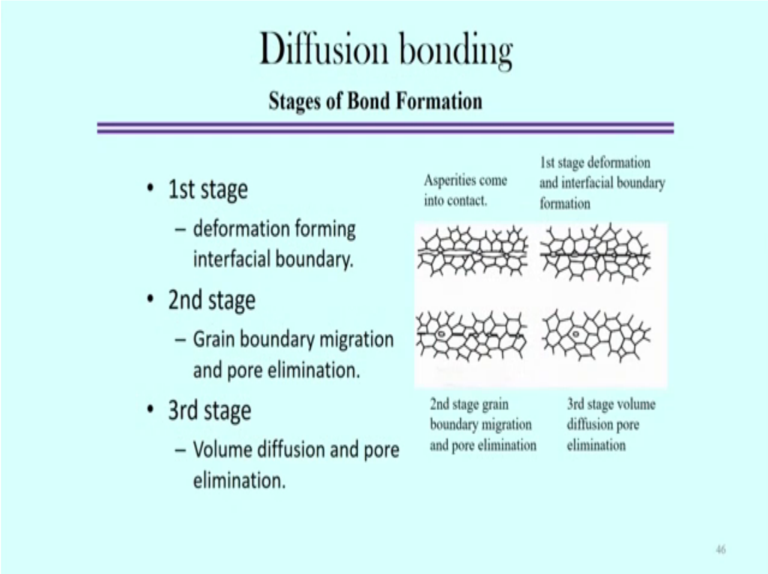

So, we can see, that first stage is the deformation forming the interfacial boundary. If you see, if we see, this is the actual contact when the two surfaces come into the contact they are in contact with the; to the asperities between the into the contact. So, that there may be some gap between the asperities.

So, then to make it flat, there is a necessary to app to the application of pressure, application of the force; so, the first stage, the deformation interfacial boundary formation with the application of the force. Second stage, the grain boundary migration and the pore elimination the grain boundary migration; so, in there is a two surface are in contact, if we assume that, that a contaminated layer or oxide layers are removed. So, in that sense, in after that, there comes the second stage grain boundary migration can happen and that there is a bonding form and between this two surfaces and third stage then overall bulk volume deformation happens and the pore elimination it is looks like a it is a continuous surface. So, this is a continuous structure. So, that is the third stage and diffusion pore elimination that is the substrate is the stage volume diffusion and pore elimination we can clearly see from the figure.

So, this is first stage, second stage and this is the third stage. Here, we can in each to mention also, that diffusion bonding the condition is that, when you it is the it is a successful welding mechanism, but, but if it is possible to remove by any contaminated oxide layers between the contact surface, then it is a very successful weld joint and it is a very good weld joint and here, only the process condition; that means, process parameters is only the application of the force and over a certain time over a long time normally, over a long time and sometimes, at the same time, there is a generation of the heat is also required between the surfaces. These are the typical condition for the diffusion bonding of the materials.

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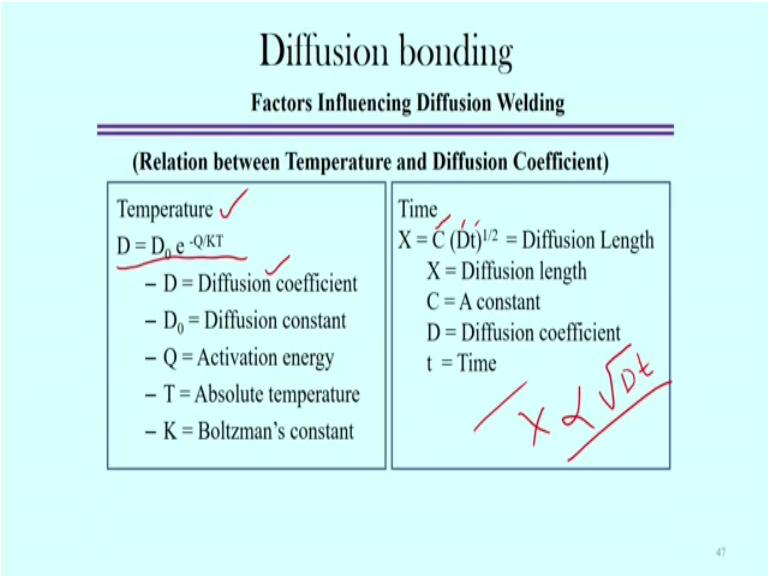

Now, if we look into that, which are the factors that actually influence the diffusion bonding; diffusion welding process? You can say that, its needs to be two things are there, one is the temperature and time how to elect in this process. So, temperature in the first case, if we see that D equal to D 0 exponential minus QKT. So, D is actually Diffusion coefficients and we can see the D Diffusion coefficient is very strongly that coefficients value is very strongly dependent on the temperature.

So, that is a function of temperature. So, D 0 is the diffusion constant independent of the temperature and normally we can assume that, diffusion constant as a room temperature and then it the value actually values with the exponentially decaying nature as a function of temperature. Here you can see. So, D 0 is the Diffusion constant, Q is the Activation energy to start the thermally activated process and then T is the Absolute temperature and K is Boltzmann constant. So, with this nature, the diffusion coefficients actually varies.

Now, we can roughly estimate that, what is the depth or length? What extent the diffusion bonding mechanism works basically? . So, that is X and that is a function of time also. So, here you can see the C is the A constant, D is the Diffusion coefficients and T is the Time and it is depends on actually X is proportional to, basically depth is very much proportional to distribution coefficients and time. So, here X Diffusion length or depth, you can see C is the one constant and D is the Diffusion coefficients and T is the Time.

So, based on this equation, we can find out the of course, if we want to get the desire depth of penetration, then we can back calculate, what is the time required for that? and of course, if we know that, what are the temperature varies within that surface? then only we can decide that, what is value of the distribution coefficient? . So, they are these two parameters are the mainly the just simple calculation these two parameters are required in case of the diffusion welding.

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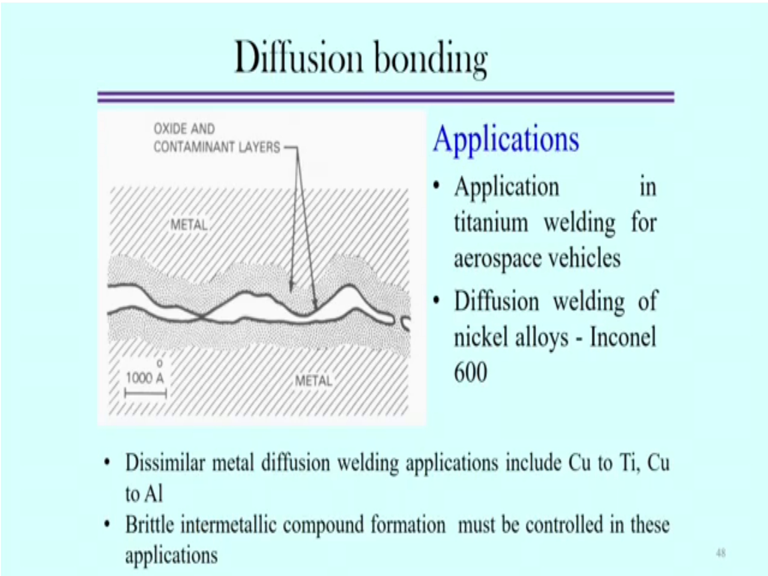

Now, as mentioned that, if you look into the picture, the two surfaces this is the typical configuration of metallic surface, that oxides and contaminated layer exists in the surface which is there and then these contaminators for the diffusion bonding to be successful this contaminates contaminated layers should be removed .

So, that pure metal to metal contact will be there and then, then diffusion mechanism will be very strong when there is a direct contact metal to metal without any metallic or contaminated layer. So, that is the only concern of a diffusion welding or diffusion bonding process. Application; we can find out the numerous application find the diffusion weld in process, application in the titanium welding for aerospace vehicles. So, titanium bonding basically which metal is very difficult or very hard material is very difficult to do weld in other processes it is a in that case, probably the diffusion bonding is the another alternative method and to get a good weld joint.

Ah second one is the diffusion bonding of the nickel alloy nickel alloy also that in for example, Inconel 600. They are also used for the diffusion bonding as well and sometimes dissimilar metal combination diffusion welding application copper to titanium, copper to aluminum, to do the dc by looking into the dissimilar welding mechanism we can join, this dissimilar combination of the material. But, even further for dissimilar material, the main concern is the inter metallic compound formation and that must be controlled in this application.

So, in that sense, because the normally diffusion bonding mechanism normally takes very high time, time requirement is very high and that we generally keep work this as a constant as a const as the pressure constant pressure for a long time and during. So, in that during that time, there is a high probability or may be probability is very high because time for the formation of the inter metallic for the formation of the inter metallic compound because of the lengthy of the time.

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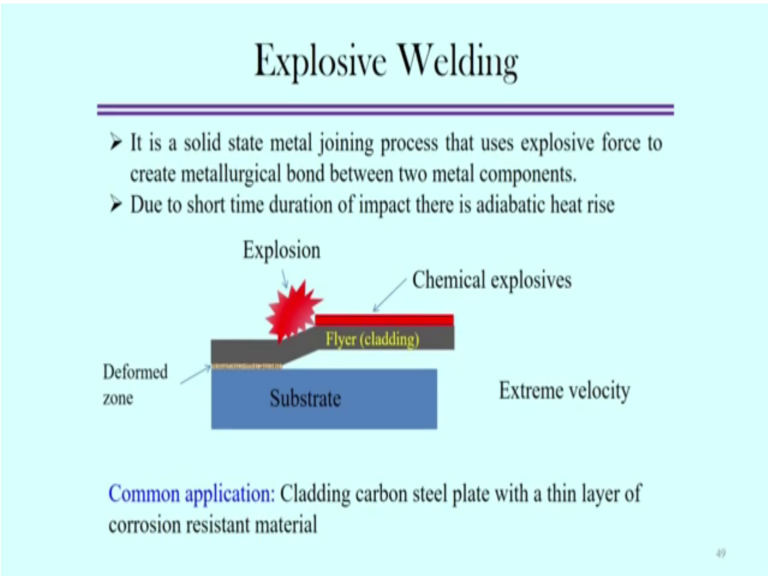

Now, after diffusion welding, we look into another non conventional welding process that is called the explosive welding process. So, in explosive welding process, it is also a solid state welding metal joining process and simply use the explosives, but in a very controlled way. So that, that explosive can create high impact of the one metal to another metal and then finally, creates the methodological bond between the two surfaces. So, that is the basic principle of the explosive welding and ah, but the time duration or time requirement is very short during this process. It as opposed to the diffusion bonding in this case, the time requirement is very high to join the two surfaces.

And since time requirement is very within the explosive happens the high red deformation happens over a short period of time. So, normally whatever heat is generated that is in adiabatic, not having the sufficient time to diffuse air or to convective air. So, if we look into the basic mechanism or basic process of the explosive welding from the figure here you can see, that, the one substrate metal is there and then flyer we use that that flyer we are supposed to join that flyer with the substrate material by control use of the explosives.

So, normally, the layer this layer substrate material, then flyer and then chemical exclusive normally in terms of powder, we can put layer by layer. Now, if we can start from the one side the explosion, then it gradually start the using the chemical explosive and creates the explosion throughout the surface. So, from it starts from this point and creates the explosive and then up to that one explosive, explosion happens and then two surfaces are joined and the in between there is a high deform zone. So, that deform do not create and that actually joined the at that point, the substrate and the flyer are joined.

So, normally, normally the most common application of this expressive value we can find out the cladding carbon steel plate with a thin sheet of thin layer of the corrosion resistance material. So, some you can use the stainless steel also as a corrosion resistance material so that we can find out the common application of that.

So here, this red color actually indicates the Chemical Explosive that is arranged and then Explosion keep on going and moving in direction. So, that the joining between these two surfaces happens continuously.

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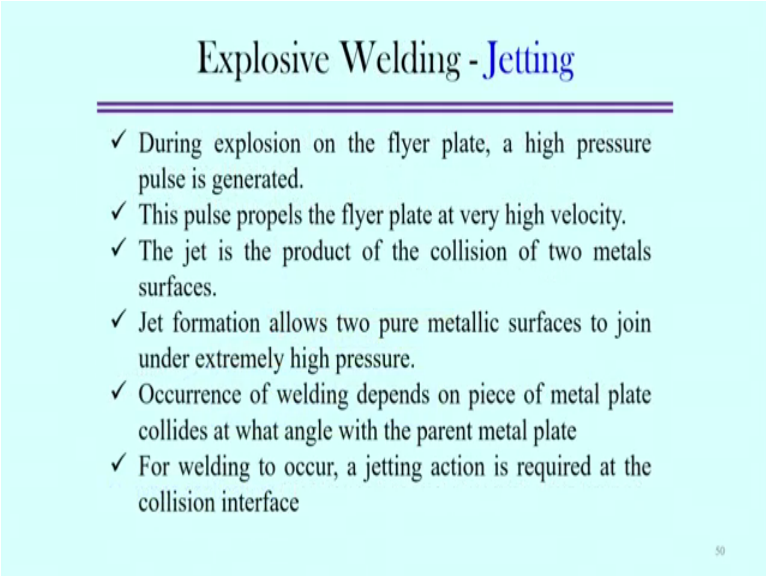

Let us look into that other aspects, the most significant aspects of this joining mechanism and express that that absorbing explosive welding that is called Jetting.

So, Jetting means during the explosion on the flyer plate, flyer plate the high pressure pulse is generated. So, during that explosion there is a high pulse pressure is generated and this pulse actually propels the flyers plate at the very high velocity, and the jet is then produced of the collision of the two metals, two metallic surfaces and the jet formation is normally allows the pure metallic surfaces to join under extremely high pressure so; that means, there is a high pressure pulse is generated during the explosion and that is responsible for the creation of the Jetting.

Now, the welding whether you can say the welding depends on the piece of the metal plate that collides at what angle with respect to the parent metal plate. So, that angle is also important and that that is related to the Jetting mechanism. So, for welding to occur, a Jetting action is required at the collision surface, then only the weld can form. We can see, that what is the process geometry of explosive welding see the parallel plate bonding is used for the large plate.

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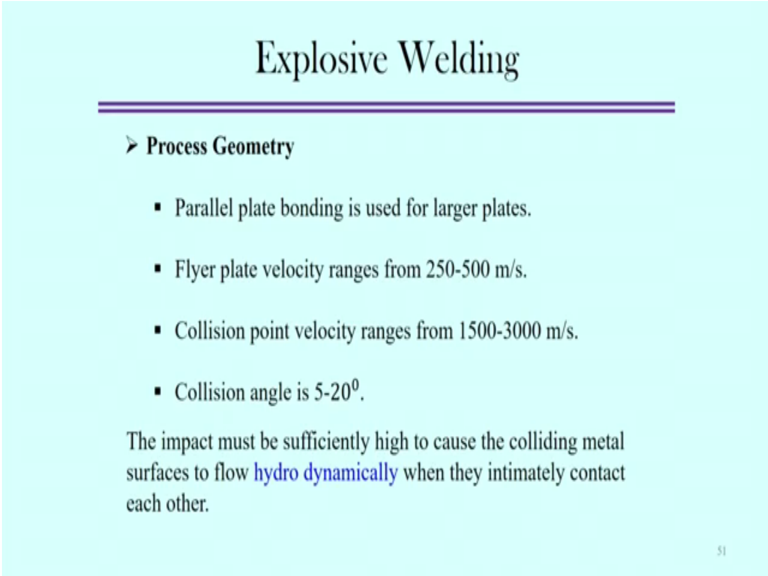

So, for the large plates to parallel plates can be used and then flyer plate velocity range from 250 to 500 meter per second, that is the flyer plate velocity and exactly at which point and with the application of the explosives that, collision point velocity ranged from 1500 to 3000 meter per second. That is very huge velocity and then angle is also an important parameters. The angle is around 2 to 20 degree.

So, the impact must be sufficiently high, to that's, to cause the colliding material surfaces to flow, hydro dynamically, when the initially contact, when they are intimately contact with respect to each other. So, that hydrodynamic flow of the material during this actually occurs and then only, welding will occur. If we look back to the picture also that. So, here if you see, that this deform metal, only the deform metal this part and this is a substrate material.

So, this, this is normally thicker as compared to the substrate material and if we create the explosive it is a directly join with this substrate material. So, that there is a, but this process happens is very small period of time and then, after joining these things, this can be compared it is a like a cladding process, just one layer is attached with the substrate material. So, that cladding layer normally, we can use the some that having the corrosive resistant material.

So, that that mean that way, it is used or you can call it as welding process explosive welding process; so, if you see that, these are the typical parameters of the explosive welding process.

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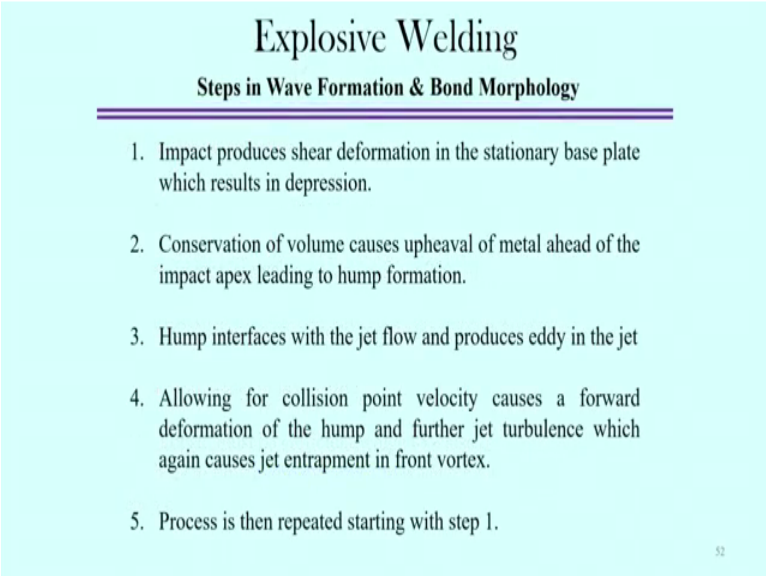

Now, steps in the weld formation and the bond morphology, first is the impact by the explosive actually produces some shear deformation and that shear deformation in the stationary best plate which results is actually depression.

So, that it causes in such a way, that it actually creates the kind of hump, during the using continuous use of the explosive or the explosive that explosion actually moves one certain direction and then, there is a kind of hump and the join and then hump interfaces with the at the same time, when the hump interfaces with the jet flow and that actually produce some kind of the eddy in the within the in the jet. So, that creates actually the collision point velocity, concerns a forward deformation of the hump and the further jet a create some turbulence which again causes the jet entrapment in the front vortex.

So; that means, this is a complex phenomena with the application of the faying surface kind of hump. At the same time, there is a jetting phenomena at the interact with respect to each other and create some ready and or so, of course, that I have seen impact on the jet turbulence as well.

So, these are the typical steps and then after doing all these things then finally, it creates the bonding mechanism between the two surface. So, it is a simply the mechanism is the basic high strain rate plastic deformation of the metals and that is responsible for the bonding between the two surfaces.

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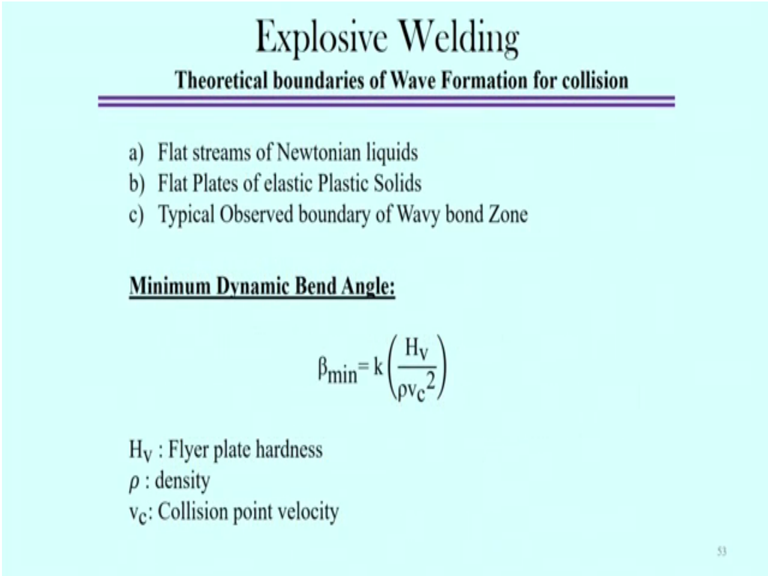

So, explosive welding, if we look into the theoretical aspects of the weld formation and the collision we can find out some simple calculation for that. That we if we assume the Newtonian liquids that flow streams of a Newtonian liquids and then, we can assume that the Flat Plate of the elastic Plastic Solid and then, we can typical observed boundary Typical Observed boundary Wavy bond Zone.

So, at the boundary, we can say not very straight zone it is a kind of Wavy bond Zone we can find out on the boundary between the two surfaces and here, the angle the dynamic bend angle that is also important parameter. So, we can empirically estimate the dynamic bend angle like that b beta mean equal to k Hv by rhos vc square. So, the Hv is the Flyer plate hardness. So, the beta; that means, that angle dynamic bend angle depends on the hardness of the flyer surface or directly proportional to that and also, at the same time, it depends on the density of the flyer surface as well as the Collision point velocity

So, velocity is also another important parameter, hardness and density. These are the parameters that actually decides the amount of the bend angle and this is empirically and definitely k is constant here.

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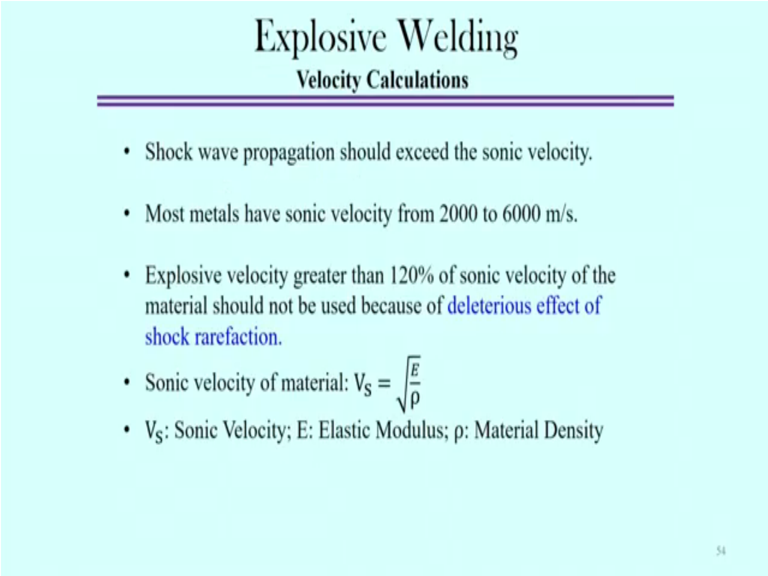

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So, velocity calculation can also be done, that shock wave propagation, the in the principle during the process is that, that shock wave propagation should exceeds the sonic velocity means the, what is the sound velocity within that medium? That means, with the that metal. So, it should shock wave is shock wave should propagate more faster than that of the sound velocity.

So, mores most metals have the sonic velocity from 2000 to 6000 meter per second, that is the data and explosive velocity is actually greater than 120 percent 120 percent of the sonic velocity of the material also should not be used because, if the explore that definitely the shock wave propagation velocity should exceeds the sonic velocity, but it should not exceed the 120 percent of the sonic velocity because, at this point, the deleterious effect of the shock reification may also happen in this case.

So, sonic velocity of the material simply we can calculate the simply square root of E by rho; that means, E is the Elastic Modulus, rho is the density of the materials and Vs is the sonic velocity. So, these are the typical velocity estimation can also be run.

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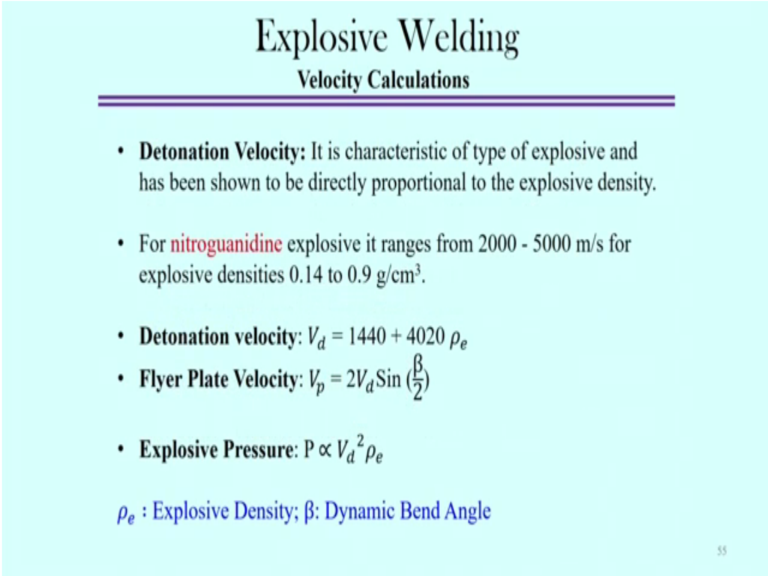

Other component of the detonation velocity it is also one kind of characteristic type of explosive. A characteristics type of explosive has been shown to be directly proportional to the explosive density. So, detonation velocity is exactly depends on the density of the exp density of the explosives.

So, for I think a nitro guanidine explosive it ranges from 2000 to 5000 meters per centigrade. This is the one type of explosive in this case, the velocity actually ranges from 2000 to 5000 meter per second and the density is around 0.14 to 0.9 gram per centimeter cube.

So, using this; a specific explosive the detonation velocities around we can empirically relate the 1440 plus 4020 into rho; that means, we can see, that, it actually depends a linear dependence of this exp Detonation velocity is a linearly dependent on the density of the explosive.

So, Flyer Plate Velocity can also be estimated from here also and here you can see that, Vd that flyer plate velocity is also depends on the Detonation Velocity and sin beta by 2 and beta is the that angle we can we have just calculated that beta equal to the minimum dynamic bed bend angle. So, beta is the dynamic bend angle. So, we can put the beta if we know the beta value. So, then we can find out that flyer plate velocity, this is the just some analytical estimation of this the order of velocity we generally find out in the explosive welding process. So, Explosive Pressure also depends on the that Flyer Plate

Velocity and the density of the explosive. So, these are the typical calculation, we can in case in case of explosive welding.

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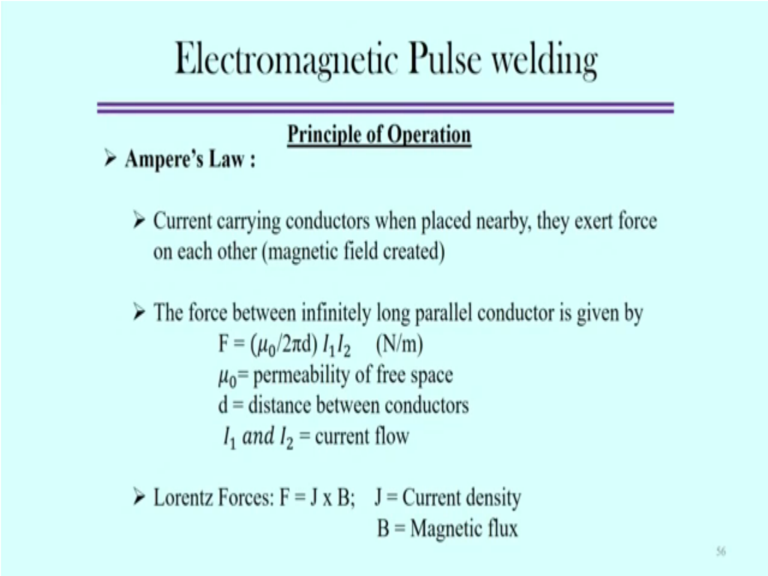

Now, we come to up another non conventional welding process, once you can say the Electromagnetic Pulse Welding process and in this case, the Electromagnetic Pulse Welding process Ertz law Ampere's Law used and they because, the if you current carrying conductors to use it then there is a magnetic force actually force field actually created with the application of the current field.

Now, if we know, this know that the force between the two infinitely long parallel conductor is given by F equal to mu 0 by twice pi d i 1 i 2. Actually, the mu 0 equal to permeability of the free space, d distance between these two conductor and i 1 and i 2 is the current flow. So, based on that, we can find out the force between these two parallel conductor. So, then if we applied the Lorentz Force, that is F equal to the cross product of the current density as well as the Magnetic flux vector.

So, based on that, we can find out the Lorentz Force. So, that; that means, Electromagnetic Pulse Welding means, just throwing up the electro current and there is a magnetic force field, but if we can use, that magnetic force field actually depends on the current density and the Magnetic flux.

So, these principles are producing the magnetic force field and that can be used in a controlled way. So, it is possible to develop the welding that based on that, the development of the electromagnetic power setting has done.

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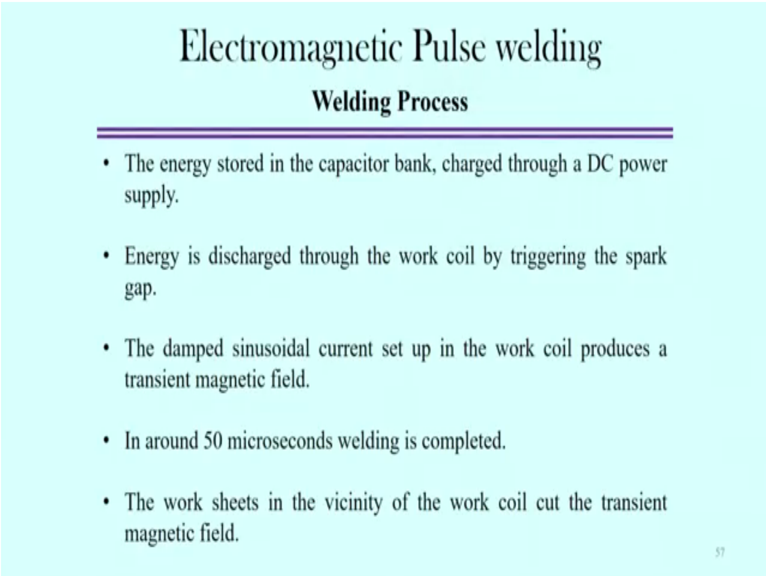

So, here if you see, the process welding process the energy the normally in the Electromagnetic Pulse Welding process the energy stored in the capacitor bank and then charged through a DC power supply. Then energy is discharged through the wok coil by triggering the spark gap and then damped sinusoidal current set up in the work coil produces a transient magnetic field. Because, that's why, here with the application of the current field itself it is can create the transient magnetic field and that transient magnetic field is basically created around very small time span around 50 second and this, this is sufficient to produce the joining of the two materials.

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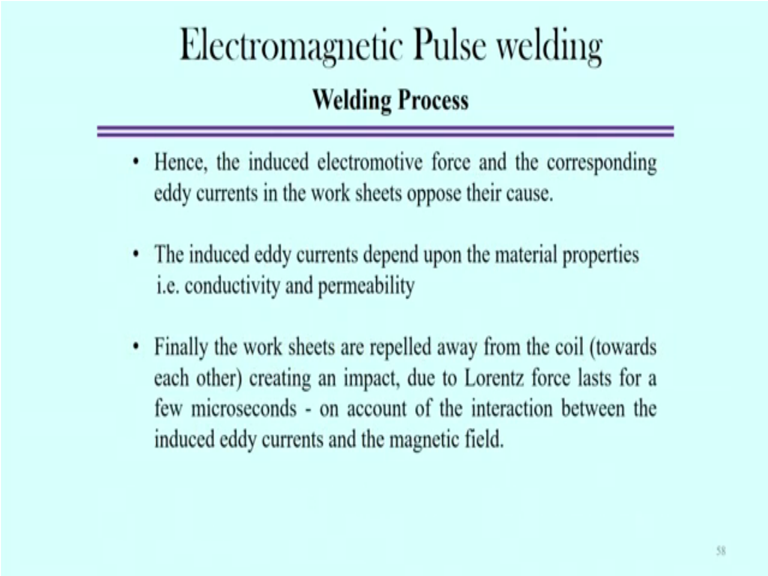

But, if we see, that transient magnetic field is responsible that here the induce electromagnetic force and the corresponding eddy currents in the work sheets, oppose their causes, oppose their causes and therefore, the induced eddy current actually depend upon the material properties and; that means, conductivity and permeability of the material and based on that, the induced eddy current actually developed.

Finally, the work sheets are repelled with respect to the away from the coil, towards with respect to each other and then creating an impact due to the Lorentz force and that happens over every few microsecond. So, therefore, on interaction of the on account of the interaction between the induced eddy current and the magnetic fields, all actually this impacting of the one metal to other metal actually happens and that happens over the very short period of the time.

So, therefore, you can see, that like explosive welding also the electromagnetic welding also happens it is a very small period of time, the bonding mechanism is that.

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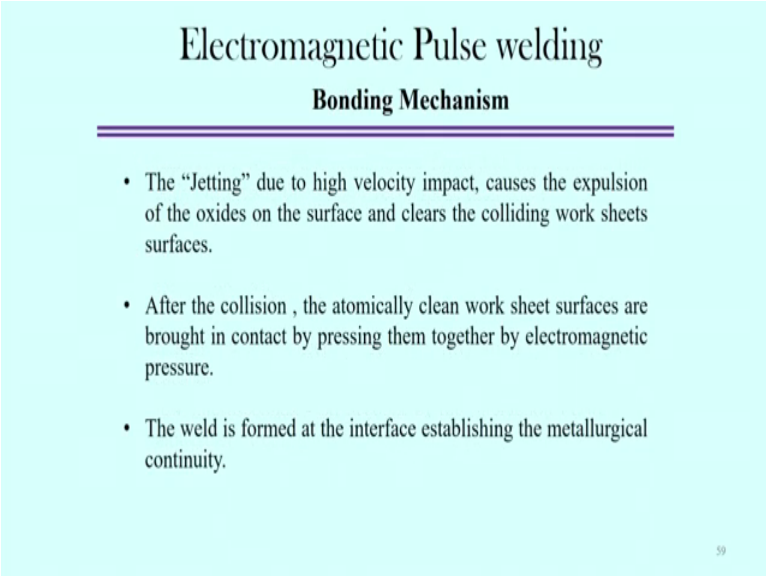

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Here also, Jetting action occur due to the high velocity impact and causes the in that high impact, but at the time, the expulsion of the oxides layer and contaminated surfaces that first clears and then, then after that, sheet metals can be joining. So, after the collision, the automatically already clean work surface come into the contact and they can contact is very high pressure and then, they can join by this electromagnetic pressure. So, therefore, the weld is formed at the interface by establishing the metallurgical continuity.

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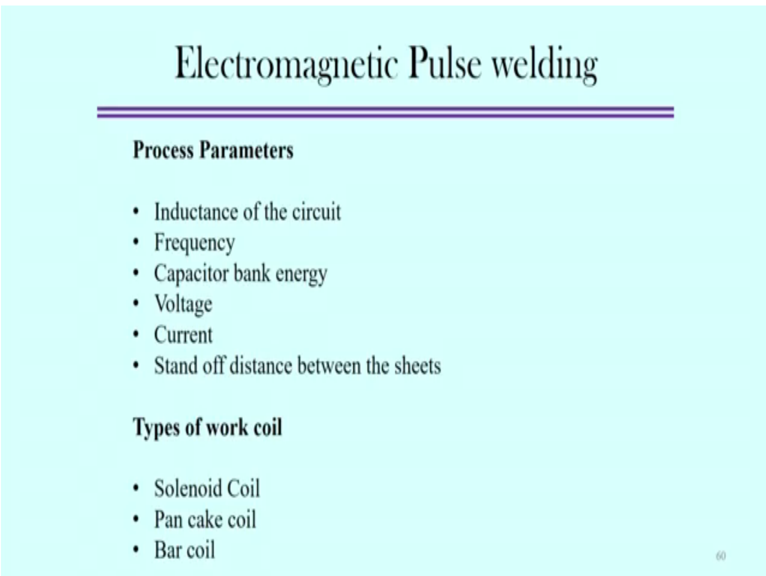

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So, what are the typical parameters for Electromagnetic Pulse Welding?. The Process Parameter that inductant inductance of the current that is the one significant parameter, Frequency, Capacitor bank energy, Voltage, Current and the Standoff distance between the sheets. So, you can say, the Electromagnetic Pulse Welding is more suitable for normally we can join between the very thin sheets because, then because the creation of the electromagnetic pulse or sorry electromagnetic force filed over a time that also having some limitations.

So, therefore, in practically, we generally use the electromagnetic pulse welding for joining of the sheet, two different sheet and we can use also, the two different geometric configuration; that means, two different sheet pipes. So, normally thickness of the pipes is less. So, that can also be joined using the electromagnetic pulse welding.

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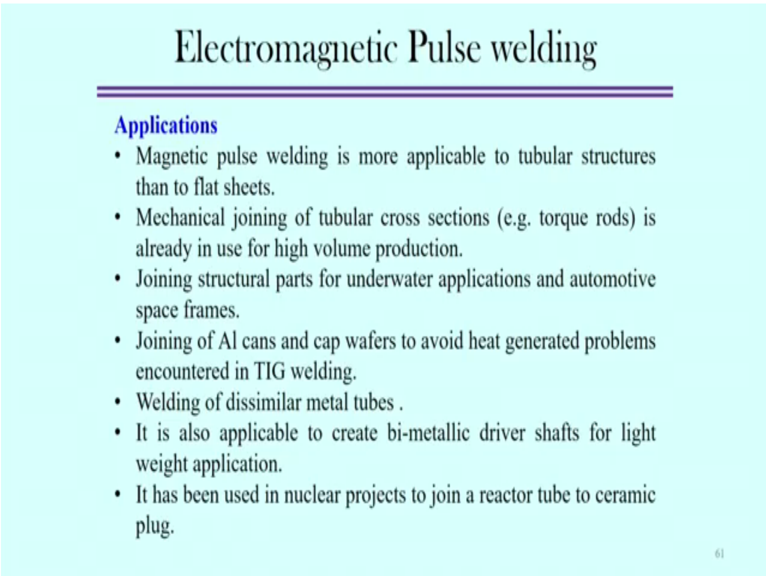

So, application we can find out, Electromagnetic Pulse Welding that, magnetic pulse welding is use more applicable to tubular structure than the flat sheets. So, tabular structure is more useful to joining using this Electromagnetic Pulse Welding.

So, mechanical joining of the tubular cross section, the tubular cross section and i torque mode, torch rods is also already in use for the high volume a production. So, therefore, joining of the tubular cross section already implemented the electromagnetic pulse welding process. Normally, this process is very much suitable for the underwater application and automotive automotive space frames. Joining of aluminum cans and the cab wafers to avoid heat generated problems that actually encountered in the other TIG arc welding processes.

So, in that case, the Electromagnetic Pulse Welding is very advantageous. This is also one thing is that, in Electromagnetic Pulse Welding that helps we need the electric current. So, it is also one kind of we can say that it is a green technology because it is there is a no fumes no gas produced during the process itself and it is a environment friendly process as well.

So, this process can also be use welding of dissimilar materials also or specifically dissimilar tubes. Bi metallic materials can also be join and specifically light weight. So, normally this process has been developed for softer aluminum based alloy for Electromagnetic Pulse Welding. And of course, it is having some nuclear projects to join, reactor tube to ceramic plug in that, particular application we can find out the Electromagnetic Pulse Welding process.

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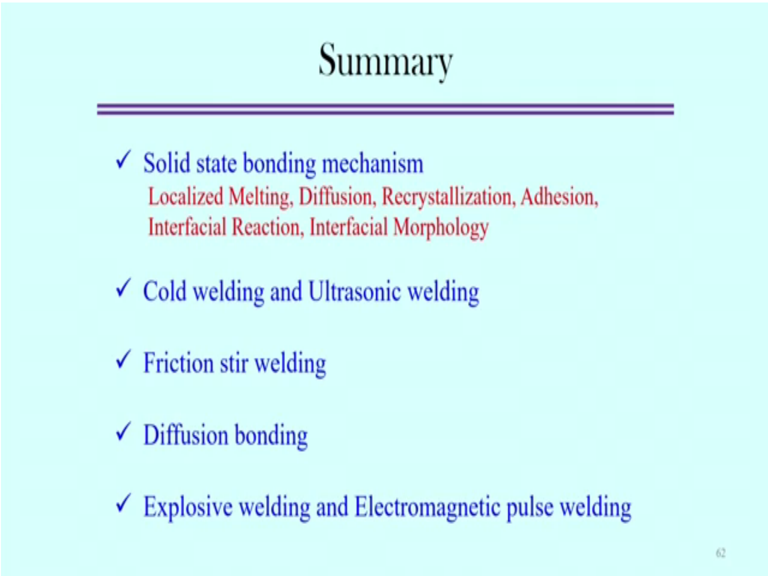

So, we have discussed, in this Solid state welding process about from conventional welding process we can say that, some other non conventional machining process just a Explosive Welding process, Electromagnetic Pulse Welding process these are the typical development of the Solid state welding process apart from the Friction stir welding process. So, out of this, all this process there is a huge development happens or still work is going on in Friction stir welding process, but till other non conventional processes is also applicable for when there is a limitation of for a welding specifically for the tubular structure and specially for the dissimilar combination of the materials. So, other welding processes are more conventionally used.

Since somewhere you can say, that first we have discussed the Solid state bonding mechanism. So, Solid state bonding mechanism here, we cover up that Localized Melting mechanism, Diffusion mechanism, Recrystallization, that is also one kind of mechanism that is responsible for Solid state bonding, Adhesion; that means, joining of the two surfaces by additives, then Interfacial Reaction then, Interfacial Morphology. Interfacial Morphology means, that joining of the high rate of deformation that we normally found out in the Explosive Welding and Electromagnetic Pulse Welding. These are the typical mechanism is responsible for the Solid state bonding mechanism.

Then, we have discussed that Cold welding and Ultrasonic welding. Cold welding processing the offsetting joining of the two materials with a application the pressure and then, Ultrasonic using the vibration energy ah; that means, mechanical energy here, we can join the two metals also and of course, the ultrasonic welding that the things it is applicable for ultrasonic welding process.

Then, we have discussing a lot on friction stir welding process. Specific or similar kind of material dissimilar material process and what are there is a development of the friction stir welding process?; that means, in terms of heavy rising of the friction stir welding process to get certain advantage of joining different dissimilar combination of the materials or similar combination of the materials.

Ah then we discussed the Diffusion bonding also. The Diffusion bonding the joining of the two metallic surface with the application of the pressure temperature, but normally, Diffusion bonding takes a long time and in that sense, the Explosive welding and Electromagnetic pulse welding that also happens. The high rate of deformation happens over a short period of time and that, that deformation of the at the interface zone high rate of deformation interface zone creates the some bonding mechanism between the two surfaces. So, here also Explosive welding Electromagnetic welding, that actually the flyer surface or faying surface that actually very which normally uses the very thin sheet to get the successful weld joint using these two weld processes. So, this I can conclude that end of the module 3 so,

Thank you very much for your kind attention.