Advances in Welding and Joining Technologies
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Lecture - 07.
Laser and Electron Beam Welding Part II

Last time we have discussed the laser welding processes and the basic principal of the lasers and the source of the laser; how we can apply in the different welding processes. Now we will shift to that another part of the laser welding process that is called laser assisted hybrid welding. So, hybridization of the laser welding processes has been started long before, but of course there are certain advantages of hybridising of this laser welding processes. So, basic idea of the hybrid laser welding processes is the sense that.

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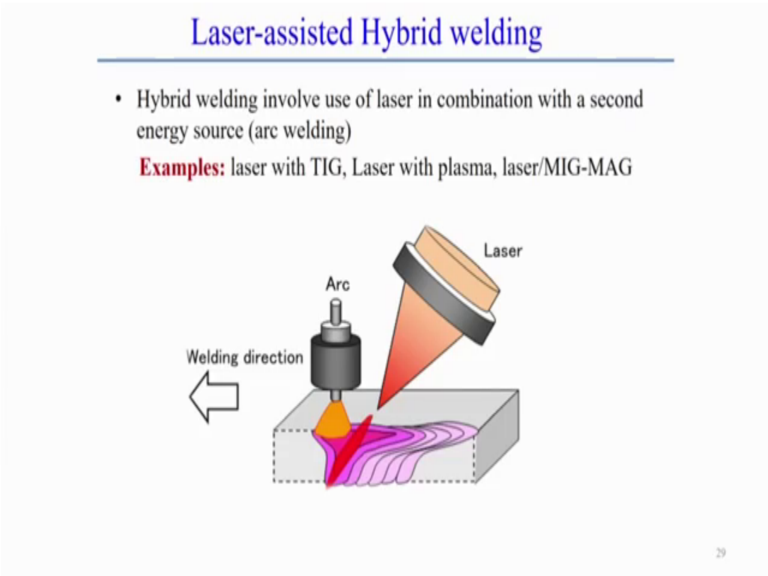

Another secondary heat source actually is added along with the primary heat source as a laser. So, we can get certain advantage in this process in that in the in other way that first main advantage is that; we can create the large oil pulled volume in general. Because application of the laser actually focus concentrate on the very small zone and normally it creates the key hole formation; that means, key hole mode welding processes. But the at the same time added heat source from the any arc welding processes helps in the several way probably that arc welding processes increases the width of the heat affected zone or molten zone. So, therefore, if there is a need for to create large volume and this of welding zone is required then hybrid laser welding processes is one of the most solution.

But the main concern in this case is that how this arc is interacting with the laser and both way it is benefiter with respect to each other. In; that means, that arc actually facilitated the formation of the key hole and at the same time key hole also try to help the; to stabilize the arc by providing the extra heat energy within the zone of interest.

Now, primarily we can see that several other arc welding processes like the tube welding or gaseous arc welding processes plasma and then laser with the gas metal arc welding; these are the typical secondary sources of the heat in case of hybrid laser welding processes. But the question is that when you try to develop a hybrid piece laser welding processes; the what should be the position of the laser? Whether it is in the front side or whether it is back side with respect to the welding direction.

Now a principal of the laser assisted hybrid welding processes we see that combination of the gas or solid state mostly CO 2 laser ND YAG laser or now-a-days fibre laser can be joined with other arc welding processes like gas tenses arc welding processes, gas metal arc welding processes and plasma arc welding processes that actually supply the secondary energy source in the hybrid processes.

Now, again we can do the further differentiation that the secondary heat source without the material addition or with the material addition.

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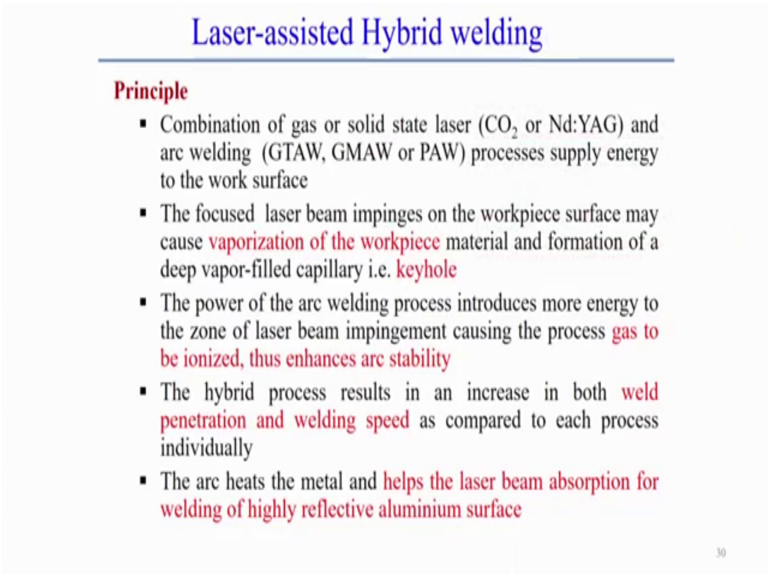

For example that gas tenses arc welding and plasma arc welding processes is used without any material addition, but gas metal arc welding processes there is some material addition along with the laser welding process. So, therefore, when there is a consider the material addition that process becomes more complex. So, analysis may not be very straight forward because there are several interaction of the metal; material deposition, interaction between the arc and laser is always a complex phenomena. So, let us see how this will this processes is be helpful in industrial practice, but we will look into that basic advantages or basics of this laser hybrid welding processes in this in this course.

So, first focused laser beam actually impinges on the work piece surface and that may cause the vaporization of the work piece material and the work piece material actually finally, form a vapour filled key hole; that means, basically the keyhole mode is mostly usable in hybrid laser welding processes. Now the power of the arc actually in the arc welding processes that actually introduces the more amount of the energy. And the laser actually helps the process of the gas to be ionized and in that sense it laser actually enhances the arc stability in the hybrid welding processes. So; that means, the laser helps the in the formation of the arc and that stability in this processes.

But if we look into other way also that arc also helps in the sense that by increasing the laser beam absorption; specifically when there is a highly reflective material well try to weld. So, in highly reflective material like aluminium is actually beneficial when you use the laser assisted hybrid welding processes. Another specific principal it follows that hybrid welding processes, there is a increment of the weld penetration basically high depth of penetration can achieve using this hybrid welding processes.

And at the same time; the welding speed high welding speed can also be used in this case as compared to the individual processes; that means, as compared to the if you compare to the with respect to the individual laser welding processes or any arc welding processes. So, in the sense both ways it is advantageous in terms of the creation of the high depth of penetration and probably we can use relatively high welding speed that we have limitation in case of individual processes.

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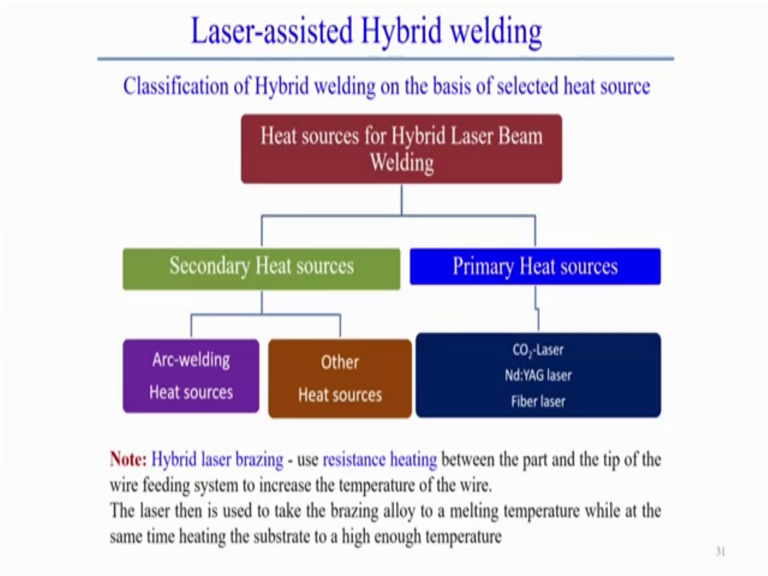

So, if we classify the hybrid welding processes in the on the basis of the heat source. So, it can be divided into two things; one is the secondary heat source another is the primary heat source. So, of course, primary heat sources that corbondioxide laser. ND YAG laser fiber laser these are the primary source; that means, it is a basic laser welding processes. And secondary source can be arc welding process that we have already discussed that several arc welding processes GTA gas tungest arc welding processes gas metal arc welding processes and mainly plasma arc welding processes these are the main processes we use in hybrid laser welding system.

But heat source can be of other types of heat source can also be used in case of the laser assisted hybrid welding processes just you can see one example that hybrid laser brazing processes. So, in case of hybrid laser brazing processes generally resistance heating between the part and the wire braze wire; we are supposed to use this wire. So, that resistance heating occurs within the wire and that actually increases the temperature of the wire, but at the same time laser actually melts that braze wire and as well as is supply the heat to the braze material.

So, these are the typical mechanism of the hybrid laser brazing processes; we can categorise as that apart from the arc welding processes the hybrid laser welding processes also develop using the other heat sources, here the other heat sources is that the resist due to the resistance heating.

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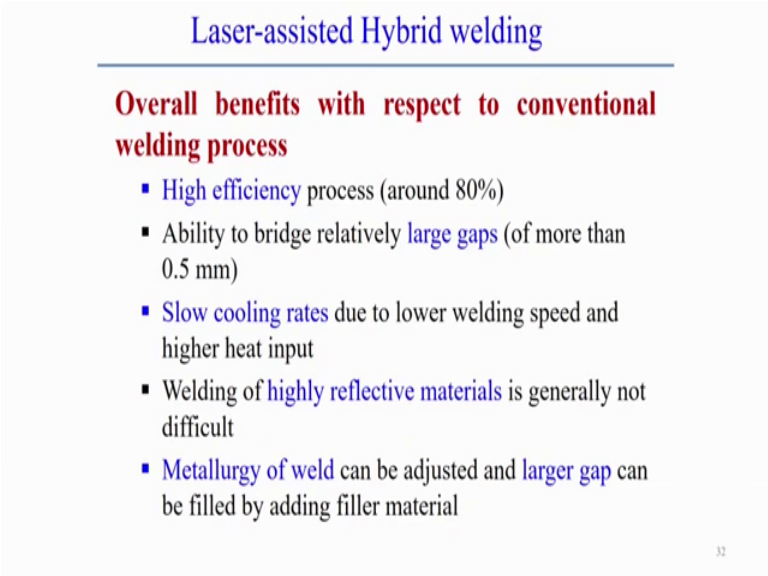

Now, if we analyse if we see that overall benefits of the hybrid laser welding processes with respect to the conventional welding processes; we can define few points that first point is that it is a very high efficiency process, so around 80 percent efficiency as compared to the individual processes, so that is the main advantage. Second advantage is that if the practical situation arise that there is a large gap between the two substate or two workpiece materials.

So, in this case the hybrid laser welding probably is a very good solution to join the material. Because in hybrid laser welding process join the material either without using any third material or without any material deposition or using the some other material deposition processes to fill the gaps. Because in this case the hybrid welding process the volume of the whirlpool is relatively more as compared to the laser welding process are even as compared to the laser welding processes. Because here the arc welding basically try to increase the surface area of the fusion zone and laser welding helps to create the large penetration in this case.

So, large when there exists some large gap probably this is the advantageous using the laser hybrid welding processes. And of course, very high thickness materials can be joined using this hybrid processes. Other processes is that; slow cooling rate if we use the relatively low welding speed and in that case that high input per unit length if it is very high; so, in this case the it follows the rate of cooling is very slow in this case. So, that slow cooling rate actually helps us in the; to structurally stable well join material can be produce based on this.

Then another advantage of laser hybrid welding processes is that for highly reflective material. So, probably when we use the individual processes at the laser arc welding process; it is very difficult to join the highly reflective material like aluminium. But with the use of the hybrid processes probably it is the advantageous or it is not too much difficult to weld of this kind of material.

And another point of benefit using the laser assisted welding process that metallurgy of the metallurgical structure of the weld join weld join can be adjusted. And at the same time the large gap can be filled by adding of the filler material. So, these are the typical advantages of the laser assisted hybrid welding processes.

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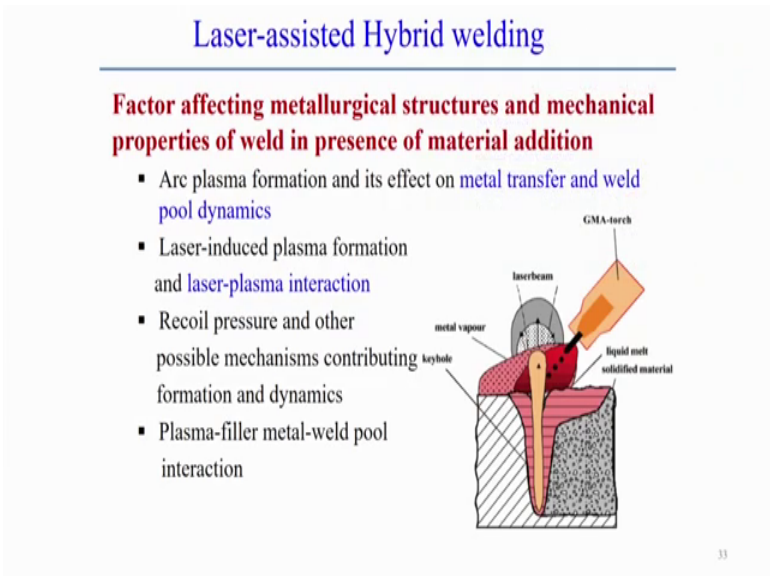

We can look into the other part of the laser assisted hybrid welding processes that what are the different factors that actually affect the metallurgical structure. And of course, the mechanical properties also depends on the metallurgical structure otherwise in presence of the material addition; that means, when we merge or may be when we create the laser assisted hybrid welding process using the laser, as well as the gas metal or cooling process the which is different from the plasma or other arc welding processes because here there is a material deposition in case of gas metal arc welding processes.

So, we see from the figure that there is a several interaction first interaction in the; the material addition to the domain and laser actually creates the large depth of penetration and of course, it os a its follows the key hole mode welding process. So, there is a some metal vapour will be there and that there is a may be typical size of the liquid melt and of course, the solidified size and in this complex interaction is really very difficult to analyze.

But if you see the keep in the few points on this type of hybrid laser welding processes; first point is that there is a formation of a plasma formation and of course, that plasma formation actually effects the metal transfer phenomena and ultimately it effects the weld pool dynamics. Second point is that laser induced plasma formation and the laser plasma interaction becomes more complex in this case. So, that the interaction actually helps to the absorption of the energy during the welding processes.

Second point is that recoiled pressure and other possible phenomena considering the formation of the weld pool dynamics. Especially the influence of the here the any any any kind of shielding gas that becomes that creates the more complicacy in this in this process. And of course, finally, the plasma filler metal, weld pool interaction also becomes another factor of complexity and that it is; it is it is a difficult to analyse all the effect of the individual phenomena in a straight forward way.

So, I am not going to much details about the how they interact with respect to each other, but rather we will try to just point out these are the typical situation that may arise during the interaction of the laser and the other gas laser and other any kind of arc welding processes that may happens in the development of the hybrid laser hybrid welding processes.

Now, in general if we try to analyse that what are the influences of the hybrid welding processes parameters and on specific to the bead shape.

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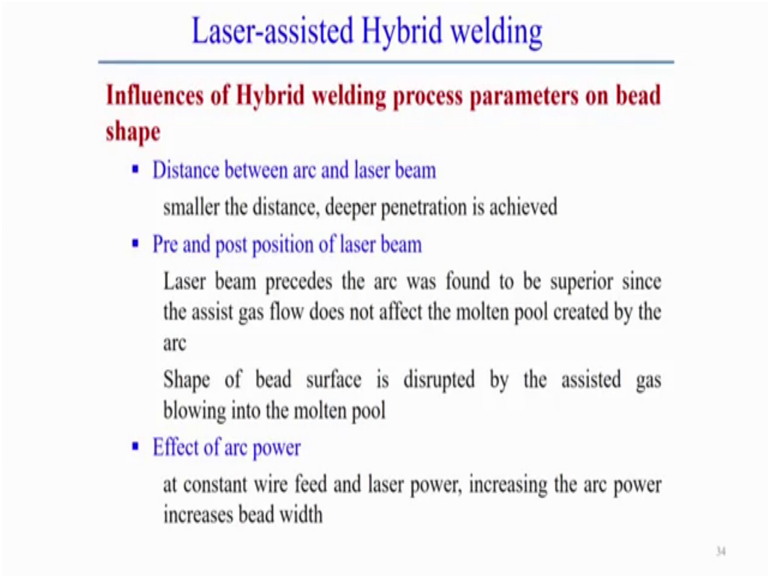

So, the bead shape also influence in general by the different parameters; first is the distance between the arc and laser beam. So, between the laser beam and arc if it is too close with respect to each other that deeper penetration is achieved. So, compact effect the arc and laser will be more and in this case probably we can relatively narrow heat effected zone or narrow weld zone, we can expect if the arc and laser beam are close to each other. If they form a; the effect or may not be beneficial; so, in that sense so, smaller the distance; so, we can achieve more depth of penetration.

Second point is that position of the laser beam whether we can put in the front; whether it is laser can be put in the front or laser can be put in the backward side during the welding process. And in this case if we put the laser beam that in front of the arc that is more preferred way specifically when we try to make the hybridization of the processes using the laser and gas metal arc welding process. Because gas flow does not actually effect the molten pool created by the arc, but shape of the bead surface is basically disrupted by the assist gas blowing into the molten pool. So, normally in case of gas metal arc welding processes use for hybridization of the laser processes. So, in this case the laser is kept at the front side and the gas metal gas metal arc welding put in the backward side.

Another effect is the hybrid process that is the effect of the arc power. So, in GMAW laser assisted GMAW process in this case that at constant wire keeping the constant keeping the constant wire feed rate and we keep it the laser power as constant. So, basically increasing the arc power that actually increases the width of the weld zone that is also obvious because arc power in this case the helps to creates the wide wide width widthness of the weld pool volume.

And of course, laser in the because laser is used to increase the depth of penetration and the purpose of using the arc is; so, using the arc power definitely it will try to create the the on top surface the size of the weld pool volume will be more. Now we covered about the laser welding processes and of course, hybridizing of the laser welding process also we have discussed.

Now, we will try to focus on the electron beam welding process this is another high power where we can use the high power beam energy and this is the electron beam welding process one of the most procession welding processes and of course, one of the most costly processes. So, we will try to discuss this electron beam welding process of course, well focus on the basic parts of the electron beam welding process.

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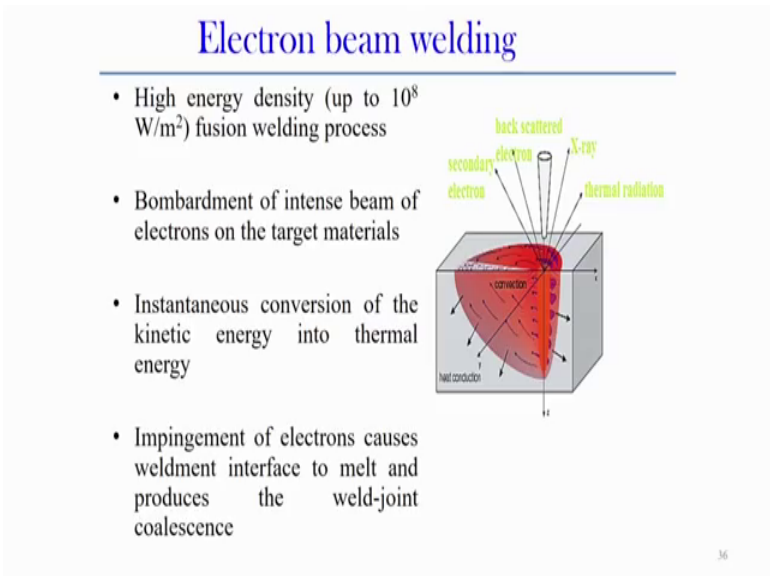

Electron beam welding if we see that in this case the high energy density can be created. So, up to 10 to the power 8 watt per meter square or I think it should be centimetre square fusion welding processes. And if you see that basic principal of the electron beam welding process that; if it is possible to create the beam of the electrons that can be done by the bombardment of the intense beam and of electrons and that can focus on a specific work piece.

So, that on the work piece the kinetic energy of the electrons is basically converted to the heat energy or may be converted to the thermal energy. And that thermal energy creates the a weld pool weld volume and of course, here also formation of the key hole happens. So, in this case the when it creates the weld pool volume and if you see that due the bombardment of the electrons to this work piece surface.

And at the same time there is just scattering of the secondary electrons also happens and the temperature becomes; so, high. So, thermal radiation also happens that is the heat loss through the radiation from the weld volume and it also creates the some X ray. So, there is a creation of the X ray effect in the electron beam welding process, but that was not there in laser welding process.

Now, of course, when it creates the volume of the molten volume then at the same time some amount of the heat is conducted a through the solid medium work piece. And within the molten pool there is a convective flow of the material also happens and at the same time there is also heat loss through thermal radiation also happen; its remember that electron beam welding generally happens in in a vacuum chamber. So, we can do the further on this electron beam welding process that basically the electron beam gun we used as a tungsten filament. So, that tungsten filament can be heated and to create some pull up electrons.

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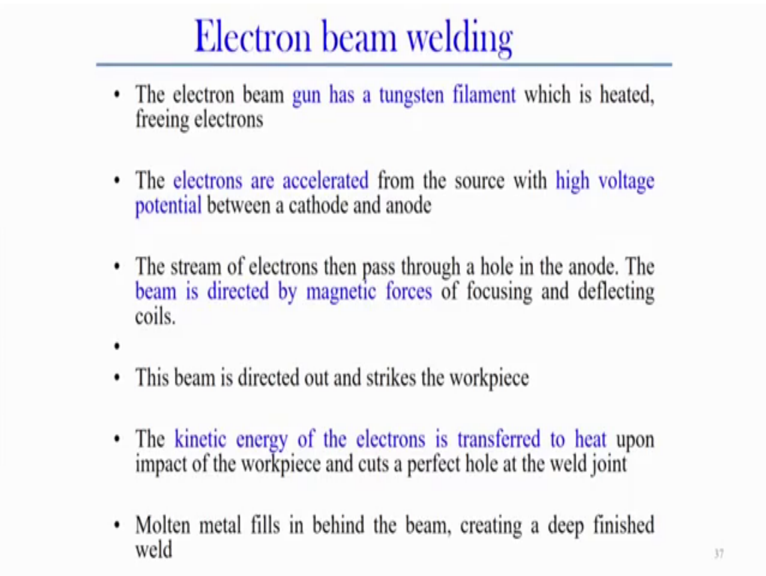

Now, second thing is that after creation of the electrons it can be accelerated with the from the source with the high voltage; if you keep the high voltage difference within the source; so, electron can be accelerated. Now the stream of electrons is passes through a hole in the anode so, that the beam is then directed by the magnet magnetic forces. And then it is a focusing and it is a focusing and then deflecting to a specific point by the focusing on a specific point by the deflecting coils; we will see in details about the what are the typical components of the ones one simple electron beam welding machines.

But finally, the beam is directed out and strikes on the work piece surface and of course, the kinetic energy of the electrons is actually transferred to the heat with the impact of the work piece. And it creates a perfect hole in the weld join; that means, perfect hole means in the sense its creates the basically one key hole. And then there is a then when the key hole moves forward the it will fill by the molten metal in this way it creates the a deep penetration welded structure.

So, of course, in this case the in principal with respect to the laser welding process the source energy; creating of the energy is different from the laser. But in general if you see the in electron beam welding process that first is that it should be done on the accelerating creating of the electrons, accelerating and the focusing on the specific point or done in a chamber and finally, the welding has done its a within a vacuum chamber.

So, that it cannot be deflected away the in presence of air or in presence of any medium, but in laser welding probably also we can we can also create the key hole mode or at the same time deep penetration welding processes; even using the laser, but point is that laser welding it is not required to create any kind of the vacuum chamber. And another point is that laser welding does not create any extra X ray production during the process.

So, of course, in if you compare between these two the high depth of penetration can be achieved using the electron beam welding processes. And at the same time the precision of the joint is more in the case of electron beam welding process because it is generally happens in a vacuum; so without any contamination of the surrounding elements; so, that is the main difference from the laser. Now, what are the typical advantages of the electron beam welding process?

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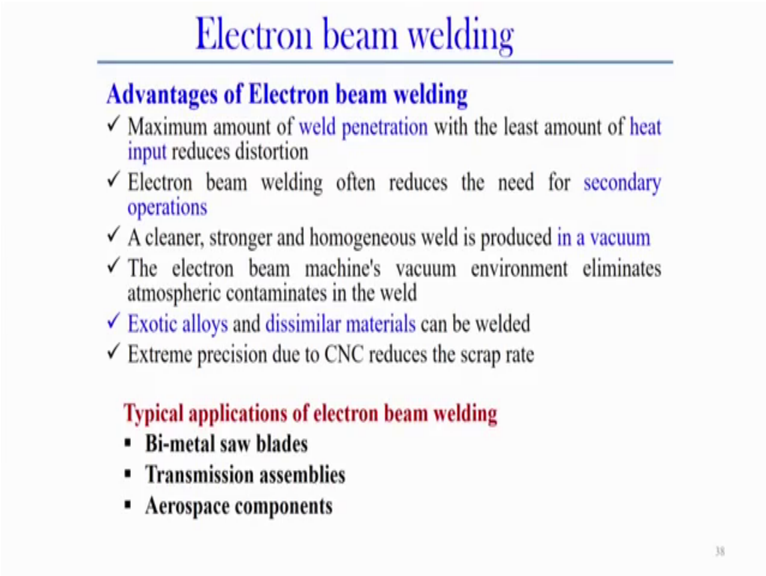

So, advantages of the electron beam welding process that maximum amount of the weld penetration is achieved with the least amount of the heat input and that actually helps to reduce the distortion. So, in this case the of course, between the laser and electron beam if you compare; the electron beam is the electron beam is a electron welding is the more preferred, but limitation is that other way it is costly as compared to the laser welding process.

Second point is that electron beam welding process may not be necessary always, but the secondary operation; a secondary operation means, so to create, remove the contaminated surfaces on the of the weld joints that type of things is not required in case of electron beam. Because it electron beam can produce very clean homogeneous structure in a vacuum; in a vacuum in a vacuum.

So, that since this vacuum environment actually eliminates any atmospheric contamination in the weld; that is the biggest or main advantage of the electron beam welding process difficult to weld metals which cannot be possible in other welding processes or dissimilar combination of the materials can be more preferred in case of electron beam using the electron beam welding process. So, of course there are some difficulty there are some issues of welding of the dissimilar materials using electron beam, but apart from that that so, many different types of dissimilar combination of the materials and difficult to welding weld materials can easily be done using the electron beam welding processes.

And another advantage is the electron beam welding process is that; extreme precision weld join can be produced because most of the cases it is controlled by CNC machines and in that way it also reduce the scrap rate. So, all these advantages points of course, exist in case of electron beam welding process as compared to the laser. And there is a typical issues in case of electron beam welding process, specifically joining of the dissimilar materials that we will discuss later on.

But what are the typical applications of the electron beam welding processes specifically industry if we see that bi metal saw blades can be welded using the electron beam welding process. Transmission assemblies to find out the application of the electron beam welding processes and of course, which application we can find out the aerospace components and the precision of the joints and homogeneity in the structure is the main important factor.

So, we can do the further on the electron beam welding process.

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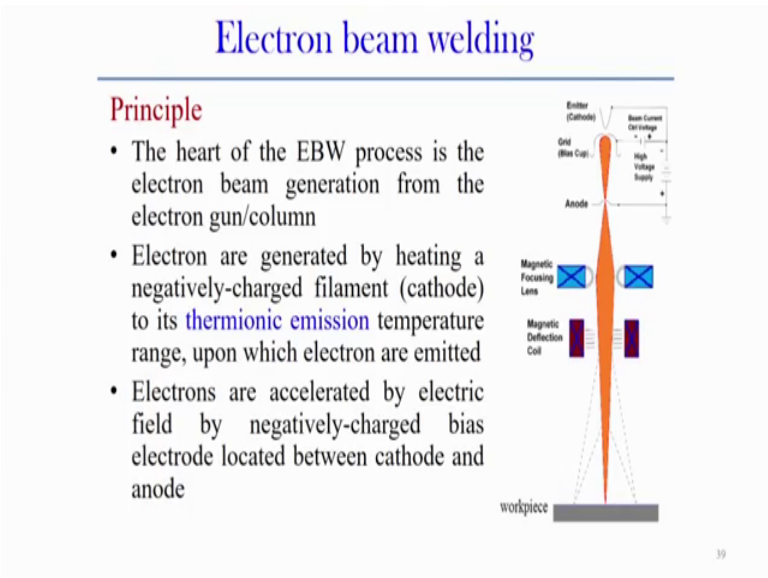

And now we will try to discuss that what are the principle of the electron beam welding process? Of course, it is mostly it is known, but here we can see the summarize that what what principle that electron beam welding process follows basically? First point is that the heart of the electron beam welding process is the electron beam generator from from which the electron is emitted. So, that is called the electron gun or electron column; second thing is that those electrons are generated. So, basically the electron are generated by the heating process negatively charged filament for example, negatively charged filament and two is heated that certain temperature that is thermo emission temperature.

So, at the temperature range electrons are emitted now when there is a emission of the electrons the machines actually control machines actually control or accelerated this electrons so that the high amount of the kinetic energy of the electrons will be able to produce the amount of the heat energy.

Now, next step is that once we can create that electron emission and from there electrons are accelerated by the electric field up negatively charged bias electrode. Because bias electrode helps to accelerate the emitted electrons and that bias is present between the cathode and anode. If you see the picture also that bias is basically present between the anode and cathode. So, after emission of the electron then it is accelerated.

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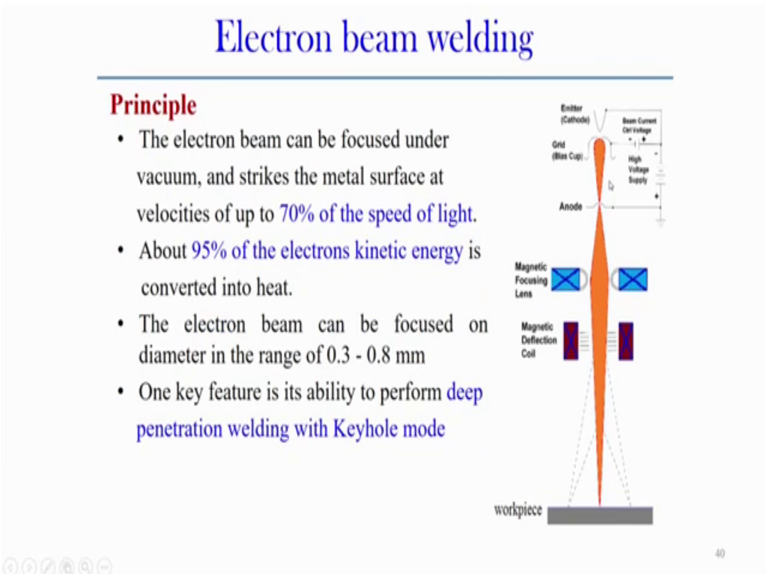

And the next step accelerated and then after that next step of the electron welding process is that that the accelerated electrons is basically using the magnetic focusing lens; it is focused and magnetic also the helps the magnetic with the help of the magnetic deflections coil, we can deflect the electron beam with the desire position.

So, these are the basic steps if we see in general that; however, the generation of the electron and then acceleration of the electron. And the next second component third component is the focusing of the electron; that means, it gives the focusing of the electron, we can concentrate one specific point or specific line and then another part is the deflecting deflecting of the beam of the electrons and whether we want to put it want to focus at that point we can put the we can put the electron beam.

Next point the electron beam is interacting with the work piece. So, basically the kinetic energy of the electron beam is converted to the heat energy and that heat energy actually creates the one deep penetrated weld by the formation of the keyhole. Now if we see the in principle that electron beam can be focused under the vacuum basically and strikes the metal surface at a velocity of up to the maximum of 70 percent of the speed of the light.

So, with this speed around 95 percent of the electron kinetic electrons kinetic energy is basically converted to the amount of the heat energy. So, in that sense the probably the fusion efficiency of this process is relatively more. So, as compared to the laser welding process this is also another advantage that efficiency of this process is relatively more.

Then electron beam can be focused on a diameter in the range of may be 0.32, 0.8 millimetre; that means, 300 micro meter to 800 micro meters of course, this focusing can also be done using the laser process as well. And then one that with this focusing diameter; the concentration of the electrode can create high amount of the energy and that energy is able to produce the deep penetration welding with the formation of the keyhole.

So, you can see the laser welding as well as electron both welding process also can create the keyhole. And that key keyhole actually helps to penetrates very high so; that means, when there is a requirement of the very high thickness material to be joined; then in that case electron beam welding process is the more preferable as compared to the laser welding process. Because high depth of penetration is more easily controlled with the minimum heat effected zone with the minimum fusion zone in by using the electron beam welding process as compared to the laser beam welding process.

Now, if you see what are the keyhole formations mechanisms in case of electron beam welding process?

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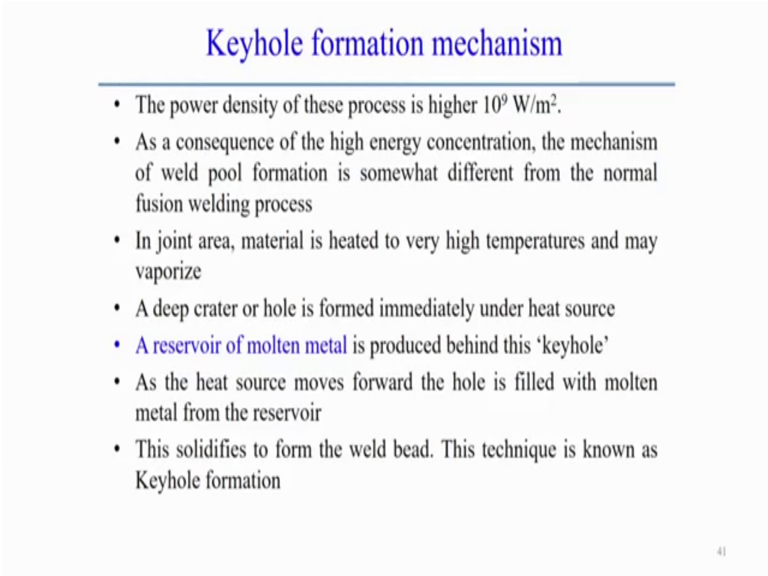

So, in this case the power density of this process is as high as 10 to the power 9 watt per meter square I think it should be more than that. And therefore, high energy is concentrated and mechanism of weld pool formation is definitely it will be different from the normal arc welding processes, but may be almost similar to the laser beam welding processes. The when the metal is heated to very high temperature; definitely it will when it is crossed the vaporization temperature, it vaporise the material.

So, therefore, when it vaporizes the material; there is a deep crater or hole is formed under the under the heat sources. So, when is the formation of the deep crater hole under the heat sources so, but at the at the same time when electron beam produce the deep hole there is may be the some reserver of the material may exist behind this keyhole. So, when the heat source is moves in certain direction. So, that hole is actually filled by the behind that the molten material from the reservoir.

So, and then it subsequently solidifies weld bead and this is the typical formation of the keyhole mechanism or keyhole formation in the electron beam welding process.

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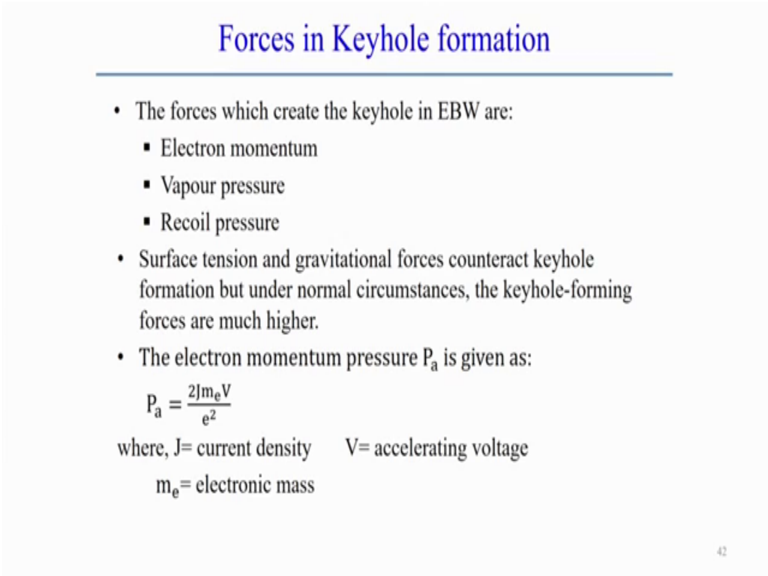

We can see that further on the what are the mechanism of the keyhole formation in case of electron beam welding process? So, basically the forces which create the electron beam welding are first there are 3 forces one is the electron momentum of electron because it moves very high speed.

Second is the vapour pressure it creates the vapour and that actually creates the vapour pressure and of course, with the interaction of the electron beam with the material and that also with the formation of the keyhole, it creates the required pressure.

Therefore, when you try to form the in general when you try to explain the mechanism of the keyhole formation; so, that we can compare between these two surface tension force of the keyhole formation of the surface tension force and the gravitational force when they are equal or maybe they actually when they are equal with respect to each other they actually opens the keyhole makes the keyhole and keep live the keyhole formation and that actually depends on the surface the balance between the surface tension force and any other gravitational forces.

So, of course, keyhole will be opened it may because depending upon the these two forces magnitude of these two forces and direction of these two forces decides whether keyhole will be open or it can also to close. That can be better explained in terms of the how these two forces are balancing with respect to each other. So, in this case keyhole forming forces are much higher; so, that keyhole keep opens during the process itself.

Now, we can do the simple calculation that electron momentum pressure here if you see the given by this expression P a equal to twice jme v by e square here is the j is the current density V is the accelerating voltage and m is the mass of the electrons. So, if you know all these parameters; so, it is possible to estimate the momentum pressure created by the electron.

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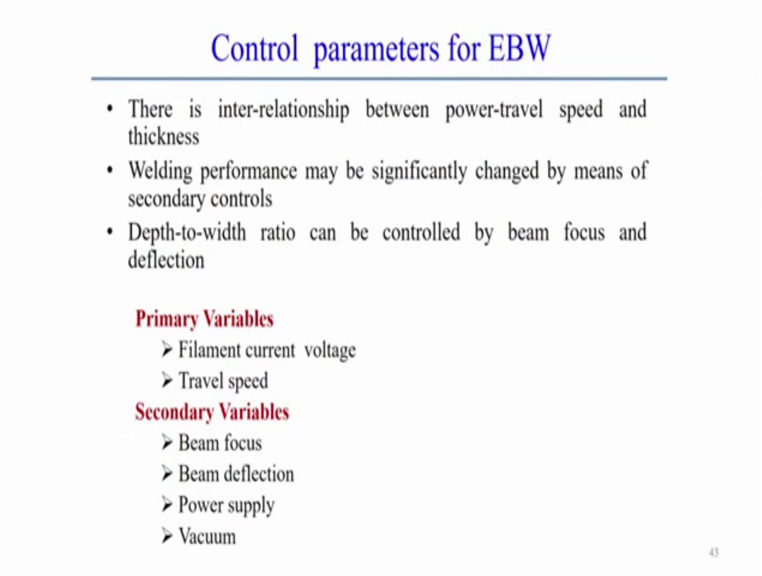

But what are the control parameters of electron beam welding process? Of course, there are several control like other welding processes or any other gas arc welding processes several control parameters also exist in case of electron beam welding process. Just we can divide into two components the primary variables and another is the secondary variables.

So, primary variables is that filament current voltage and the travel speed and the secondary variables is the beam focus deflection of the beam, power supply and of course, the vacuum chamber or to what up to what extent what pressure we can create the vacuum. So, all these are the secondary variables now of course, with these variables, but primary variables actually more controllable variables in the sense that there exists some interrelationship between the powers of the beam and as well as the travel speed. And that actually decides what is the amount of energy exactly is used for the welding purposes.

But of course, the performance of the welding can may be scientifically changes by varying the secondary variables. The most important thing is that the depth to width ratio can be controlled by the beam focus and the deflection of the beam by this in these are the two parameters that actually influence the depth to its ratio; that means, basically depth with ratio is decided, ultimately it effects the molten zone or the heat effected zone of this process.

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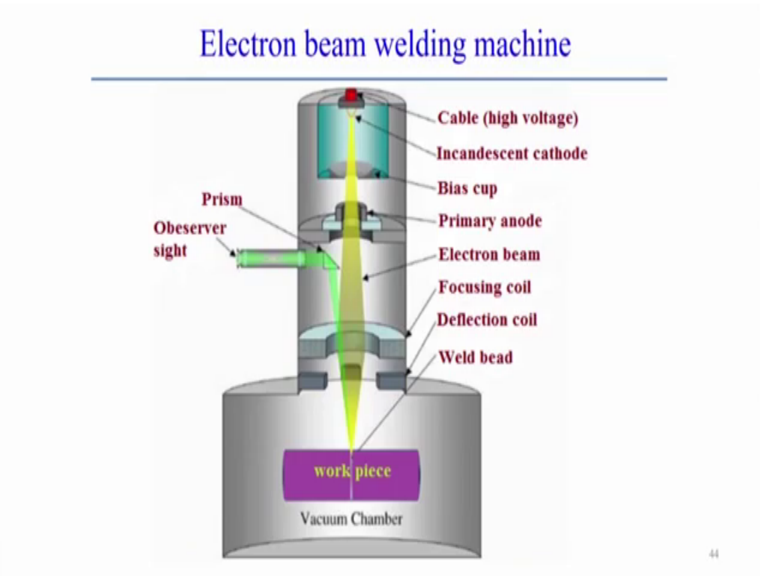

Now, we can see that the one is the typical electron beam welding machine; what are the typical components of the electron beam welding machines? Here see that cable then the top the high voltage is applied then cathode that actually creates in its the or creates the it generates the electrons here. And the bias cup that actually bias cup actually helps to accelerate the created electrons, then primary anode and cathode basically that they create the they actually create the circuit in this case and then electron beam, if you see the yellow colour that shows that electron beam.

So, after creating it is accelerated and then electron beam is put in the focusing coil goes to the goes through the focusing coil. So, focusing coil helps to focus this thing and focus in a specific position and then deflection coil; deflection coil also helps to deflect the electron beam and finally, it is focused on the work piece that actually kept as a vacuum chamber. And if you see that there is a observing system also there to see the position of the work piece. So, these are the very typical and very simple way to presence the typical components of the electron beam welding machine.

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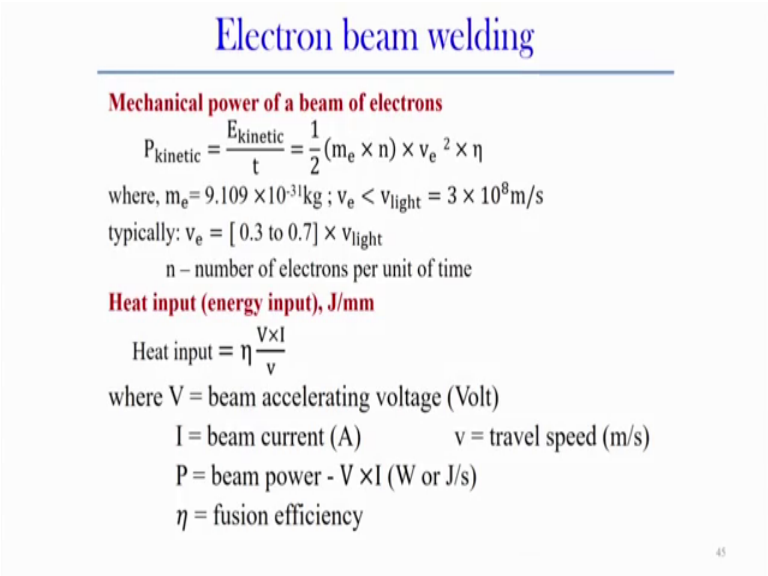

So, we can do further on the electron beam welding processes the very simple or the basic calculation. First calculation is that how to estimate the mechanical power of a beam of electrons? If you see the formula, that kinetic energy the kinetic energy of the electron divided by t. So, power is the energy by t that is estimated the by half of m e into n v e square into efficiency.

So, basically here if you see the formula that m e actually represents the mass of the electron that is given ve is the basically velocity of the electron that is of course, it should be less than light velocity of the light. So, around 0.30 percent depending upon accelerating of the electron it can be around 30 to 70 percent of the velocity of the light.

So, if you see the ve is equal to 0.3 to 0.7 times of the velocity of the light. So, velocity of the light into 3 into 10 to the power minus 3 into 10 to the power 8 meter per second and n since there is a time component here we are estimating the beam power. So, here n represents the number of electrons we can estimate in that way the number of electrons per unit time. So, that it represents the total kinetic power of the electron.

Now, in other way that heat input can also be estimated; that means, energy input into per unit length. So, it specifically by the unit of joual part millimetre. So, when we estimate the heat input per unit length in this case the two parameters; what is the beam power and at the same time what is the speed? It takes the combined effect of the welding velocity as well as the power welding power also.

So, ratio of that is the measure of the heat input per unit length unit length so; that means, here heat actually decides the for the same incoming power, if we use the high welding velocity. So, actually heat input will be less as compare to the when you consider the very slow velocity.

So, basically in low velocity the heat input will be more and very high velocity the heat input will be the less even for the power remains the same. So, that is why it takes it takes the effect of the welding velocity also; so, here if you see the efficiency into volt into current divided by the welding speed. So, beam V is the accelerating voltage I is the beam current or V equal to small v equal to actually travel velocity that is welding speed and capital P is the power beam power of the beam; so that also equivalent to the volt into ams; that means, volt into current.

So, power is represented watt joule per second and another efficiency (Refer Time: 43:09) also given in this case. So, these are the basic calculation we can find out the kinetic energy of the electron or may be kinetic energy; as well as the power, power of the electron basically we can estimate here and what is the how to estimate the heat input per unit length in case of electron beam welding processes.

Or specifically I can say that this formula for heat input not only electron beam welding process may be in other arc welding processes also we can use the similar kind of formula; if you know in that arc welding process what is the voltage what is the current is using and what is the welding speed? So, this is the heat input per unit is length is one of the typical characteristics parameter that actually takes care of the welding velocity.

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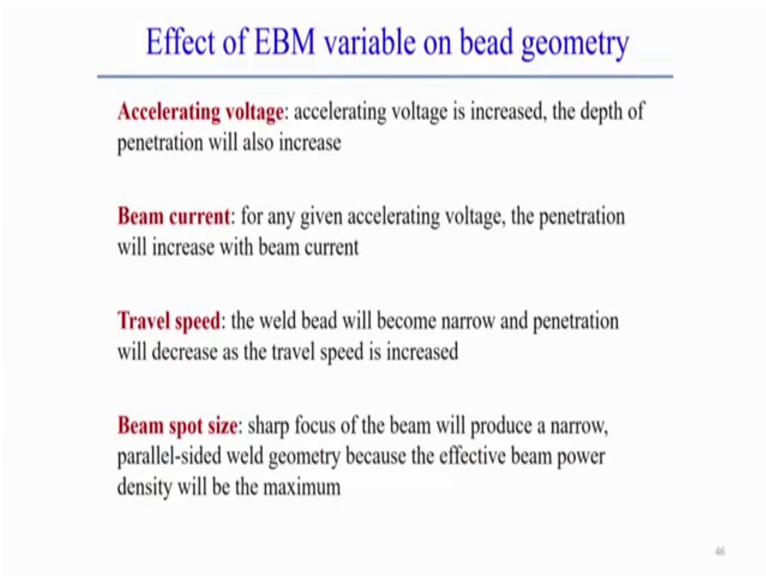

Now, what are the effects of the different variable on the weld bead geometry in case of electron beam welding process? So, first is the accelerating voltage of course, accelerating voltage is increased the depth of the penetration will also increase.

So, then; that means, when accelerator accelerating voltage is increased; that means, the electron is accelerated more that the it will can create over a small focus zone, the high amount of the heat energy and that always helps to creates the more penetration of the material. But of course, the accelerating voltage and the velocity of the electron having some limitation; it can goes up to the maximum of the around 70 percent of the velocity of the light. So, that is why the accelerating voltage in general accelerating voltage actually increasing the accelerating voltage increasing the penetration.

The beam current for any given accelerating voltage the penetration will increase with the beam current of course, other way also if will increase the beam current also heat also helps to increase the total amount of the beam power and in that way that actually creates the more energy that can be released on the workpiece and finally, influence the the penetration of the welded joint.

Next is the travel; speed travel speed basically understand that if travel speed is more the amount of the heat input to the workpiece surface actually decreases. So, that or if travel speed is very low that amount of the energy goes to the workpiece surface that actually increases. So, with respect to that point of view that weld beam will become narrow and penetration will decrease as the travel speed will increase travel speed will increase means less amount of the energy that will decreases the penetration.

But at the same time when it decreases the penetration and that it will try to narrow down the narrow down the weld beam. But if travel speed is very low it can the width can be width that in that case it beneficial both, it will increase the width as the well as penetration. So, these are the basic idea about the effect of the travel speed on the weld beam geometry in case of electron beam welding process.

So, of course another parameter that actually influence the weld beam geometry on the electron beam welding process that is the beam spot size. So, basically very sharp or small focus beam will produce the high power density on the surface; definitely high power density will produce the very narrow and high depth of penetration and geometry. Of course, parallel sided geometry means almost it is a kind of a cylindrical shape kind of geometry without much variation from the top and the bottom; that type of typical geometry is possible to in case of the electron beam welding process.

But in that case the beam spot size should be the very small ok; if beam spot size is bigger probably it may not be the variation of the from the top to the bottom, there is must be some it will try to the available geometry must be gradually decreasing the width actually size of the geometry cross section of the geometry from top to the bottom is gradually decreasing if beam size is bigger.

So, other way the beam spot size actually decides the power density on the surface. So, in that way it will try to impact on the size of the weld bead.

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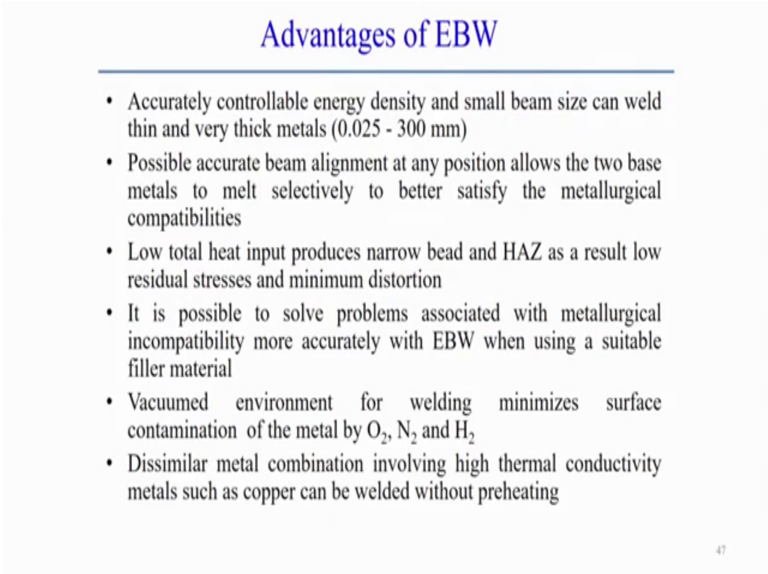

Now, in general if you see what are the typical advantages of the electron beam welding process. Here we can see that accurately controlled energy density is basically possible in case of electron beam welding process. So, that may not be possible in case of other arc welding process. And to some extent it is possible for the laser welding process, but in electron beam welding process it is more controlled energy density is possible to produce. And of course, very small beam size can weld very thick material; so, take that 0.025 very thin to very thick material.

So, there is a quite controllable electron beam energy is possible so; that means, it can be possible 0.025 millimetre welding of the 0.025 millimetre material. And of course, in this case we need to control the electron density or energy input to the subsequent material, but at the same time it is possible to produce 300 millimetre; so use thickness is possible using the electron beam welding process that may not be possible in case of other arc welding processes or in using the laser welding processes.

Next point is that very accurate beam alignment at any position is possible using the electron beam welding process. Therefore, the two base metals of the it is a very control the melting of the base metal in the selective way. So, that when you try to join some dissimilar materials that actually helps to produce the weld join and increase the metallurgical compatibilities.

So, in that way it is very advantageous in electron beam welding processes when you try to join the specifically dissimilar combination if the materials. The third advantage is that since low total heat input produces the narrow bead and the heat affected zone. As a result low residual stress and minimum distortion is possible in this case. Because heat affected zone and narrow heat affected zone and narrow weld pool zone can be created in case of electron beam welding process that actually helps to reduce the distortion minimum with minimum possible distortion and very low residual stresses.

So associated with the material; so, certain material because most of the combination of the dissimilar materials is difficult to join in other welding processes. Because that may not be the metallurgical that issues of the metallurgical incompatibility between the materials. So, that incompatibility of the metallurgical incompatibility of the materials can be controlled using the electron beam welding process and sometimes these can be done using some using some filler metals also.

But the joining of the dissimilar materials is may be can be done more control way using the electron beam welding processes. The main advantage is that we use the vacuum environment when you try to join the work piece material whether the similar or dissimilar materials using the electron beam welding process. Therefore, having the minimizes having minimizes the effect of the surface contamination of the metal by oxygen nitrogen or hydrogen which is typically present in any arc welding processes or even for the laser welding processes. So, that contamination from the outside atmosphere can be minimized using the electron beam welding process that is the biggest advantage in case of this process.

Dissimilar material combination, already we mention that involving the high thermal conductivity metals such as copper can be welded; welded using the electron beam welding process without any preheating. So normally any other arc welding processes or laser welding processes when you try to join with the high conductivity material. So, like copper; most of the cases we use as a preheating the surface and then we can do the main source of the energy in terms of laser or from the arc welding process and normally in that way we can do the welding of the highly conductive materials.

But in this case in electron beam welding process, we can do easily without any preheating sources, the welding can be done. So; that means, the in general the advantage of the electron beam welding process is that the dissimilar combination highly reflective material and highly conductive material can be joined more easily in using the electron beam welding process; which may not be possible at all in other type of welding processes. But of course, there is certain other disadvantage or negative points of the electron beam welding processes we will try to see that what are the disadvantage of this process?

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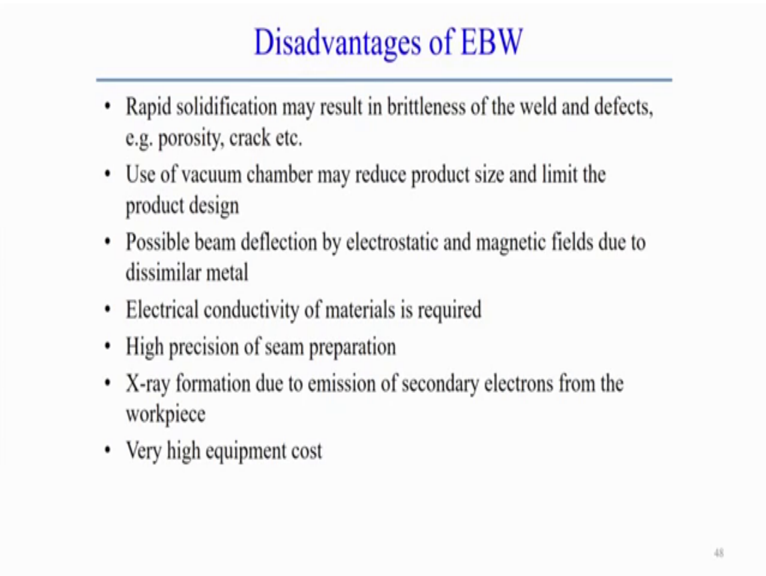

First is the of course, high heat concentration. So, rapid solidification may happen and this rapid solidification also produce the different type of the structure and finally, it results in the most of the cases we can find brittleness of the weld and several other defects porosity, crack may form due to the rapid solidification. This is the one disadvantage and second is that using the since electron beam welding process the using the vacuum chamber; that actually the all welding process can be done in the vacuum chamber.

So, because of that heat actually reduce the product size and limit the product design because vacuum chamber may not be created for a large scale welding process or very very big component; we try to weld in a small part it is very difficult to separate out keeping the separate out this only for small parts for a large component to create the vacuum there and doing the electron beam welding process. So, that is one biggest advantage of the using the vacuum chamber.

Another thing is that the since electron beam is easily deflected by the any other electrostatic and magnetic field specifically; it is important in case of dissimilar material. So, that is the other way we will we will discuss this issue that when you try to produce the dissimilar materials; how, what are the difficulty of what difficulty of application of electron beam welding process is there?.

Another is the another limitation of the electron beam welding process is the heat should be the electrical conductivity electrical conductivity of the materials is required. So, non electrical conductivity metal is not having any electrical conductivity, we cannot apply this materials or electron beam welding process.

High precision of the seam preparation when you try to join the material; then high precision may be fitting of this metal is required to keep to produce the successful weld join using the electron beam welding process. So, other way that X ray actually forms during the emission of the secondary electrons from the work piece. So, that is another application we should consider during electron beam welding processes; that is absent in other welding process that is the one of the one of the important disadvantage of electron beam welding process.

And finally, the of course, this machine is very costly; so, cost is the mess main limitation of the application of the this welding process in widely. Of course, apart from all these disadvantage and we can stick with the advantage very precision even if we compromise with the cost in other disadvantages of the electron beam welding process still it is a very good solution; specifically for the very high thick material and several dissimilar combination of the materials.

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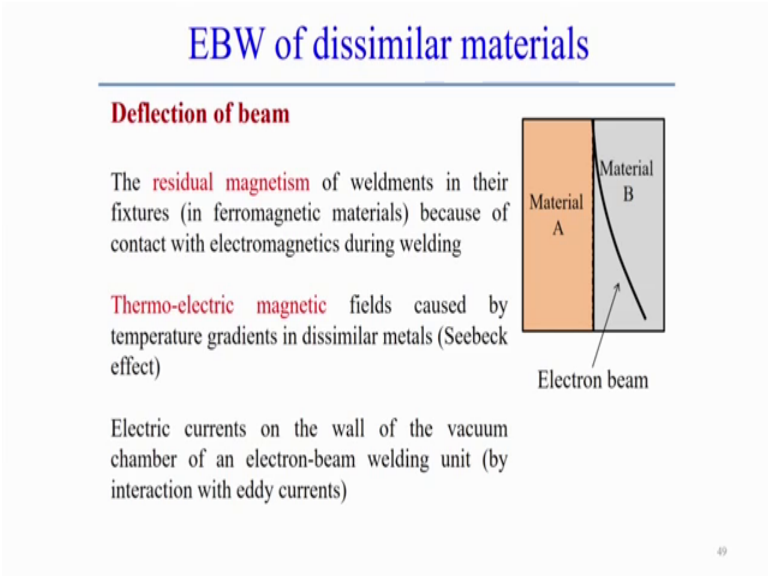

Now, try to focus on the what are the electron beam welding processes for the dissimilar combination of the materials? We can see the dissimilar combination of the materials there are several issues. So, we will try to discuss these things that there is a when you try to join practically the through dissimilar materials look into the picture itself that material A and material B, two different materials. So, their physical and thermal electrical all these properties will be different and these two materials.

So, we found out that the difference of the specific; if there is a difference of the since there is a difference of the properties of materials between these two. So, most of the cases dissimilar combination of the materials, the beam got deflected with the towards certain material. So, if you see the figure in this figure that we started exactly the putting the focusing on the electron beam on the interface between the metal A and B. But if you look into throughout the depth of this penetration that gradually the beams been deflected towards one of the material; so, that actually creates the insufficient joint between these two dissimilar combination of materials.

But what is the physical sense or physical reason for this kind of difference? So, this one of the typical problem of the electron beam welding of the dissimilar materials, but this beam got deflected not always necessary that high amount of the deflection will happen; may be some certain combination of the materials the deflection can be also very small.

But anyway since the metal properties are different, so definitely we will be getting at least some amount of the deflection of the electron beam.

So, what are the typical design of the defection of the beam within this along the depth direction of this material? First thing is that residual magnetism may be one of the reason of weldments in their fixture residual magnetism may exist in the fixture; in case of ferromagnetic materials. And because during the welding the heat the beams get deflected due to the electron magnetism creation during the welding process that is the most important things when you during the joining of the dissimilar materials.

So, what may be the other reasons for the beam deflection another point is the thermo electric magnetic field caused by the temperature gradients. Of course, the thermal properties between these two materials are different; so, it may not be the single point the there must be some temperature difference between these two materials at the specific point. So that temperature difference as well as gradient; so, that temperature gradient to some extent, influent the thermo electric magnetic field that is typically known as the Seebeck effect.

So, that Seebeck effect is responsible for in this case joining of the dissimilar materials for the deflection of the beam. Another point is that sometimes the electric currents on the wall of the wall of the vacuum chamber of an electron beam welding process; actually when the electric current interacted with the electron beam. So, that actually responsible for the deflection of the beam. So, these are the typical 3 basic reasons that the deflection of the beam happens we observe in case of the electron beam welding process of the dissimilar combination of the materials.

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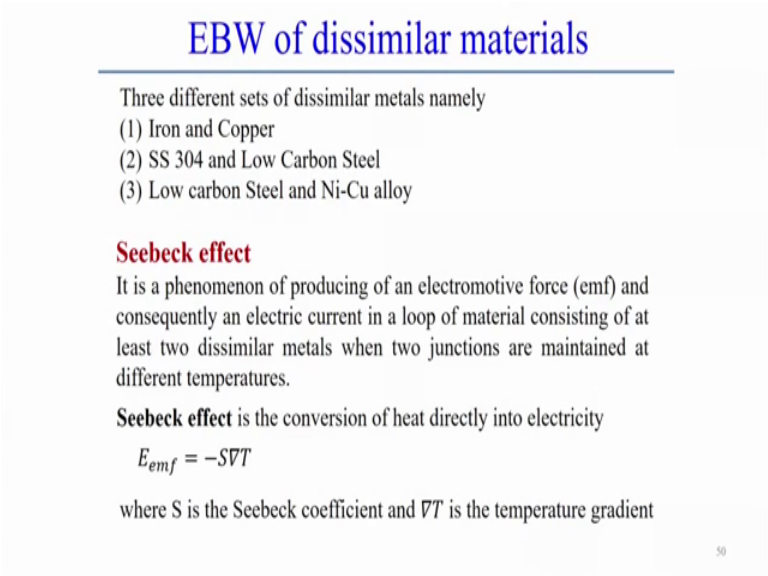

So, we can see that if we analyse that the electron beam welding of the dissimilar materials. So, here we consider the 3 different sets of the dissimilar materials that is the say for example, we want to join between the iron and copper, second is the stainless steel SS 304 and the low carbon steel, third is the low carbon steel and nickel, copper, alloy. So all these 3 dissimilar combination of the metals, if you try to join by the electron beam welding process; so ideally what will happen between these? So, before doing that we will try to look back that what is the Seebeck effect?

So, Seebeck effect is the phenomenon producing the actually producing the electromotive force and consequently an electric current in a loop of a material consisting of at least two dissimilar materials where the junctions are maintained at two different temperatures. So, that different temperature is basically creates the Seebeck effect, but Seebeck effect can be represented that it is a in general the conversion of the heat directly into the electricity.

So, that heat it comes in terms of the temperature gradients. So, E emf the electromotive force can be represented minus S into delta T, but S is the coefficience and delta T is the temperature gradient. So, basically the see presence of temperature gradient actually creates the some electromotive force that is the that is the; that is the Seebeck effect and that effect is basically responsible here to create the deflection of the beam.

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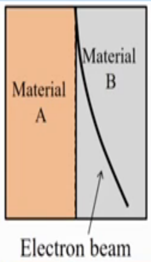
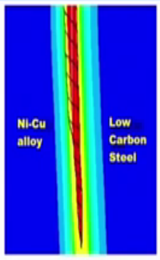
EBW of dissimilar materials



Higher seebeck emf:
Fe, low carbon steel, low carbon steel

Higher relative permeability:
Fe, low carbon steel, low carbon steel



Sl No	Metals	Deflection angle (degree)	Deflected direction
1	Fe and Cu	2.86	Fe
2	SS304 and Low carbon steel	2.50	Low carbon steel
3	Low carbon steel and Ni-Cu alloy (7150)	8.51	Low carbon steel

So, we have analysed this things that combination of these 3 materials and if you see that materials 1, 2 and if we roughly estimate that deflection angle if we look into this figure. So, beam is deflected towards the material B; so, during the dissimilar combination of the materials; it is important to know that the beam will be deflected in which direction whether towards material A or whether towards material B.

If you know the deflection of the beam probably there may be some solution to stop this deflecting of the material accordingly. Or may be other way we can we can initially we can initially put the focus on the beam to compromise the minimum deflection of the beam or maybe we can minimize the deflection of the beam. So, if we analyze these things that which material it will be deflected.

So, look into the table that combination of these 3 materials. So, in serial number one that iron and copper we estimate that deflection angle is around 2.86 degree. So, of course, the deflection angle is very small and this deflection is depends on the properties. And the basically this analysis has been done only considering the there is a Seebeck effect.

Now deflected direction; that means, deflected direction means the beam will be deflected towards the iron if we consider the combination of the iron and copper joint. So, beam will be deflected; so, for example, the material A should be the copper and material B should be the iron in this case; so, that beam is deflected towards the iron in this case. Second combination and we can see that stainless steel and low carbon steel here we estimate roughly estimate the deflection angle is around 2.5 all all although it is a very small, but beam will be deflected in this case towards the low carbon steel; that means, in this case the material A is the stainless steel and the material B is the low carbon steel.

Third is the low carbon steel and the nickel copper alloy. So, the nickel copper alloy if you see the, but in this case we estimated the deflection angle is very high let us say around 8.5 degree as compared to the other combination of the material, but in this case also beam will be deflected towards the low carbon steel. So, material A should be the nickel copper alloy and material B should be the low carbon steel. And we have seen that some stimulated results also that if you see the colour highlighted colour between these two the it is a simulation has been done between the nickel copper alloy and right hand side is the low carbon alloy. So, here if you see the beam is deflected actually towards the low carbons steel.

So, from that stimulation it is obvious that there must be some deflected; if we correctly consider the in the Seebeck effect in all these cases. But if we look into all these combination and we will try to look into the what are the higher side Seebeck electro-magnetic force? Seebeck emf will be generated all these 3 cases if you see the first cases iron, second case is low carbon steel and third case is also low carbon steel the higher side of the emf generation and higher relative permeability.

So, basically the magnetic permeability since the magnetic permeability of this materials are different; that actually that actually helps to create the beam deflection. So, in this case if you see the higher relative magnetic permeability or basically higher side more in case of iron first case, second case also low carbon steel and third case is also low carbon steel.

So, higher emf generation and then high amount of the electric magnetic permeability of all these this low carbon steel and iron. So, that is why all the cases we found out that beam is deflected either in pure iron or beam is deflected in the low carbon steel because the permeability relative permeability is more for all these 3 materials. So, this is the way if we know that about the materials combination of the materials and we can roughly estimate what are the beam deflection angles for the specific material when we try to use the electron beam. So, in this figure also another point out that this figure the red zone actually represents the depth of penetration; that depth of penetration we can see this type of depth of penetration can be created using the electron beam welding process. So, this specific size is entirely different from the laser welding process.

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Comparison between laser and electron beam welding

Perspective	Electron beam welding	Laser welding
Weld zone and HAZ	Narrow/smaller	Narrow/smaller
Penetration	Deep penetration	Lack penetration
Welding speed	Very high	high
Shielding gas	Not required	Nitrogen or argon shielding
Vacuum chamber	Required	Not required
Cost	Very high	Comparatively low
Generation of X-ray	Possible	Not-possible
Power efficiency	80-90%	10-20%
Size of work piece	Limited due to vacuum chamber	Not limited

So; so after discussing this typical issues in the dissimilar combination of the material welding using the electron beam welding process now we will try to overall as a try to compare between the laser and electron beam welding process. Because in this we will covering only the laser and electron beam welding processes. So, let us see in the in a summary that what are the difference between these two processes? First is that what are the different perspective is the first in terms of the weld zone and the heat affected zone?

So, in case of electron beam welding process it is a very narrow very small weld zone smaller in the sense it is a very narrow. But it can create the high depth of penetration laser welding also we can find out the narrow and smaller weld zone, so very narrow weld zone and depth of penetration is less as compared to the electron beam welding process.

Second point is the penetration of course, penetration deep penetration can possible in case of electron beam welding process; little low penetration welding low lack penetration can also be possible in the normal in case of laser welding process. So, so in this case the if we compare the depth of a penetration in this electron beam welding process is more as compared to the; in general laser welding processes. Welding speed very high welding speed can be used in case of electron beam welding process.

But as compared to the electron beam welding process the speed of the laser welding process is less. Because if we too much of high speed that actually may not stabilize the key hole formation in case of laser welding processes. So, there may be some limitation of the welding speed we can use depending upon the other combination of the primary and secondary variables, we used in the laser welding process.

Shielding gas electron beam since electron beam is producing the vacuum chamber; there is no need of the shielding gas in case of the electron beam welding processes, but laser welding process to protect the molten pool, we generally use the shielding gas either nitrogen or argon these are the typical shielding gas can be used in case of the laser welding processes.

Vacuum chamber in terms of the in terms of the vacuum chamber; so, electron beams welding process there is a of course, there is a need of the vacuum chamber other the beam control of the beam may not be possible. And laser welding process that is the advantage we do not need any kind of vacuum chamber. So, in a large scale welding process or very big component when there is a no limitation of the size of the vacuum chamber.

So, in that case laser welding can be a better solution as compared to the electron beam welding process. Cost of course, electron beam welding process is very costly process. So, cost is very high that is the main limitation of the electron beam welding process , but laser welding process comparatively low as compared to the electron beam welding process. Generation of the X ray in that perspective; the electron beam it is possible generation of the X ray, but laser welding even it is not possible in case of X ray generation.

Now, the biggest advantage of the electron beam welding process is that the in terms of the efficiency if you see the efficiency of the electron beam welding process around 80 to 90 percent, but in that laser welding is the less efficient 10 to 20 percent. So, there is a basic difference between the electron beam welding process and laser beam welding process.

Size of the work piece; there is a limitation of the size of the work piece in case of electron beam welding process and it is limited by the size of the chamber vacuum chamber. But in that case laser welding the size of the work piece material there is no limitation so; that means, for a big component if you want to do local welding process.

So, probably it is more easier to apply the laser welding process as compared to the electron beam welding process. So, by this we have tried to discuss about the laser beam welding process and electron beam welding process. And and what are the difficult issues and what are the recent advances in case of laser or electron beam welding process; we will try to cover through some basic knowledge of all these processes. So, thank you very much for your kind attention this is end of the module 2.

Thank you.