Welding Processes

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Laser Welding Process Part 03

Okay we will begin, so in the last class we were looking at the laser beam welding the keyhole right. So the most important factor which controls the stability of welding is the keyhole stability, so when you are doing laser beam welding with high-power so you need to achieve a stable keyhole otherwise, your weld seam properties and the weld geometry would be severely affected if keyhole stability is not achieved. So there are 5 forces which affects which controls keyhole formation, 3 forces which aid and 2 forces which actually closes the keyhole. The forces which are aiding keyhole they are what are the forces?

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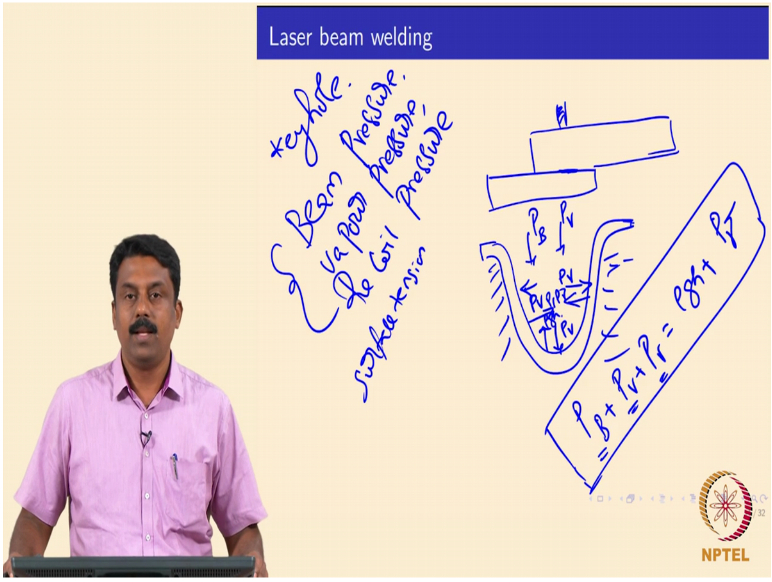

The beam pressure, beam pressure is coming from the momentum of the beam itself right so that comes from the power, the cross-sectional area right of the beam that is why it is known as smart (())(1:12) alright. So beam pressure and then the vapour pressure and then the recoil pressure, so these 3 pressures they aid keyhole formation right, so in that the beam pressure is the factor which is actually coming from beam power that the moment ok so the energy of the beam itself which actually comes from the beam. The vapour pressure is the vaporisation of the delicate metal which are welded, so the vapour pressure is generated generally when you are doing overlap configuration welding.

So welding if you are doing in overlap configuration ok something like this, so we are doing laser welding with this spot over here so the vapour that are generated at the interface, it affects the keyhole stability in a significant way specially if the material which you are actually using it has some coating. Say for example galvanized steel, so galvanised steel has a zinc player right and zinc vapour point of zinc is much much lower than the actual vaporisation of the steel itself. So if you are doing an overlap configuration, overlap weld of an galvanised steel, the amount of vapour that are generated from the vaporisation of steel, the amount of vapour that are generated from vaporisation of zinc can be very significant so that would affect the key hole stability very significantly right.

So especially if you are doing it in vowel of configuration without any gap, there is no gap, it has a simple overlap without any gap so there will be buildup of vapour inside the material, and then these vapour will tend to release is not it? So the vapour which is actually contained inside close geometry will tend to release if the gas which is actually generated is not released smoothly sequentially. And if it is released after accumulation of critical pressure then the keyhole stability will also affect is not it because for example, if you look at the force balance I showed you in a damp situation, so the beam pressure is coming from the beam itself is not it and then the vapour pressure is obviously so vapour pressure would tend to expand the keyhole in all directions, is not it?

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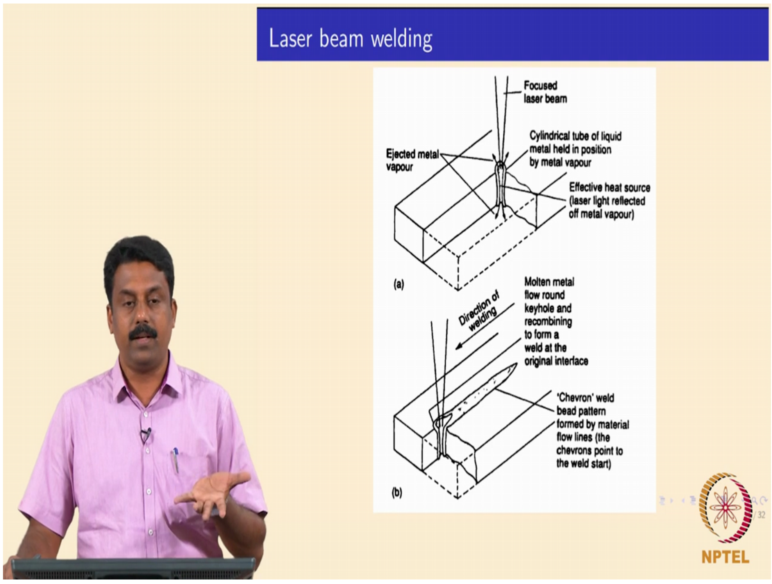

So the vapour pressure would expand keyhole in all directions because vapour generated they are trying to escape from the confined volume. So the vapour pressure can significantly affect the size and shape of the keyhole okay, so if the vapour which is actually generated if it is not released smoothly for example, if you are generating a very slow kinetic of vapour, vaporisation is very slow and steady that means it has to accumulate and upon accumulation of critical pressure it will expand is not it so there will be an explosion. So that would cause severe instability in the vapour so that is the reason the major reason for spatter formation doing laser welding.

The accumulation of critical vapour pressure and upon achieving critical pressure there will be an explosion is not it, so explosion release of the vapour inside the keyhole would cause spatter of liquid metals surrounding the keyhole is not it, so that is not advisable so the balancing the vapour pressure is extremely critical to achieve stable keyhole as well as the spatter free weld formation. Similarly if the vapour pressure gradually building then what will happen when we are doing a transient weld, the keyhole size would always expand continuously is not it? So if the keyhole side is expanding, the surrounding liquid metal pool volume would also expand is not it, the keyhole is expanding that means that the material surrounding the keyhole will also expand that means that the weld seam size would gradually change.

So you will end up getting 1st smaller keyhole but then if you are moving along the material in the interface the keyhole expands because of the accumulation of vapour pressure and then surrounding liquid metal will also expand is not it? Right, so the seam size the weld side itself will become maximum and upon accumulating the pressure once the vapour pressure reaches critical value it will explode, so then the keyhole will collapse fully so then you need not have any keyhole at all right. So then the shape and the symmetry of the weld seam is continuously changing so that is not advisable because you need to make sure that the weld seam in continuous and the same size when you are moving along the weld centerline from start of the weld to the end of the weld.

And we will see how the vapour pressure can dictate the keyhole size and shape in today's class because that is extremely important to achieve the stable keyhole right. So the 2 other forces which actually always oppose the keyhole formation obviously surface tension is not it? Surface tension of the liquid weld pool, so liquid pool surrounding the keyhole so obviously will tend to close because of surface tension is not it so the surface tension would always add opposite to the forces which are aiding the keyhole formation. Similarly gravity as weld, so gravity would always try to pull up with the edge to close the keyhole formation because in most of the cases laser welding is done down hand welding right.

So if you are doing down hand welding, that gravity will always oppose the keyhole formation. So obviously the force balance would be there right, so otherwise you may have in stable keyhole so force balance which I showed you in last class, the beam pressure, the vapour pressure, the recoil pressure should be the gravity plus the surface tension is not it. So the beam pressure is given by the beam power right, so that is the leather parameter what we are choosing. So you have high power that means you will have high penetration a larger keyhole, so obviously the PB right. The vapour pressure again it is very critical, vapour pressure can go up to 10 power 5 Newton per square meter ok so that is an enormous amount of pressure we are talking about.

And then the recoil pressure, recoil pressure is due to the release of vapour so when the vapours are released it is like a rocket, so when vapours go up they also have an opposite force subjected to the keyhole bottom keyhole surface is not it, so when the gases are released upwards, there is a downwards force is not it, so vapour pressure when the vapours are escaping from the keyhole there will be a pressure acting the opposite direction so that is what is called the recoil pressure ok, so recoil pressure is due to the operation of the liquid vapour upstream and recoil force will be created downstream and that would also aid the keyhole formation because it is going to push is not it so it is going to expand, it is like a mechanism of rocket propellant right.

So these 3 forces should always be equal or balanced to the opposing forces, if force balancing is adequate and properly controlled then you will have a very stable keyhole right it is clear. And most of the cases if the keyhole is not stable and that is due to the vapour pressure because beam pressure is anyway highly controlled right. In most of the cases when the stability is not good, it forms a lot of spatter and highly likely that that the vapour pressure at the interface is not adequately balanced by the other forces right. So we will see one example I show you when we carried out the experiment as a function of varying vapour pressures, how the keyholes will be affected, subsequently how the weld pool geometry is affected and the weld seam characteristic and spatter formation is affected by improper balancing of vapour pressure.

Right so this is clear right the keyhole formation so what I showed you over here, so this is a beam and this is molten metal surrounding the keyhole and this is the keyhole which actually formed by the keyhole formation by 3 forces, the beam pressure, vapour pressure and recoil pressure right so they form a keyhole, it is like. Why it is called keyhole because if you look at the door key, it is like the same shape okay that is why we call it keyhole right. And then surrounding the keyhole we have liquid metal which we already showed you in the previous class in the video, we will also see in this class as well. So now I am going to show you an example how the force balance can affect the stability of the poll right, so we will look at videos.

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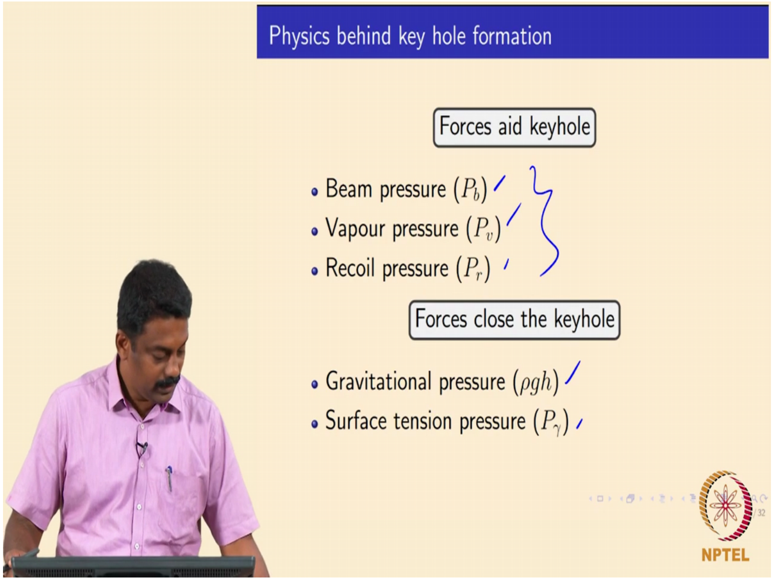

So where the forces should be properly balanced to achieve a stable keyhole formation, so forces that are aiding keyhole, beam pressure, vapour pressure, recoil pressure, close the keyhole with gravitational force and surface tension so this is the handwritten drawing from Lancaster ok. Lancaster simple cylinder mechanism so the forces aids the keyhole formation is recoil pressure, beam pressure, vapour pressure, those oppose is gravity and surface tension ok, so the gravity and surface tension would try to close the keyhole ok whereas, the aiding forces, recoil force, beam pressure and vapour pressure would always aid the keyhole formation okay and then surrounding keyhole we have a damn of liquid which is weld poll right.

So the force balance at the bottom of the keyhole so the aiding forces would always balance to the the closing forces right. So suppose if this force, the vapour pressure is significant then obviously the keyhole shape would not be same right, if vapour pressure is continuously gradually building when you are welding along the length of the weld that means that the keyhole is not in the same shape right.

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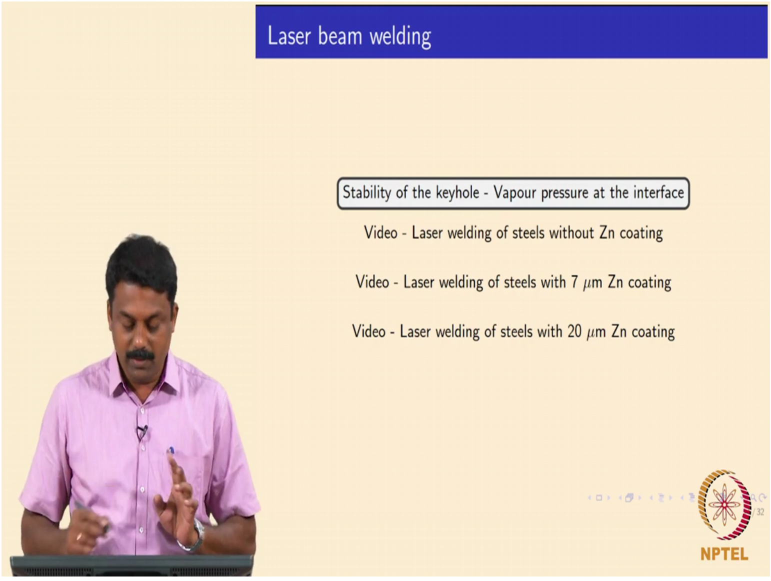

Let us look at it right, so the 1st video that I am going to show you is welding without any coating right, so how the keyhole is going to be without any coating, it is a bare surface of the steel right. Obviously, we can control the vapour pressure formation by balancing the force because there is no severely vaporising material on the surface okay. So the keyhole stability obviously will be very good because the vaporisation of steel can be controlled very significantly and very easily ok.

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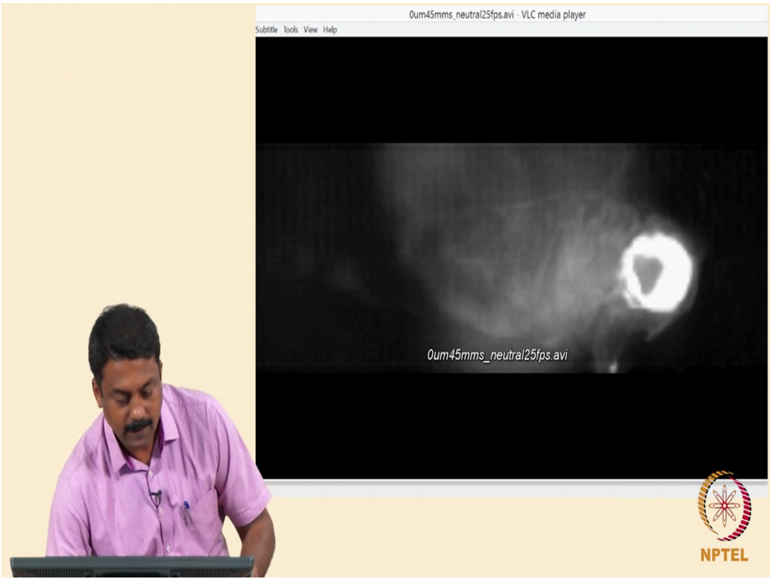

And if you look at the keyhole stability, it is it is extremely good. So what do you see over here is top of the, the top view, the video that you see in the Laser's point of view, how laser looks the base material or the interface ok. So you see the keyhole which is opening right and then surrounding, so the illumination is from the laser ok laser spot. So this is reasonably stable keyhole and then surrounding the keyhole we have a teardrop shaped weld poll right. So now and this is a stable keyhole, and imagine unstable keyhole how would it look like? So we will move on now to overlap configuration overlap welding of 7 micron thick galvanised zinc right.

So obviously if we have a zinc layer so zinc is operating much easily than the steel surface, so now we see over there so what is happening to the keyhole ok, so there will be an expansion and continuous expansion, and upon expanding critical volume there is an explosion, you see that now, can you see that? So when the sink vaporises and it gets trapped at the interface and zinc vapour is gradually building up at the interface at the centre of the keyhole in the middle of the keyhole. And upon achieving critical pressure, vapour is vapour pressure is released suddenly and causing an explosion ok, those explosions obviously would also take liquid metal outside from weld pool and we call it as spatter right.

So you see over here the keyhole is not stable, so now there is an explosion is not it? So keyhole is reducing it and then expanding and suddenly upon reaching critical pressure and the pressure from the middle of the plate exploding from the top of the keyhole because we are looking at the top surface ok. So the gases are accumulating at the interface because there is overlap joint is not it. And then they are accumulating upon reaching critical pressure they explode from top and bottom ok. So during this explosion obviously it also takes liquid metal from there that is why you call it as spatter ok.

So this is due to the accumulation of critical vapour at the interface and most of the cases this would happen when you have lower vaporisation point coating like zinc coating at the interface, and we do not have any gaps. There are various ways we can overcome, so one way of overcoming is to maintain some gap between interfaces, so that is what is known as the preset gap ok, so if you maintain some gap so obviously you have some vent for the vapours that are actually forming at the interface right. Or other way of overcoming is which we found from our research is through using zinc vapour beyond critical limit always.

So what do we mean by that, so in this case what is happening is, so when you are welding with a 7 micron thick so zinc is vaporizing but it is released upon reaching a critical vapour pressure right, so that way it is affecting the keyhole stability significantly. Having vapour gradually building up vapour pressure gradually building up, what if we make enough vapour which would always getting released from the interface it would expand the keyhole, which is also not bad because you will also end up making a somewhat larger seam but your weld pool stability will be much more higher than releasing the gases in the explosive manner ok. So what we did is instead of having a 7 micron thick zinc coating, I have 30 micron thick zinc coating. So what will happen then, so we may form much large volume of vapour continuously, you see that now.

So this is 20 micron case, the keyhole is much-much bigger than uncoated material but you see that the stability of the keyhole is improved is not it, so in this case what is happening here is the zinc paper thickness is higher almost like 2-2.5 times, 20 micron thick. So due to that we have a lot of zinc is vaporizing and the vapour pressure already reached beyond critical limit so it is getting released continuously so by doing so we are expanding the keyhole right, the keyhole diameter is increased compared to the new zinc coating material, so the zinc the keyhole diameter is increased significantly right but the stability of the pool is improved because in 7 micron case there is a critical pressure beyond which there is an explosion.

In this case because we generate more vapour of zinc and zinc is continuously released from the interface that means the vapour pressure is increased, keyhole is expanded ok key hole is expanded but it does not matters but (())(18:09) is improved is not it. So it shows that the vapour pressure can play a significant role in keyhole stability okay, so if vapour pressure is not gradually is not continuously maintained if it is not balanced by the closing forces right, closing forces may try to act, when the vapour pressure is little then the closing forces they try to close the keyhole and vapour pressure would gradually built and then suddenly once it reaches the critical limit, vapour has to expand vapour has to escape right.

And then during this process there is an explosion, explosion can lead to an instable keyhole and this explosion can also take liquid metal out elsewhere that is what is known as pattern right so because liquid metal goes elsewhere and then form pattern serious pattern. And we can avoid that right so either by maintaining a preset gap ok so that bending can be there, but maintaining preset gap is also very tricky because geometrically if you maintain preset gap after welding, you may also have some notch like resistance spot welding, is not it. So the best way of doing it is to increase the vapour formation, so you always have enough vapour pressure which can push the keyhole walls so that the gases which are actually accumulating at the interface can come out smoothly and steadily from the keyhole Centre right.

By doing so we can improve the welding properties the weld seam properties right, so now this is the case for 20 micron thick, you see the keyhole is expanded but the shape of the keyhole is very uniform is not it, you see the gases that are coming out you could see that and then the pool is very stable, there is no spatter right and then the weld seam size it will be bigger than the no zinc coating case, what does it matter? The weld is good, more spatter because of continuous operation of zinc vapour from the interface right because now we are balancing the forces in such a way that the vapour pressure can continuously aid the keyhole formation in a steady-state right.

So comparing to this we will go back to 7 micron and see that, so in 20 micron case keyhole was bigger but it is very steady where as in 7 micron case so it is closing and then expanding and then see that an explosion and then closing continuously, again expansion explosion, upon explosion closes and expands and then continuously steadily and upon a critical pressure and then there will be an explosion of the keyhole which would push the liquid metal to surrounding area forming spatter. So this is a very up world welding condition, in all the 3 cases the be pressure is the same, the welding parameter the beam pressure is the same ok, the only factor that influence here is the vapour pressure and recoil pressure ok.

So recoil pressure is a product of vapour pressure okay so if you change the amount of vaporisation at the interface, obviously their proportion also change and vapour pressure would affect the recoil pressure significantly if the pressure is not maintained in the steady-state. If it is continuously built up, obviously the keyhole stability will also change continuously and then vapour reaches critical pressure to be on which they explode, releases abruptly from the keyhole causing explosion, spatter and then instability in the welding right.

Student: Sir, where is the keyhole like this is moving…

Professor: This is actually moving…

Student: This is the work piece the black one.

Professor: The black thing is work piece. Okay so what you see over here is the illuminated spot that is from the laser ok, and this is a whole. You see this opening so this is a through thickness whole okay so it is like a cylinder what I have drawn ok, so the cylinder and obviously the surface tension would close the bottom, the liquid would come in contact with that. So it is like the old coffee tumbler okay so it is like like this in the wall ok. So what do you see over here is the hole which is actually going until the bottom, and the bottom you will have surface tension closing however, is you will have a through thickness whole which would remain.

Sometimes if you use a very high power you will have a continuous whole where the liquid cannot fill, surface tension of liquid cannot close the whole, you will end up forming hole at the end of the weld that will continue okay that will happen because if you have a very high beam pressure, you may have a full hole and if you maintain the pressure generally we maintain such a way that at the bottom the liquid surface tension would close okay by a small layer and then subsequently when you are doing welding the keyhole would be supplied by liquid metal from the adjoining regions ok so this is the hole what you look at it here.

Student: How do we give the gap?

Professor: Yes, the preset gap we need to maintain by fixtures clamps.

Student: Between the workpiece?

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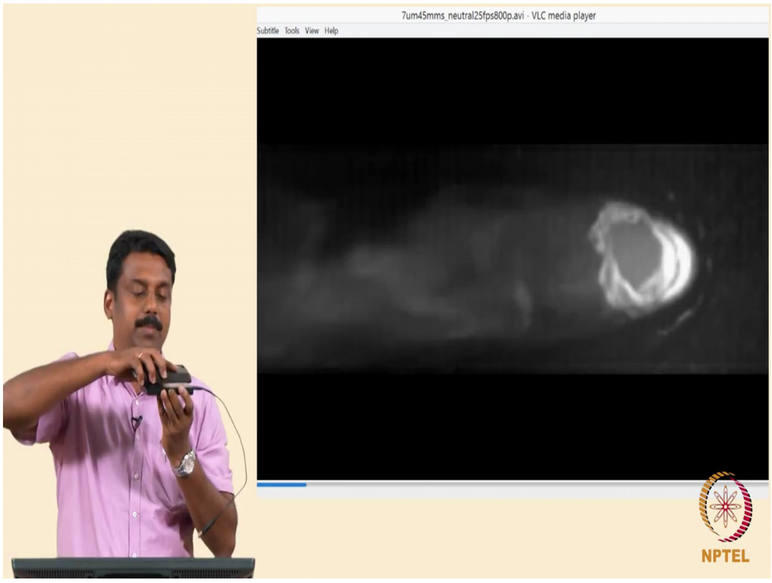

Professor: So it is done like this okay, so the videos I showed you they all done something like this, no gap and then do a weld something like this right. So the preset gap you can maintain but geometrically it is not advisable, so you can maintain some gap between these 2 ok very tiny, I am not exaggerating, very small gap of say 200 micron or so, so that gases can be escaping from either sides or that is not advisable. If you are doing welding so obviously there will be a gap maintained after the welding in either sides as well, is not it? So then it is not good because stresses will be severely acting on the weld itself right so the preset gap is not advisable especially if you are using thin sheets like in automotive industry right.

So instead of doing it the best way of doing in this case, because if you use a very small 7 micron thick zinc layer, the vapour pressure which is building up it is not severe, so it gradually builds up so you are welding at so vapour pressure builds up and you are moving in this direction and then there will be explosion where the vapour which are accumulating would explode and come out like in this video. And then if you move continuously under some regions, the seam would be increasing and then suddenly there would be an explosion like we see over here in this video ok that is what happens here so shrinking, now keyhole is closed.

You see that ok and then see now the keyhole explosion and keyhole is closing and then becoming larger and then explosion right, so now it is exploding and then closing now yeah again explosion right. And compared to this case, 20 micron case if you look at it and the keyhole is always open, is not it, the shape of the keyhole is very steady it does not change. And you see the vapour in the top which you do not see in the previous case, in this case the vapour is continuously released because the critical pressure for releasing of vapour to overcome the closing forces is always there, that means enough vapour pressure is pushing the keyhole walls and then the vapour can be released continuously from the interface ok, it is clear and leading to much more stable keyhole it is clear.

So this is extremely important to look at if you are doing keyhole welding to improve the stability, so you need to look at the weld seam. If you have a spatter obviously you may have a severe vaporisation, so you need to balance so once we are balancing, suppose if we do not have any advance mechanism, you can play on the beam pressure okay. So beam pressure beam pressure can be calculated in laser welding case (())(26:41). So beam pressure is the laser power divided by the cross-sectional area of the beam that means the beam size beam spot size and then the velocity of light ok, so that is what laser beam welding, the beam pressure is ok.

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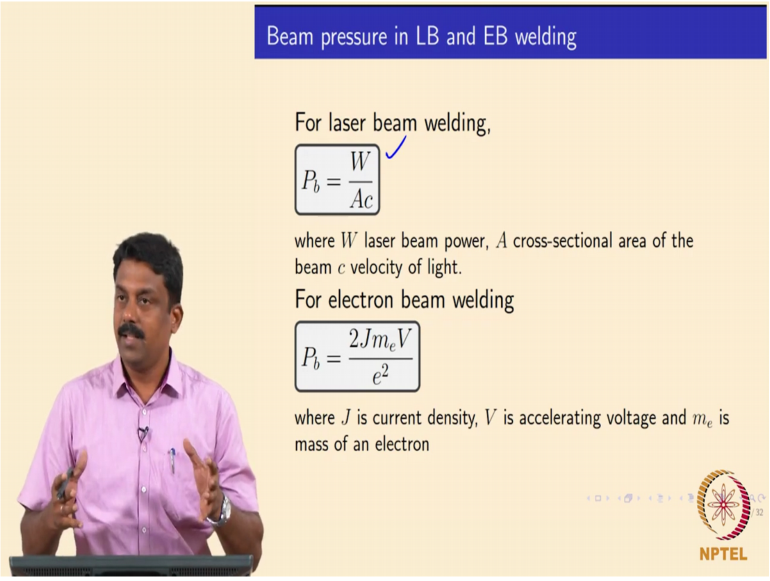

So if you think that you know your keyhole stability is not good that means you are vaporising more. So one way of avoiding or one way of improving stability is to play around with the first beam pressure, but we have cases like this the playing around beam parameter will not improve the keyhole stability ok. So then one way of doing is either to achieve the steady-state you will vaporise more okay so you end up vaporising more so that keyhole is always expanded to release the gases that are trapped at the interface okay, so vapour pressure can be much higher. The hole is expanded and then vapour can be sent out from the keyhole surface right.

Recoil pressure we can't control because recoil pressure is the product of the vaporization rigt. Again surface tension is the material parameter and that has a very little influence, gravity is there ok so it is always there, you can pair on the inclined angle weld to improve the keyhole stability. Or in most of the cases for example, when you are doing welding in vacuum or in control atmosphere, the keyhole stability can again significantly affect it because of the influence of gravity ok as well as the vapour pressure which is that is containing. Suppose if you are welding it in high pressure condition okay, so you are welding in high-pressure environment, there is no way the gases can escape okay because the atmosphere is high-pressure is not it.

So there must be a pressure drop, Delta P should be there so that the vapours which are generated in the keyhole can be escaping to the outside right. So in high-pressure environment when you are doing welding, especially if you are doing underwater welding with a closed environment the keyhole stability is a big issue because you cannot form keyhole at all because in order to form keyhole you need to have a vapours released vapour pressure generated and recoil pressure should be generated, and those are generated by the escape of vapour from the keyhole. If there is no way the vapour pressure and the (())(29:24) that means the vapour is not allowed to escape (())(29:28) right.