Welding of Advanced High Strength Steels for Automotive Applications

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Lecture - 12
Introduction to Laser Beam Welding - Part – II

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So in this video we looked at the deformation of keyhole as well as the whirl pool, liquid pool which actually forms the surrounding of the keyhole. The stability of keyboard is extremely important for that as I already told you. And if you have instable keyhole and it can also cause instability in the weld pool. And if you have an explosive a keyhole that is formed and during the welding process due to instabilities we may also have an explosion.

And subsequently these explosions in short bursts can lead to a spatter formation and the instable pool can also lead to the changes in the solidification behavior of the material. And so if you look at the weld pool, we have an as a tear shaped weld pool and if lasers heat source is moving and the material the liquid cools down and forming the solidification from its fusion boundary towards the weld center line, okay.

So, because of the extreme temperature gradient percent in the fusion boundaries and the solidification is generally in a columnar manner.

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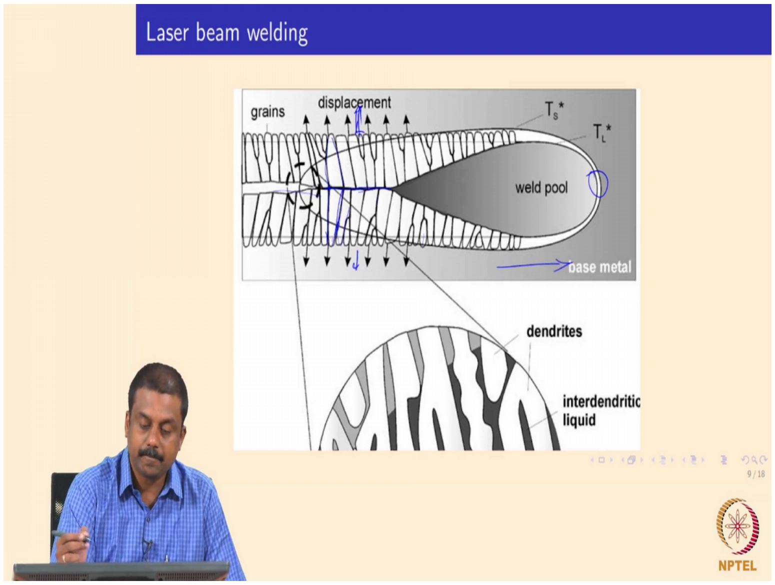

So, as shown in this diagram, so, what we looked at in the high speed video, this is actually also shown in this schematics. So we have a weld pool, a keyhole is somewhere over there, here, is formed. So if you link it with the keyhole so we have a liquid pool that formed in a tear shaped manner when the source is moving along this direction the weld pool solidifies under this process. So, we have a solidification that is happening from the fusion boundary towards the weld center line.

So if you look at it in this picture, the solidification is morphology similar to what you have it in resistant spot welding where we have when a columnar grain growing and meeting coalescing at the center of the weld pool. Again because of this solidification morphology, you have segregation and the solidification grain boundary as well as at the weld centre line. And apart from this segregation you also have a solidification shrinkage leading to a tensile stress development at the weld zone and because when this; the solidification happens we also have a volume shrinkage.

But these volumes shrinkage is accommodated by the tensile stress applied from the heat affected zone leading to an tensile stress generation in the weld zone and if these tensile stress is not accommodated and if you have an as with strong center line segregation, it will end up cracking the weld center line resulting in solidification cracking, okay. So that we will see in detail the solidification cracking in during lesson advance high strength steels in and when you look at the welding metallurgy.

So right now we can see that you know are these the solidification is progressing from the fusion boundary towards weld center line in a columnar manner and with segregation the grain boundaries as well as weld centre line.

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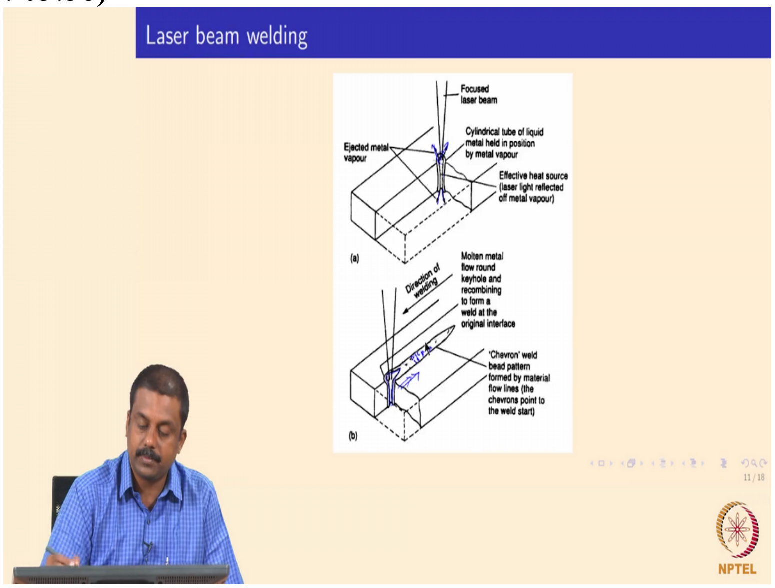

And if you look at in depth now what is happening inside the key hole, so basically you form a key hole by the evaporation of the substrate and once you have evaporation you eject the metal vapour that is formed in from the top and bottom of the key hole. And because of this evaporation you also have various forces that are generated and we will see in the subsequent slides the forces and how we can balance it to from the stable keyhole.

And after the representation basically you know, you also have a heat dissipated towards the adjoining regions of the substrate leading to the welding of the substrate. So, this keyhole when you have a stationary weld you have a circular hole and through thickness hole when you have a transient welding situations, keyhole also gets elongated forming the shape what you see in the what we have explained in the previous slides.

And in the shape of a keyhole in a door for example and because of the transient moment of a weld laser source with respect to the sample substrate, subsequently, when you move away the surrounding liquid metal solidifies in the columnar manner forming the solidified microstructure.

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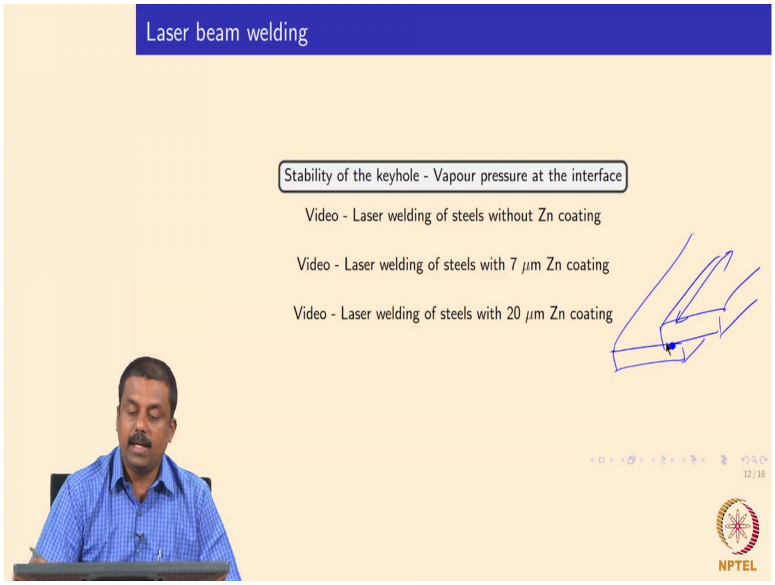

So, the stability of the Keyhole is determined by the amount of the vapor you generate during this process. So, for example you may also have some of the coatings you are applying in especially in automatic Steels we use galvanized zinc coatings under seals of substrate and zinc wrapper is much more, easily much more vaporizes at low temperatures than the seal itself.

And when you have an overlap joint that is what most likely in the most of the automotive applications you have an overlap joints and you may also tend to trap the zinc vapor that is formed at the interface and it can lead to severe disturbance in the keyhole stability as well as the weld pool stability. So it is important to understand the vapor pressure at the interface because that is going to determine your keyhole stability.

And that is again determined by the nature and the thickness of your corrosion production coating you have what the interface. So I will show you three examples of keyhole stability affected by the vaporization at the interface in overlap joint and without any piece of gap. So, there is no gap just we have in a welding carried out in a overlap configuration. For example overlap configuration and then we have a laser welding somewhere along the overlap configurations shown in this picture right.

So, because of the vapor generation at the interface due to the vaporization of in this case zinc so we may end up trapping gases in bit, in the interface and this can severely affect your keyhole stability. So, how it is going to affect we will see in subsequent videos that I am going to show you. The first we look at laser welding of advanced high strength steel without any zinc coating.

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So, this video shows laser welding and the keyhole stability without any zinc coating. If you look at it here your key hole is so more or less stable it is expanding which is but it is not irregularly changing as compared to in the other cases what I am going to show you in subsequent videos. And this is reasonably a stable keyhole which we have in a circular keyhole.

And the weld pool which is formed surrounding the keyhole so, you do not see any visible spatter formation because of a reasonably good keyhole that formed and during welding of the uncoated dash steel. Suppose instead of using no coating if you use a zinc coating of some 7 micron thickness and because of the vapour generation at the interface lead to the accumulation of vapor at the interface.

And subsequently when the vapour pressure builds up and because of this vaporization of zinc percent at the surface of these Steels and it can be released suddenly when upon a critical vapor pressure leading to the explosion of the key hole and this explosion can also cause severe turbulence in the surrounding weld pole leading to spatter formation. Say for example, in this case, so we have a 7micron steel.

Zinc coating is applied on a steel and subsequently we weld it on a overlap configuration and you see over here keyhole is extremely turbulent and violent when compared to the last uncoated welding casing. So for example if you look at the time from the beginning again, so keyhole is expanding and there is an explosion upon a particular pressure. You see the keyhole expands and then contracts.

And during this expansion basically you push surround liquid metal and then this is actually a sped-up which is actually formed and because of the explosion of the keyhole and due to the build-up of the vapor that is generated at the interface due to the appreciation of zinc in overlap configuration. So, this in this case because of this unstable keyhole, you end up forming and a discontinuity in the weld as well as the severe spatter formation.

And during this process leading to a poor quality the weld in terms of properties as well as in terms of appearance, so now we need to understand how we can control the vapor pressure. So, one way of doing it what we found from our research in my earlier research group, so by increasing the coating thickness from 7 micron to 20 micron so what we found is so we may vaporize more volume of zinc leading to a production of continuous supply of zinc vapour.

That can lead to an expansion of the key hole compared to the steel welded without any zinc coating. But the keyhole stability is improved significantly and because of that you know, we can reduce the spatter and we can improve the weld pool stability significantly. In this case we have overlap galvanized sheets of 20 micron thick and if you look at it and because of increasing zinc coating thickness we generate more volume of zinc vapor and which is continuously released at the top of; top and bottom of the keyhole leading to an expansion of keyhole.

But the keyhole is extremely stable compared to the 7 micron thick galvanized layer. So, thereby you know, because of improved stability of keyhole, we can avoid the formation of spatter due to the increased amount of vapor generation leading to a much more stable keyhole compared to 7 micron case. And in 7 micron case, the vapor is not released continuously vapor is trapped at the interface and upon reaching critical vapor pressure might release in explosive manner leading to like an instable key hole and spatter formation.

Whereas after increasing the zinc coating thickness and we you form a much more volume fraction of vapor and due to that you know, the vapor is continuously released leading to better stable better stability in keyhole as well as in the well pool and with this we can also improve the weld quality. Again so the by understanding the vapor pressure and the key hole stability, we can modify either the material as well as the process to get a good a period weld, the stable weld as well as a good property weld.

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So the lesson I want to tell you here is the keyhole stability is extremely important to obtain a good quality weld and spatter free weld. And if you see unstable keyhole during welding process we may end up producing a lot of spatters as well as your weld quality deteriorates in terms of appearance and the geometry.

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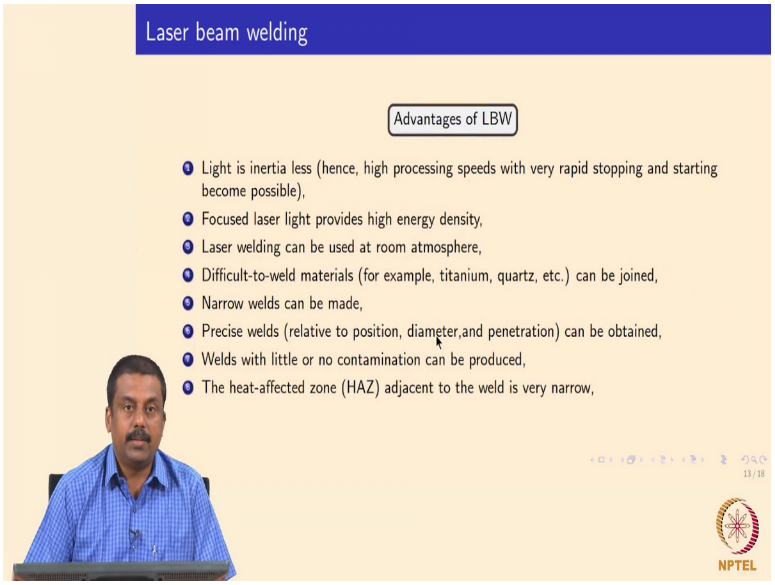

So, we move on the advantages of laser beam welding. The main advantage here is, laser is extremely manipulative. So, we can transport laser from one location other locations and it can also be turned and off very rapidly. And also laser is inertia less. So, then, due to that we can process it much more rapidly and transport it one place to other place very easily. So, if you focus a laser light into a substrate, we can transport the energy almost without any loose, without any loss in energy.

And the one of the major advantages of laser is it can be operated at room temperature. So, on contrary to other high beam processes for example, electron beam melding which is done at the vacuum, laser can be operated in a room atmosphere because it is just light photons. And we can also use laser for dissimilar welding and because of the extremely in the concentrated heat source and we can make very narrow welds in precise locations because again a laser can be focused on to a very narrow and precise locations.

So, the fit up is improved tremendously and we do not need any impractically shielding gases because you also have welds made without shielding gas. And welds so can be made because of narrow configuration no contamination and the temperature gradient in the weld is extremely steep. So, you move away from the fusion boundary to base material within a few millimeters in a typical 1.2 to 1.5 mm sheet thickness steels. So the heat affected zone is very narrow and there are some disadvantages due to the narrow heat affected zone.

We will see that later. So, the main advantage of laser beam welding is laser can be manipulated at very high speeds. It can be focused to narrow regions to produce very narrow welds. The heat affected zone is also very narrow due to the steep temperature gradients we obtain during welding.

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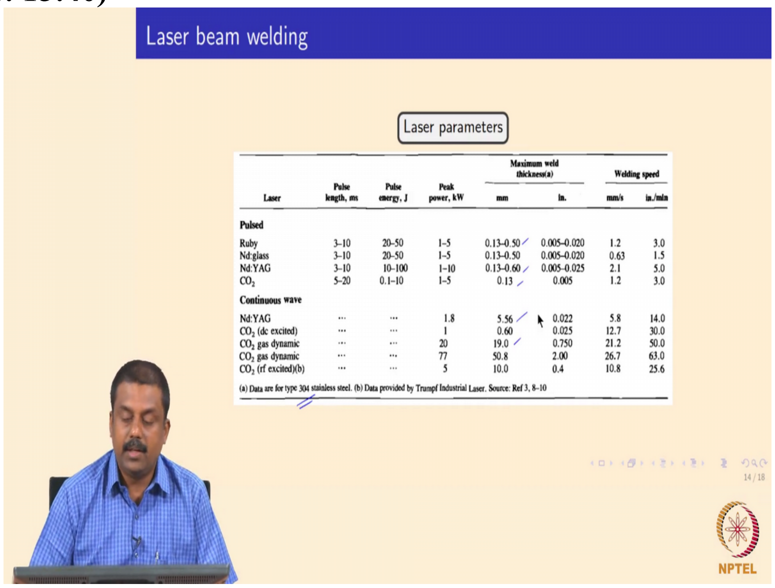

Laser	Pulse length, ms	Pulse energy, J	Peak power, kW	Maximum weld thickness(a) mm	Maximum weld thickness(a) in.	Welding speed mm/s	Welding speed in./min
Pulsed							
Ruby	3–10	20–50	1–5	0.13–0.50	0.005–0.020	1.2	3.0
Nd:glass	3–10	20–50	1–5	0.13–0.50	0.005–0.020	0.63	1.5
Nd:YAG	3–10	10–100	1–10	0.13–0.60	0.005–0.025	2.1	5.0
CO_2	5–20	0.1–10	1–5	0.13	0.005	1.2	3.0
Continuous wave							
Nd:YAG	...	...	1.8	5.56	0.022	5.8	14.0
CO_2 (dc excited)	...	...	1	0.60	0.025	12.7	30.0
CO_2 gas dynamic	...	...	20	19.0	0.750	21.2	50.0
CO_2 gas dynamic	...	...	77	50.8	2.00	26.7	63.0
CO_2 (rf excited)(b)	...	...	5	10.0	0.4	10.8	25.6

(a) Data are for type 304 stainless steel. (b) Data provided by Trumpf Industrial Laser. Source: Ref 3, 8–10

So, this slide I just borrowed it from an ASM handbook showing the laser parameters generally used for varying thicknesses of material. For example, here is actually I took it from reference which actually showed welding parameters of high strength steel of a varying thicknesses for example from 0.5, 0.6 and 5.59, 19.0. So, those are the maximal thicknesses CQ can be operated welded using various gas hoses, laser sources and you can take this reference when you are designing your welding parameters.

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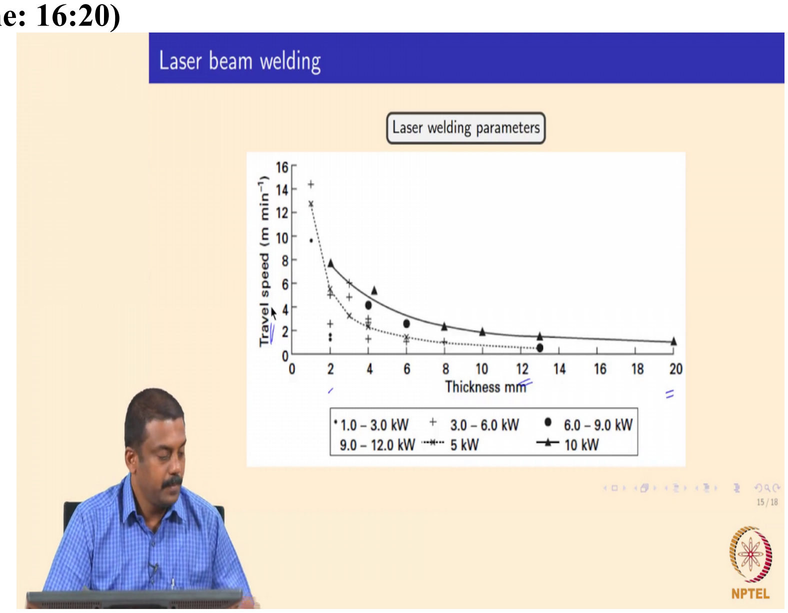

So, the laser welding parameters again it is also function of thickness and the travel speed. And if you use a larger thickness material for example 12mm material so, you can choose laser power based on your travel speed or welding speed and there are a lot of literatures you can find in open literature's for various materials. And so this slide actually shows the laser welding parameters of mild steels of varying thicknesses from say 2 mm to 20 mm and so what are the typical laser powers you need to weld these steels at a given welding speed.

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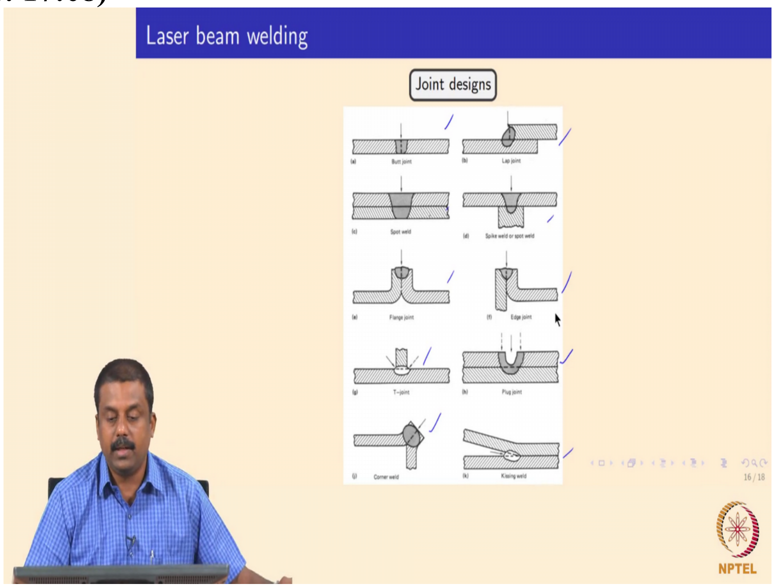

So, joint designs because of the very easy the manipulative nature of the laser and laser can be focused into various joints, so we can make a bud joint and lap joint. You can also make a spot weld using laser which is also considered advantageous in various aspects so in a spike and then a flange or even in edge joint and a T joint and a plug joint in this case. That is similar to what you do it in the conduction joint I can be do it in a corner weld or in a Zinc weld.

And some of these configurations are very difficult in resistance spot weld whereas any laser welding so because of the accessibility is of an accessibility it was a beam. So, we can focus the laser beams in various locations and these joints are all made possible using laser.

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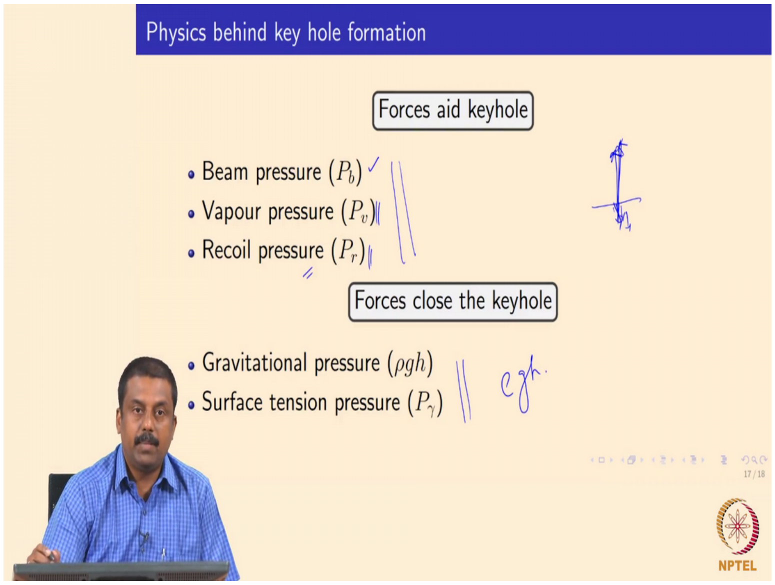

So, some physics about keyhole formation and then we wind up the laser welding. So there are 5 important forces that control the Keyhole formation, as I had already explained about keyhole formation is extremely critical in laser beam welding. A good stable key hole is formed by balancing the 5 natural forces and during welding. So there are 3 forces which actually aids the keyhole formation and two they try to close the key hole.

And if you do not have a balancing between these 2 types of forces and you have an extremely unstable keyhole. The forces that are generally aid the keyhole or a beam pressure. So, that is the photon or the pressure which is actually applied by the laser beam itself and the vapor pressure, the Vapor pressure which is the pressure generated by the metal vapor due to the attenuation of the photons and the recoil pressure.

Recoil pressure is nothing but the pressure erected onto the keyhole by the release of vapour from the keyhole. It is very similar to a rocket principle. So, when the metal vapors go away from a substrate so this vapor going away can also push the substrate towards the other direction. And this is generally happens when you have a severe laser formation and when the vapor escapes from the for example a liquid regions.

And this vapor also erects an equivalent force in the other direction which is known as recoil pressure. And these 3 poses will always aids the keyhole information. That means that when you increase the beam pressure so you also widen the keyhole. When increase the vapor pressure you also widen the keyhole and keyhole recoil process is higher that will also lead to the increasing in keyhole diameter.

The other 4, 2 forces which forces the keyhole to close and that is the gravitational pressure that is given by the Rho gh. The gravity and the surface tension of the liquid which is surrounding the key hole would always try to push the key hole in. So if you have one have an stable keyhole and these two types of pressures should be balanced. And if any one of them exceeds, supersedes the other one, obviously you may have instability in keyhole.

For example the video I showed you we have a very high amount of vapor generated leading to an increase in upper pressure at the interface and this vapor pressure is not a steady at steady state it is continuously building up and then released. Again it is building up and leading to an keyhole expansion and sudden collapse on the keyhole because the keyhole is not the force is not balanced.

So the vapor pressure leading to a buildup of the force and then the release of pressure leading to an explosion resulting in the keyhole, expansion contraction in the wild manner.

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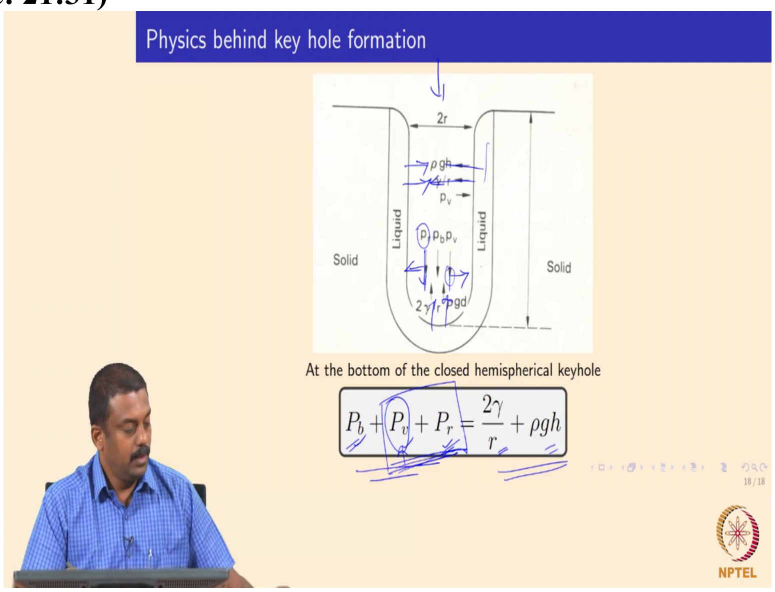

So schematically if you look at it so this is a typical keyhole what you see in the video as well. So these three poses so are balanced by the key forces that are forcing keyhole to close. So you have an beam pressure, vapor pressure, recoil pressure which aids the keyhole should be balanced towards the surface tension of the leak the weld pool you have in surrounding the keyhole and the gravitational force.

So you have the recoil pressure which is acting in this direction of the keyhole and the beam pressure which is when the beam is coming from this direction. You have pressure of the beam aiding the, the keyhole formation as well as the vapor pressure, which is actually pushing the keyhole to open along this direction as well as in this direction. And the gravitational force which will try to pull the key hole towards inside as well as the surface tension of liquid will also try to pull the keyhole inside.

Similarly in this direction as well your surface tension will try to close the keyhole and the gravity as well. They will try to close the keyhole. So, if you have one of the pressures building up and exceeding the other pressure which is aids the keyhole then you may have instability in keyhole information. So the most important force that effects the keyhole stability as we have looked at in video is the vapor pressure at the interface because being pressure is determine by your laser beam characteristics.

The vapor pressure because of the vaporization of metal can lead to steady buildup or the collapse. And the vapor pressure under the amount of vaporization can also determine or can also change your recoil pressure. So the important forces that control the stability of the force the keyhole is the vapor pressure and the recoil pressure. So with that we will wind up the laser welding process characteristics.

So we looked at in detail about the physics behind the laser welding. So in this lecture we looked at the effect of various pressures acting at the interface and that derives that drives the formation of keyhole. And if you have severe metal vaporization at the interface, how the keyhole is affected by the vapor pressure build up and how we can modify the key goal in order to improve the weld stability. So it is important to understand the nature of the vaporization of your substrate suppose if you have a galvanized sheet.

So, we may also severely vaporize the surface at the interface leading to an instable process. So, if you want see the stability issue so we like to look at the keyhole. And if the keyhole is not stable then we may have to work at your, the force balances upon looking at your various forces that are acting at the keyhole whether it aids the keyhole formation or closes the keyhole formation. And we can understand why the instability is happening at the key during welding and subsequently we can overcome this problem. Thank you.