Welding of Advanced High Strength Steels for Automotive Applications

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Lecture - 11
Introduction to Laser Beam Welding - Part - I

So we will move on to the next welding processes that we have looked at you know in introduction to the welding processes using automotive industry. So we looked at in detail about the resistance spot welding. Resistant spot welding as is a unique characteristics and it is used for welding of thin sheets of automotive Steels. The other welding process which is commonly used in automotive industry apart from resistant spot welding is laser beam welding okay.

So laser beam welding you know it has its own advantages as well disadvantages compared to resistant spot welding. And we look at in detail first the working principles of laser beam welding and why we need why we use laser to as a heat source in the welding processes and even detailed the, some of the characteristics of the laser welds that we make in automotive Steels okay. We move on to the introduction about laser beam welding.

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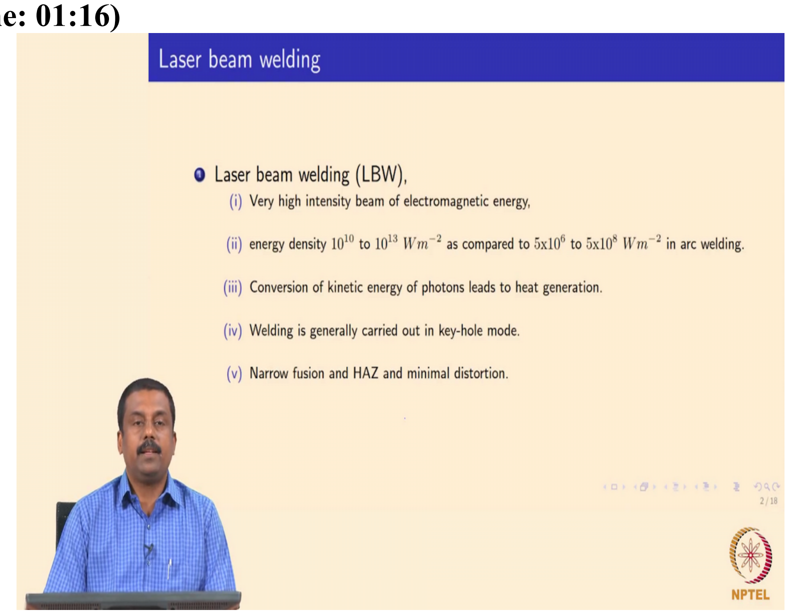

So, laser beam welding as I told we use the laser as a heat source to heat up the work piece and melt and then form a fusion joint. So the laser we all know that it's a very high intensity beam of electromagnetic energy, so we make use of the electromagnetic energy the photons the light photons to heat up the work piece. And how do we heat up the work piece? Because when you pass on a laser beam the kinetic energy of the photons in laser beam is converted into heat energy in the work piece when they get attenuated in the work piece.

So, energy density of the laser beam is extremely high compared to the conventional arc welding processes. So for example in a typical Nd-YAG laser source the current density can vary from 10 power 10 to the 18 watts per square meter as compared to the 10 power 6 to 10 power 8 in arc welding processes. And because of the extreme the energy intensive the heat source which is laser and the most of the welding process welding week is carried out here in keyhole mode.

So keyhole what is key hole? It is extremely important to understand what is keyhole. I will explain in detail in any subsequent lectures. So Keyhole is basically you have a full penetration. The weld is made in full penetration mode and because of the concentration of heat in a very, very narrow region your fusion zone which is formed in the laser beam welding is also very, very narrow.

And the temperature gradient also is very steep so resulting in narrow heat affected zone and also as well because of the these reduced size of these heat affected zone, you may also expect a minimal distortion laser beam welding. So these are the advantages of laser beam welding and compared to the conventional fusion welding processes and the laser is also extremely easy to manipulate. So we can all we can transfer laser beam from one place to other place very easily using an fibers.

And we can also focus it in various places and we can also defocus it to our advantage and we can also produce the varying intensity and as well as the power in a given source. So these advantages you know they make lasers attractive as a heat source for welding processes.

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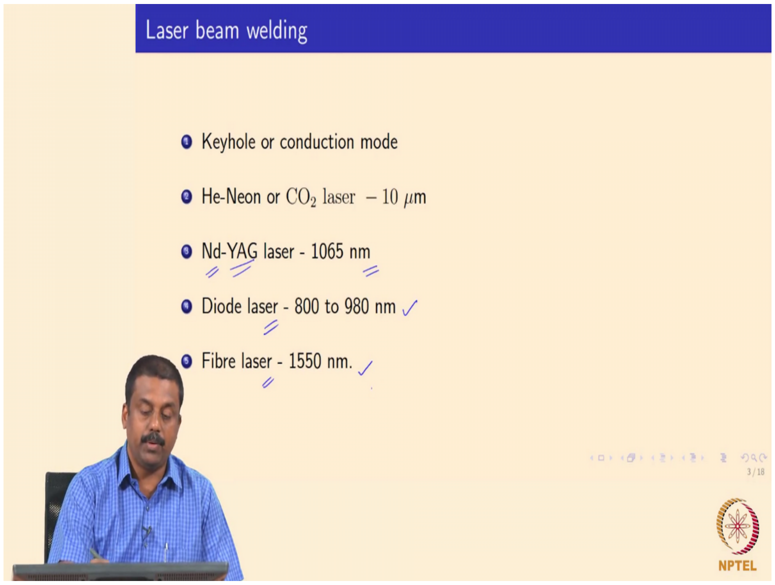

So, if you look at the various lasers and that are commercially available as I already explained you know, based on your intensity and the focal point we can either do a welding in keyhole mode or full presentation mode or in conduction mode. Some other applications of lasers suppose if you want just do in a surface hardening treatment, you want to deposit powder, using a laser source so, in that case, know, we limit the damage to the microstructure or the substrate to minimal levels.

So, in that case, we can also operate a laser beam in a conduction mode. Again we will see in detail in the subsequent slides. So, you can also do a full penetration weld and what we call it as a keyhole welding there are in by and large there are three or four types of lasers that are commercially available. So we must have studied in your physics or in your +2 physics on the types of lasers that are earlier available.

So, I just listed the most common laser sources that are used in the welding. I mean, the first is the gas lasers like helium, neon or carbon dioxide lasers which actually produce wavelength and around 10 micrometer, okay. So in this case, we use a helium and neon carbon dioxide gas as a gain medium, okay. So what is gain medium again we will see in our subsequent slides. And the most the common the type of laser is a solid-state laser where at the gain medium is made of Nd-YAG.

So Nd-YAG here is a neodymium yttrium aluminum garnet so this laser is very commonly used type of solid-state lasers beam welding industry which produces and a monochromatic beam with the wavelength of thousand 65 nanometers, okay. And so apart from the gas and salty lasers we also have a diode lasers. The various diode sources are possible to generate you know the wave lengths varying from 800 to 980 mm nanometers.

So we can, based on the diode configuration now we can generate wave lengths varying from 800 to 980mm nanometer. So the recent times there are a lot of science and development went in to generate very stable lasers. So the most recent development in Laser industries are to develop or generate lasers using an optical glass fiber. So the fiber laser for example can generate the wattage which cannot be, know, possible by conventional lasers.

So we have seen systems which can produce hundreds of kilowatts of laser power. So the fiber laser generally you know, has a wavelength of 1550 nanometers. So it also produces very stable light over the years through for the high productivity jobs especially in automotive industries where we if you have a laser welding applications, the fiber laser can give very stable beam over the years, day in day out, without losing its wattage significantly.

So other type of lasers, they have their life time based on the usage generally laser source deteriorate over time because of the excitations maybe we do to generate lasers okay.

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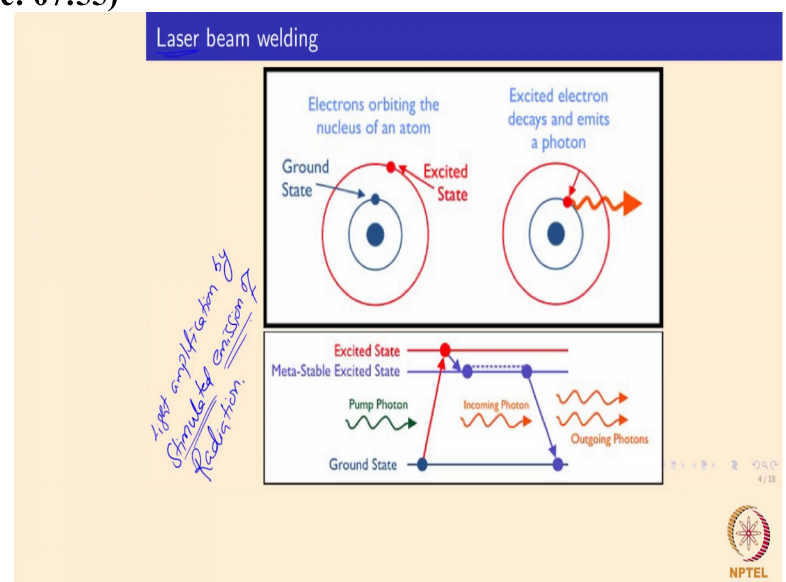

So, some fundamentals about lasers so this you already have familiar with the yeah you already have familiarity with these diagrams. Basically how do you generate laser before going to that we will also understand what is laser signify laser is, so light amplification by stimulated emission of radiation. Each word has its very significant meaning. So in this case, the stimulated emission, so what, and what does it mean here?

So in this is inducing an emission by its stimulation, right. So it is explained very simply. So you have an electrons revolving around a nucleus of analyzer medium, for example, say, you say in India. We excite an, the electrons from lower orbital to higher orbital to an excited state and this excitation is by some external stimuli and upon excitations they gain energy the once you, when you take the stimuli out, these excited atoms come back to its ground state releasing a photon okay.

So the excited electron decays and emits a photon. And the stimulations can be you know carried out either by electric source or any other light source. For example in the bottom figure we have the same diagram on the top in a different schematic. So we have a ground state electrons when you have a sent from photon, for example, it excites electron to excited state. And once you will take the, from photon out then it comes to meta-stable state and subsequently it can also brought to the ground state releasing the multiplying the photons which is actually known as laser okay.

So if you look at an actually equipment which is actually used to generate laser it is very simple.

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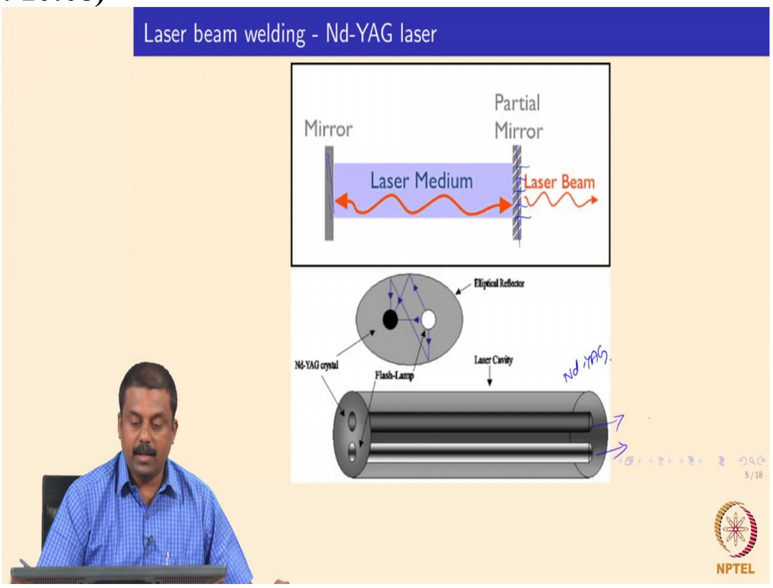

And which is actually used in various applications. So one of the lasers I am going to talk about today is the Nd-YAG laser. Nd-YAG laser as I already explained is so the gain medium the neodymium yttrium aluminum garnet is actually used to excite and used as a gain medium. That means that you know the when you have a pump electron which is sent to the gain medium and you excite the electrons of the gain medium and when these electrons return to ground state they release laser photons.

And these laser photons are all amplified and using an mirror arrangement. So for example, we have a gain medium is surrounded by two mirror. One is completely effective and the other one is partially reflective. So, when the gain medium is excited and you get the photons release which are actually accelerated and gained in power by reflecting back and forth from these mirrors to mirrors.

And this partial mirror they sense the excited and the collimator and coherent laser beam upon attaining its required power to the application, okay. So this is basically a schematic of Nd-YAG on a laser source two mirrors which actually generates the laser light and then it actually sinks to the for example the welding setup. The laser gets it's the property which is highly coherent. And this property the coherent laser beam makes the laser useful for various applications.

Because when you when the laser is highly coherent heat never diverges, when it travels to over a medium and the power can be transmitted from one point to other point, when it actually travels through a medium as well as you know it can also made it to collimate and utter mate at a point by dissipating its kinetic energy. So therefore we can use lasers very useful very handy in various engineering applications.

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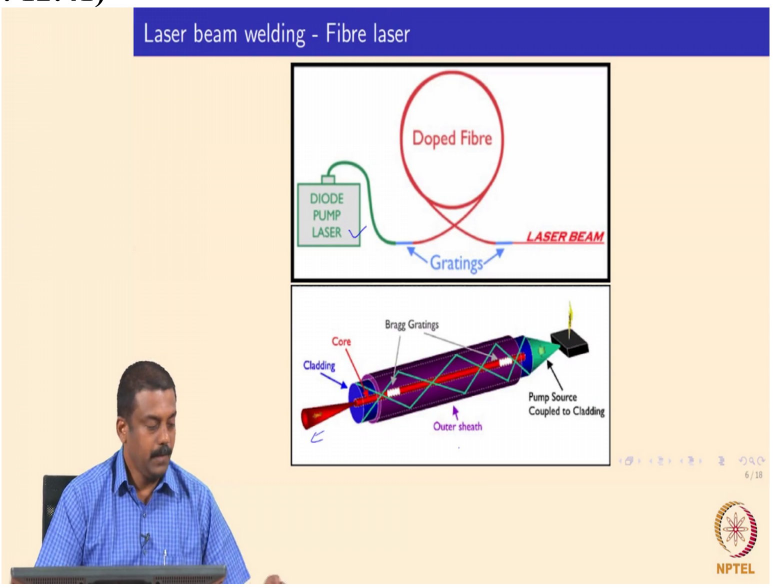

So apart from Nd-YAG lasers, the recent development in to in laser industry is the fiber laser. So in fiber laser, so we do not have an solid gain medium. And instead of a gain medium we have glass fibers which actually acts as an gain medium. So in this case the excitation or the pumping is done using on a laser itself. So we generate a laser using a diode source and then this laser at access reads an excitation source which is actually sent to a fabric, the fiber, the glass fiber cables.

And this cable is actually made of three layers okay. So the top layer is completely opaque and the middle layer is completely transparent so that when you sent an; and laser beam and it actually is get reflected and then made in to gain it in power. In the in same in the, in the middle layer and then upon gaining enough power it is actually sent to the source from a pump source, from one end to other end towards the applications.

So, the advantage of fiber laser is if you look into the actual, the schematic the fibers can be made into as flexible as possibly as long as possible whereas if you look at the solid-state lasers or gas lasers the gain medium there is a limit in its size as well as its flexibility; whereas in a fiber lasers fibers can be made as long as possible. So we can also make extremely powerful collimated coherent laser beam and it comes to be transported from the fibers because fibers can be flexible, made into flexible and as well as it can be made as long as possible.

So we can generate extremely powerful coherent laser and we can also manipulate its path as well as you know we can transport the laser using fibers so much more easily than using a solid or a solid state or carbon dioxide or a gas state lasers. And the life the excitation life of gas and as well as lasers are also limited because of over the time they also decay in its properties. Whereas if you use a fiber laser you can enhance the life of the laser source much more compared to the solid state or gaseous lasers.

So therefore the and the fiber laser because of these parts advantages is nowadays it is getting widely applied in welding industries to generate the very good quality and laser beam for welding applications okay. If you want to further detail you can refer some of the physics books. So we do not want to go in a detail about the physics of laser excitations and the wave theories which is irrelevant for this course.

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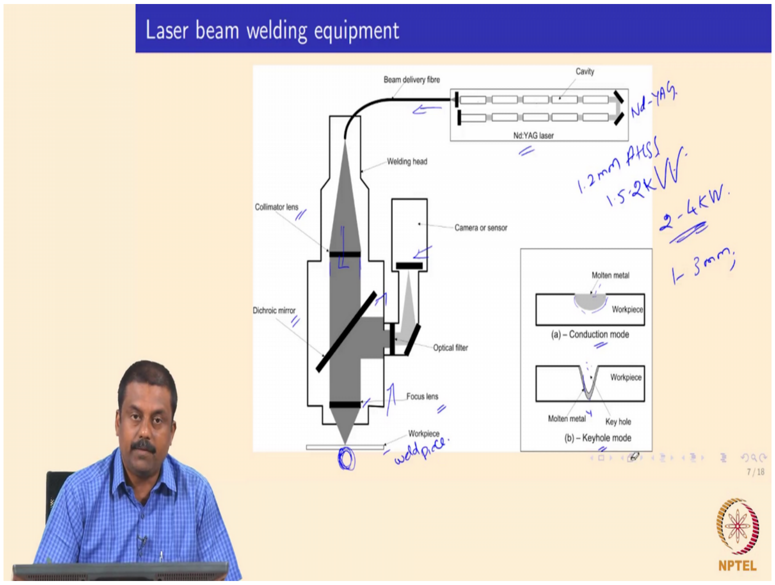

So, the once we have a laser source obviously we need to make a welding setup. So, this slide shows a typical welding setup, used in one of my earlier laboratories in Netherlands. So, we had an Nd-YAG laser okay so, the Nd-YAG laser medium it is schematically shown over here. So we have one so about 10 gain mediums made of Nd-YAG material and we generate lasers and this laser is actually sent to beam delivery cable towards an welding station.

So the actual welding station contains the optics to focus the laser beam. So we have the collimator lens as well as the mirror to reflect the actual vision what you see to a high speed camera or camera sensors. So basically you know if you do not have the dichroic mirrors. So, we can have a simple collimator lens system, to focus the lights the lower surface which is actually coming from the laser source towards the weld piece using this collimator as well as the focal length okay.

So, the collimator lens takes care of the divergence that may happen when the beam is delivered to the workstations and the focal lens focuses the optical and the laser optical race and to the work piece. So we have a mirror assembly system and in order to look at the actual the behavior, the welding behavior, the weld pool behavior during welding and using this mirror and we can have an vision and to the camera as well.

And this is optional we do not need it. The conventional welding setup we have when a laser source and a beam delivery towards the laser optics. And laser optics contains one collimator lens and another focal length, Focal lens. And so this focus, focus length as I explained focuses the laser beam onto the work piece. And so these lenses are all mechanized for example you can also move the focal length as well as the table also most likely no fixed with an CNC coupled machine.

So we can independently chain the focal length axis as well as the work piece axis in order to be focused or focus the laser beam onto the surface. So generally in, if you have an a focused beam within a good wattage for example, if you have a say1.2 mm thick advanced high strength steel so by using an assay 1.5 to 2 kilowatts laser, so you will have an complete full penetration to lower lasers.

So you will have a complete full penetration resulting in a keyhole weld. So keyhole welds basically you vaporize your material and form a keyhole and then surrounding regions you form a liquid metal. And subsequently if you switch of the favored liquid metal solidifies and then form the weld pool. So you can also use laser in a conduction mode, wherein conduction mode that you do not really send a full power for a completely vaporizing and forming in a whole through thickness whole.

So we adjust the power or a focal distance such a way that you just melt a top layer or we may also even reduce the power where if you have a powder feeder, for example, you melt the powder and deposit on top of the substrate. So it can either operate in two modes in a keyhole mode or in conduction mode. In keyhole mode, you have enough full penetration and in conduction mode you have only the surface heated area where melting in an, ah local surface.

Or you may also control the power such a way that you do not really change the microstructures of its substrate when you just melt the feedstock either powder or a wire and deposit and that is actually used in laser cladding applications. But it was in for welding applications in most of the cases will be operating in a keyhole mode in order to make take the full advantage of the process you have.

And a typical the operating wattage of an eraser welding used for a sheet thin sheets applications especially in a car bodies. So the generally the laser capacity, generally changes goes around say 2 to 4 kilo watts okay. So you can also have a more than 4 kilo watts. But for thin steel application, for example, 1 to 3 mm, so 2 to 4 kilo watts of wattage rating of laser is sufficient to make an a complete keyhole weld.

So apart from so these you should also understand that the efficiency of this process extremely poor that is mainly because of the absorption of laser by the, the metals and alloys. So the laser absorption changes as a function of again composition. So, steel has a reasonably good absorptive whereas an aluminum has a very poor absorption for laser. So most of the time when you want to weld aluminum alloys using laser so we need to increase the wattage significantly compared to the steel with similar thicknesses because the absorption of laser in aluminum is extremely small.

So, therefore you need to increase the power significantly compared to steel but even for steel the absorption is very poor as well. So, the laser is considered to be not that efficient process because most of the lights the energy you generate they are all in a way wasted. It is only a fraction of energy from laser is transferred to the other piece okay.

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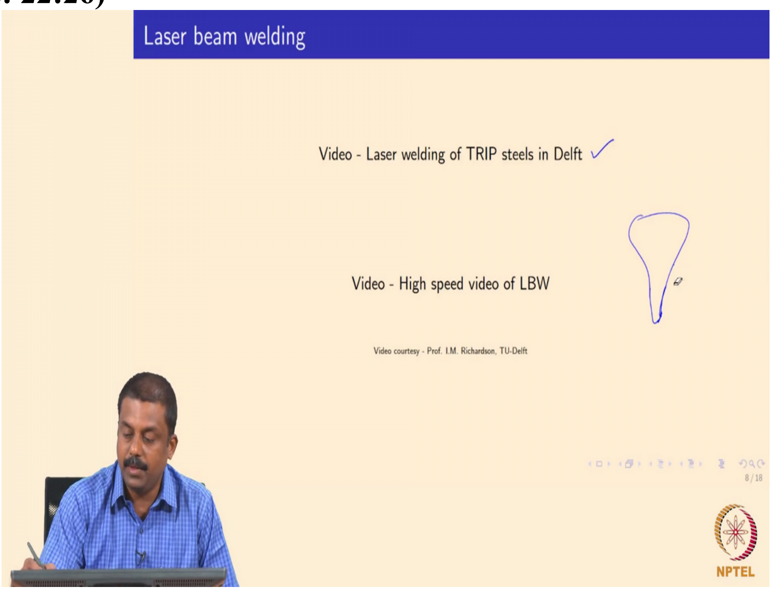

So we, we go and look at in detail about the various procedures involved in a laser welding processes before that I will just show you and a couple of videos of a typical laser welding setup. See the first video I will show you laser welding setup in a laboratory in Netherlands. Now that is where we have been welding a trip stream using a laser beam.

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So the video is running already. The videos what do you see over here. So, so this is your the welding table number in the X Y Z. That is the X Y in the table. So here you have an work piece mounted onto on a clamp and this is our laser optics head. Laser is actually coming from the top floor and to this optics. The collimator lens and the focal length or placed inside these optics. And this can be moved independently with respect to your XY table and Z here is the laser axis.

So generally we have the focal length defined from your lens, focus lens to the work piece and that can be changed based on your thickness used or based on the power you want to transmit to the work piece. So I generally we do it in a full focal patience so when you have a full focal patience, so based on the efficiency so you have a maximum power transmitted to the work piece.

So in this case, so we look at the laser welding and the trip steel is actually mounted over here and we are doing a bead on plate welding on this trip steel using the laser coming in. So the process is completed within few seconds. In this case we were welding. So in this case we were welding a trip steel of 1.2 mm thickness **(Video End Time: 24:53)** you would see the amount of heat that is actually transferred to the work piece and we end up making in a complete penetration a complete full penetration forming a keyhole in laser weld and we ended up making a full penetration joint.

So what we showed over here is an laboratory setup for, to understand the actual process and disability of the process. And we also look at in was all the cases what is actually happening inside the material when we melt and then solidified. The important factors that govern the stability of the weld in Laser welding, laser beam welding is the stability of the keyhole and how stable is the keyhole so, because that is going to determine the quality of the weld as well as the appearance of the weld.

If your keyhole is not stable and we may end up forming spatters or improper penetration or sometimes even undercuts. So even if you have a very turbulent keyhole as well as in the weld pool, you may also trap the atmosphere gases end up forming porosity as well in the weld. So, it is important to understand used the keyhole stability and subsequently develop will behavior during this kind of welding.

So we generally look at the keyhole using an high speed camera and which is also used to you can also make use of the videos which we get it to understand the how the laser welding actually happens yeah by in a keyhole mode. So I want to show you in a video, another video wherein we were looking at the actual weld pool and a keyhole during laser welding, in laser point of view.

So, for example, we mounted a camera and using a mirror, we reflected the sample surface onto a camera which I showed you in the schematic. So that we can look at the work the weld pool in laser beams perspective. So how laser sees the work piece we can also see your laser, laser beam a weld pool in a laser beams perfect beam.

(Video Start Time: 27:16)
So what you see over here is again a trip, in this case galvanized steel is welded using a laser. So in this case, what you see here is the bright spot it is actually laser illumination. So your laser source is moving along this direction and so we have a laser illumination. And what you see over here at the middle of this illumination is a hole which you formed by the severe appreciation of the substrate and forming and a complete through thickness hole, actually known as a keyhole.

(Video End Time: 28:02)
Why it is known as a keyhole because in the form of a keyhole in the door. For example, so the typical shape of the hole is something like this you form so this is the typical shape of the hole what you form, it is the same as you know I door key knob.

(Video Start Time: 28:17)
So, we are looking at an a high speed video of a laser weld and what you see over here as already explained is laser illumination. And this is the keyhole and we are looking at laser's perspective. So, laser is coming from the top of this image and going through the substrate. And this illumination shows the actual exposure and reflection of the laser from the substrate and what you see over here is the keyhole what is formed by this vapourization of the metal. In this case the keyhole is not really stable, so the process was not stable and the surrounding the keyhole you have a molten metal which forms weld pool.

In this case it is a tear-shaped and most of the transient laser welding which is done in a high welding speed. So, generally because of the temperature gradient we steep temperature gradient from the weld centerline towards the weld surface, the weld the weld pool what you form here is most likely in tear shaped. So we have an important metal and this is the top and bottom of the substrate and it is the interface is molten and subsequently when you move the laser source and this weld pool solidifies and forming a fusion joint okay.

(Video End Time: 29:52)
So we will end up from here. So we will have a quick recon. So we looked at the laser welding process. So these one of the most commonly used welding processes other than resistance spot welding and we also looked at some fundamentals but I can refer some of the physics textbooks

to understand the laser generation and commonly used laser sources that are commercially available the gas based solid-state lasers as well as the fiber laser, a diode lasers.

And so nowadays we are also generating the fiber based lasers which are actually very attractive for welding applications because of the beam quality we generally get by the fiber. And then we looked at a schematic of a laser beam welding setup. So we have also looked at in a video the actual laser welding setup in one of the laboratories and finally we have looked at high speed video showing presence of keyhole and the formation of pool by the laser source in a joint.