Welding Processes
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Electron beam welding process

So I will begin from last class. Right, so last class, we were looking at arc laser welding and then in the last unit, so we were also looking at laser arc hybrid welding. So how to combine both, arc, heat source and laser so that we get the maximum benefit out of the both heat sources. Right? So laser welding, it has its own limitations because of the faster cooling rates and a very narrow fusion zone. Okay. So the mechanical properties or the welds you know may not be as good as in sometimes in the arc welding process.

Moreover, in the arc welding processes, so you may not have a good penetration. So by using both, the laser heat source and the arc heat source so we can get the benefit of the both processors. Right? So we can get a deeper penetration and we can also increase the width of the fusion zone and so that we will have a good fit up. Okay. So we can also slightly increase the bead geometry in such a way that you know you may not have a very strong load partition into the fusion zone.

And by using arc, you can also fill more volume. Is not it? Because the GMAW, if you use filler, it also gives more liquid metal which can be used to fill the cavities. Right? Otherwise you will have to melt the interface, more volume of materials. So in GMAW, you can use a filler to fill the weld cavities and the laser can be used to achieve a deeper, much deeper penetration.

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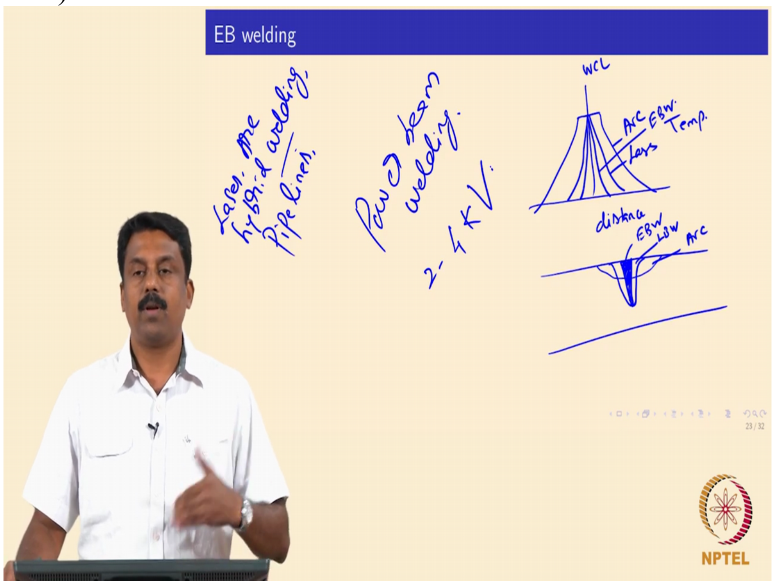

And then we looked at the electron beam welding, the first slide be looked at. So electron beam welding is also another type of power beam processes. Right? But in a electron beam welding compared to laser, the power density of electron beam is much higher. Right? So we can make use of the high-power to make very precise, narrow bead weld for various applications in the electron beam welding. Right? So we can achieve extremely narrow weld zone using electron beam welding because in contrary to laser, laser absorption of the material is very low.

Right? So as I said I mean an aluminium does not absorb any laser lights. And steel, maximum 30%. That is why it is good to absorb. Whereas the absorption of electron to material, especially in alloys are much higher. So the efficiency of the process is quite high. (())(2:49) 90-95% efficiency we can achieve by electron beam welding. So that means if we have power of 2 kilowatt of electron beam okay which is passing to in a work piece and almost 90-95% of the power which is actually there, electron beam can be absorbed by the material because the absorption of material by electrons you know it is much higher okay than laser.

So the efficiency of the electron beam is very high compared to laser and we can make use of the power which we generate laser to melt much more volume. Right? Much more thickness is to generate deep penetration welds using electron beam welding. So that is why, the electron beam welding is widely used for various strategic applications. Okay. So why they are used? Because we can achieve good fit up. That means that you know we can, the weld can be made with very narrow regions and the because of the very narrow heat source we apply, the temperature gradient is also extremely steep. Okay.

So if we look at the electron beam welding, the temperature distribution, so this is the weld central line as a distance in electron beam welding it will be extremely narrow. Right? There is GMAW. So you will have a much wider fusion zone and then right? So this is distance, the temperature. And the laser beam welding, so it will be slightly higher, the temperature gradient, it will be slightly lower than the electron beam welding. So it is like this. Right?

So this is the arc, the laser and then this is EBW. Okay. So the electron beam welding, the the temperature gradient is much much steeper than laser, much steeper than the arc welding. Right? So suppose if you have a weld made, say suppose this is your interface, in laser beam welding, so suppose if you are achieving weld bead geometry something like this for this thin profile, electron beam welding will be much narrow. Right? And for arc welding, so it will be much shallow and then wider. Right? It is clear?

So because of the temperature gradient and then the focused heat source what we use, we have depth of penetration approximately much small much deeper and the laser electron beam me achieve a depth of penetration but the weld zone width will be much lower in electron beam welding because of the very highly concentrated heat source what we use. Right? It is clear? So now, so what is source of electron?

The electron generation and we already studied about it in the first chapter. Right? Thermionic emission and field emission. Right? So using a low current and extremely very high voltage source, we can achieve field emission as well as thermionic emission. Right? So breakdown voltage, so remember right? So we will have to achieve very high voltage in 2 to say generally 4 kilovolts and very low current, some under 200 milliamperes current is supplied to an electron source which is the target which is also the cathode. Right?

And then we can apply a very high breakdown voltage to emitthe electrons from the source and that can be accelerated towards the anode which is the base material. Right? So we can keep the acceleration voltage. Based on the acceleration voltage, we also gain the energy, the power in the beam and unfortunately when you are accelerating the electron that are generated from the cathode to anode, the electrons would also diverge. It is not like laser. Is not it?

So now we need to use some lenses which can also converge the beam and then can be focused onto the work piece using electrostatic lenses or magnetic lenses because the electrons can be focused, defocused, converged and diverged using magnetic and electrostatic lenses. Right?

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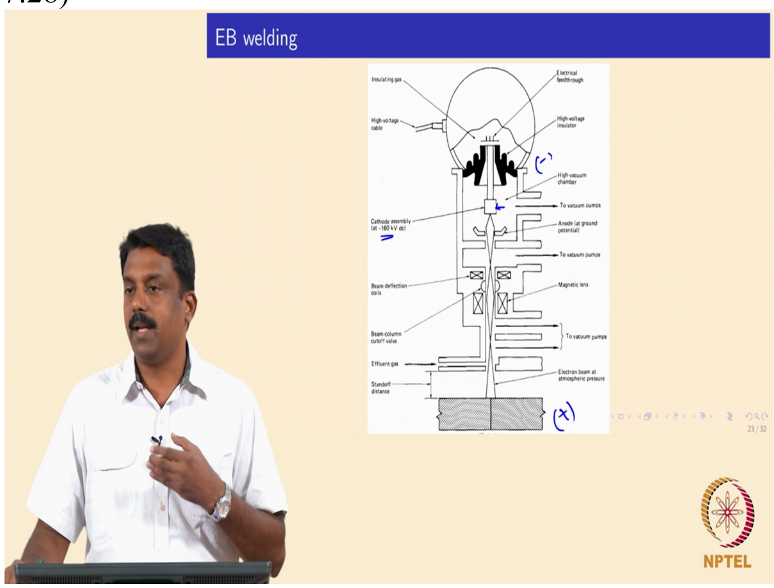

So the electron the optics gun is similar to any other electron microscopes you can imagine. But the thing is here, the beam energy is much higher than what we use in electron microscopes. Right? So what we see over here is a simple schematic of an electron beam welding setup. So this is the cathode assembly. Is not it? And we apply very high voltage to omit the electrons and this is for ya much higher electron power, 160 kv, kilovolts. So you can generate about 30 kilowatts of power using electron beam. Okay.

It is much higher. So the entire setup would be in very high vacuum and then we can use the electrostatic and magnetic lenses to converge the beam as well as to focus the beam onto the workpiece. And so we always know that my cathode should be negative and then the your anode can be positive. And we can maintain the voltage differences between the cathode and anode and that will determine the oxidation voltage and then the power, the acceleration power what you achieve from the electron beam and it can be accelerated based on the voltages that are kept between anode and cathode.

And then using the lenses, we can focus and defocus the beam onto the workpiece. And then the spot size is much smaller. We can achieve much smaller spot size than your laser but we can focus a very have power onto a very tiny spot. Due to that, now we can have a very narrow heat affected zone as well as the fusion zone. And the material absorption of electrons is also much higher. So electrons would penetrate the material much deeper than the lasers.

Right? So moment the electrons are de-accelerated, obviously so the kinetic energy of the beam is dissipated as heat in the material and then you end up melting the interfaces forming weld. Right? It is clear? So the the I do not want to go get into how the lenses work, electrostatic lenses work, I mean these are all simple physics, right? So we do not need to go about the optics. What we concentrate on the welding using electron beams.

So we assume that we have the electron beam setup. So what are the parameters we can control so that we can control the beam pressure and so what are the geometrical designs we can achieve using electron beam welding? That is what we are going to see. Right? It is clear? Any questions? We move on. Okay.

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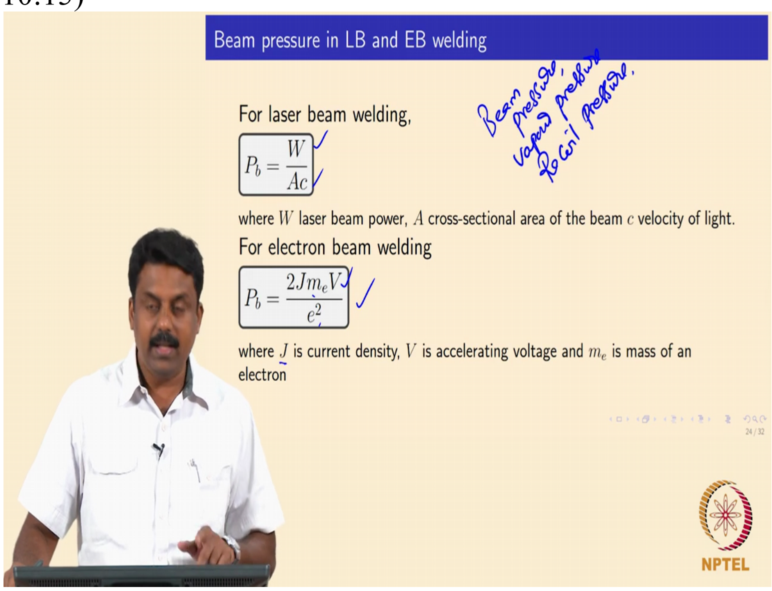

So the keyhole again formation is the same as laser beam welding. Right? So the (())(10:23) that 8 kilowatt formation beam pressure, vapour pressure and then recoil pressure. In electron beam welding process, the beam pressure is much wider than laser beam welding. So in a way, it is difficult for anyone to do welding in conduction mode using electron beam. So in all the cases, when we use electron beam, we always use keyhole welding in electron beam welding

So why? Because if you look at the beam pressure, the pressure which aid keyhole formation, okay the main pressure which actually aids the vapour pressure and beam pressure, but if you look at the beam pressure, so for laser wave in a welding, the beam pressure is the power divided by the cross-sectional area and the velocity of light. Okay. So the watts what you have it is it is from your the laser power source. Okay.

So in electron beam welding, the beam pressure is controlled by the current density which is the electrons we generate in the source and then the which is the accelerating voltage, the voltage between your target the this material and the electron target, the cathode, okay. So we can also increase the beam pressure by changing the acceleration voltage. And we also have the current density, what is current density is the number of electrons, right? Number density that is generated from the cathode, okay.

So that can be changed by changing the the voltage at the cathode, the target, the breakdown voltage. Okay. So that can increase the number density of electron that are generated plus how fast those electrons that are generated accelerated from the cathode to anode, both would contribute to the beam energy. Right? Beam pressure. Right? The M and E, these are all electron mass and the charge. Right? So the J and V determine the beam pressure.

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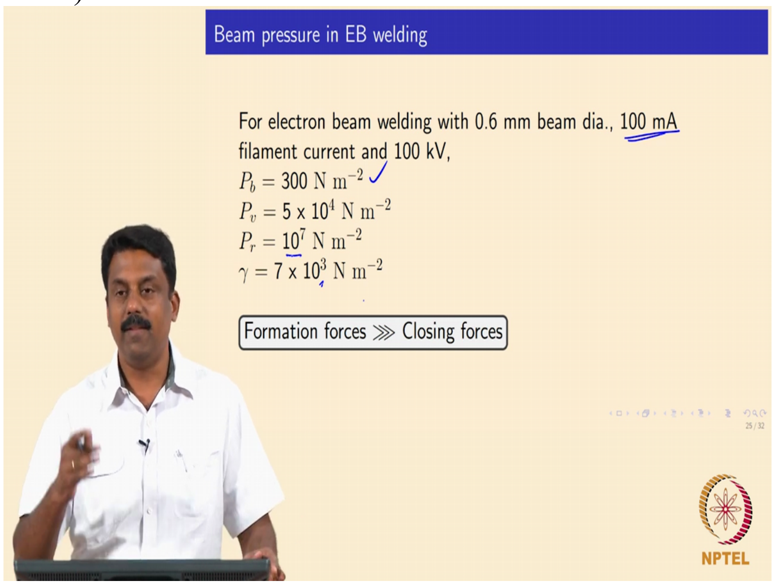

And if you look at the beam pressure of the electron beam welding, it will be much higher. Right? The beam pressure in electron beam welding it will be close to if you do a simple mathematics using target current of 100 milliamperes and then the isolation voltage of 100 kV and we can achieve the beam pressure of 300 newton per metre square. So that is 300 newton square. Okay. That is huge, the beam pressure itself. Okay. So it is acting.

Now imagine, this is Newtons per square metre and the beam size is few microns. Okay. So the pressure which is acting on a very tiny area is huge. So even if you have an acceleration voltage of 100 KV and then a beam current of 100 milliamperes, the amount of energy which is actually sent, the pressure is there by the beam at the keyhole is huge. So you always end up making keyhole. Now keyhole cannot be closed because compared to the beam pressure, the surface tension and the gravity is negligible.

Okay. So surface tension is the formation pressure I think it is - 3. I will check it and then correct. The surface tension is much lower, gravity is much lower compared to the beam pressure, the vapour pressure and the recoil pressure. Okay. So the surface tension and the gravity which are actually closing the keyhole is negligible compared to the pressure we have in the beam. The vapour pressure, the recoil pressure. So recoil pressure, you see that it is around 10 power 7 newton per metre square. Okay. So huge.

Because of the vapour which is actually pushed from the weld metal to the atmosphere. So whatever more do you actually use, whatever current actually it is voltage, in most of the cases you will end up making keyhole in electron beam welding whereas in laser beam welding so you can make weld without keyhole in conduction mode, it is possible. But in electron beam welding whenever you well, you always see that you know the keyhole shape. Okay.

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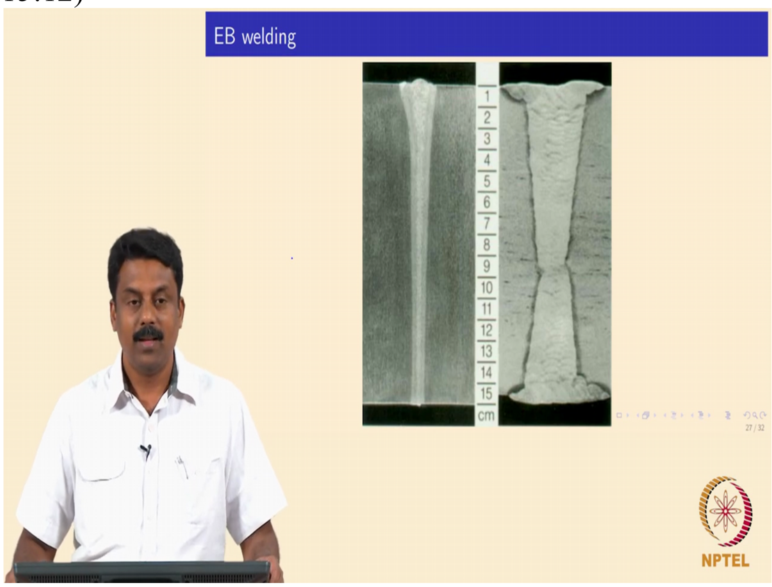

So the keyhole shape would always be like this. So what you see over here, so this is 15 centimetre, it is not millimetre. Okay. So that is 150 millimetre. And you see, we can achieve full penetration of 15 centimetre and you could have full penetration of 150 millimetre. So once the millimetre, 15 centimetre, something like this of steel. Okay. And you can have complete penetration in a single pause. Yes?

Student: Sir, in case of laser beam welding, yesterday we discussed that sometimes the beam pressure is so high it might lead to a cool like from here we pass it to the other end. So here…

Prof: Ya, this is also a hole here. This will always be there. That is a problem in electron beam welding. The beam pressure is so high, you always have a through-hole. Right? And then this hole has to be closed. And if you look at electronbeam weld joint, always at this top (())(16:20), you always see a hole. Okay. So that is why we need to have a proper start and stop control so that the keyhole at the end can be filled by the surface tension of the molten pool.

So you will have to make sure that at the end of the at the end stage or the last stage of the welding and you will have to reduce the current or the power in such a way that you do not form a full keyhole, you just melt or superheat the liquid in such a way that the liquid can fill the keyhole which is formed by the high-power beam. So if you do not do that, if you do not use proper stop procedure, the keyhole would remain as a keyhole because the keyhole would not be filled by the surface tension of the liquid. Okay.

That is why when welding is done at the end, electronbeam welding, we always maintain a very low current and low-power in such a way that we just melt and then or superheat the liquid which is there and surrounding the keyhole at the end of the melt. Otherwise if you look at it, even in laser welding if you are not doing if you are using very high-power laser and if you are not doing proper welding procedure at the end the there is a pinhole, the keyhole remains at the end of the weld. Right?

So in this case, so this is actually done in a flat slab. So if you are doing it in pipelines, so you will have to make sure that at this top, you need to defocus the beam or in the laser, you also have to defocus or maintain low-power in such a way that the molten metal is heated and you are not forming any keyhole and you are doing in the conduction mode and then the liquid which is there can fill the hole. Otherwise you will see a pinhole at the end of the weld. okay.

So now imagine, the power of electron beam. So this is the 15 centimetre slab and you can achieve a single pause weld. Whereas in you know this is in GMAW for 15 centimetre 150 millimetre to need to have hundreds of passes. So you see, this is one pass. Right? So imagine how many passes will have to do in this cross-section. Right? So it will take enormous amount of time and energy and then manpower to achieve a weld of such thickness. So that is why the electronbeam welding is very widely used for such an application. Okay.

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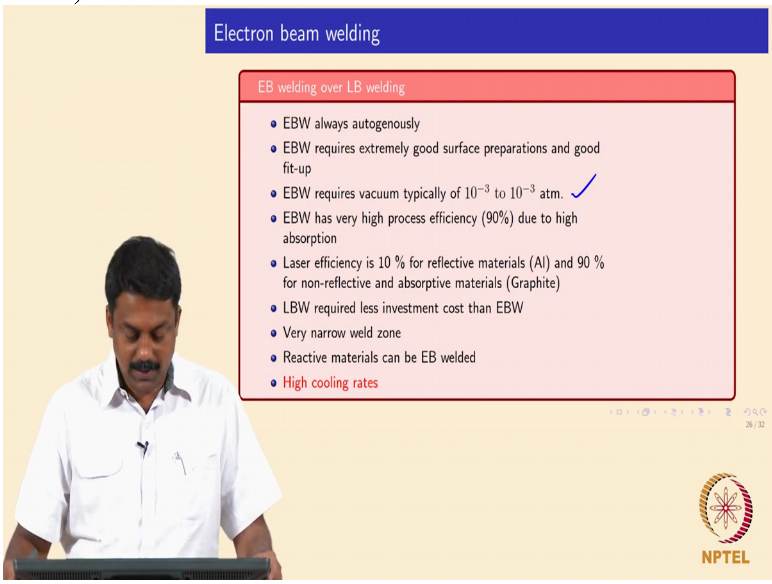

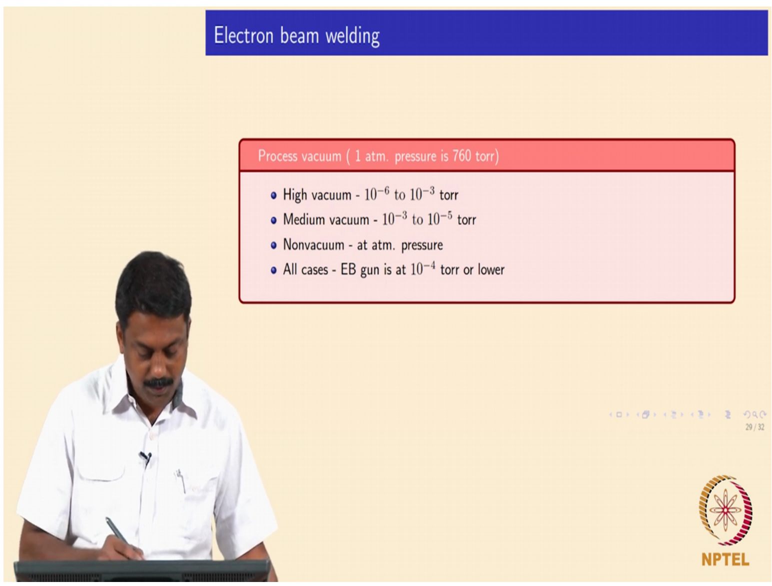

And so what are the advantages of electronbeam welding over laserbeam or any other welding process? In electronbeam welding, we always use it in autogenous mode. What does autogenous mean? No filler. Okay. So nowadays, we are you know we also developed 3-D printing at the manufacturing using electronbeam. Okay. So Siaky is a very famous company or EBAM, so they make the equipment using electron beam for IT manufacturing and where we also add filler to deposit layer by layer to make components.

But for welding, electronbeam welding is always used in autogenous mode. Okay. And because a very heat I mean the narrow power source, the surface preparation should be extremely good and the fit up has to be perfect. Even a small roughness and small distortion is not going to make a good weld. Yes? So the other properties of the electron we will have to make it, we will have to make sure that the electrons are generated and then transported in vacuum. Otherwise, it is going to ionize.

Now we are going to lose all the electron properties, the energy. So generally, the so I think it is 1. The electronbeam requires typical vacuum temperature, 10 power - 3 10 power I think - the low electronbeam, low vacuum system can also be used. Okay. So the low vacuum, it can go up to 10 power - 1 as well. okay. We will go back to that. And it has a very high process efficiency, 90% because of the high, very high absorption. Because optical spectrum, laser material does not absorb effectively but electrons can bombard the material. Right?

So laser efficiency much lower, say not even 10% for aluminium. Whereas 90% can be achieved in electronbeam welding. Okay. So what are disadvantages of electronbeam welding is electronbeam is extremely expensive, the setup. So the the problem is the very narrow weld zone. Okay. So because obviously the power source is very narrow. And the the electronbeam welding advantage is very reactive material can be welded because the waiting time is much lower and for example, t is 64 titanium oxide, titanium it oxidises very quickly and laser eam welding and GMAW welding if you are using, you need to have a proper shielding.

Or you need to do it in glove box. The welding has to be done in a controlled atmosphere. Otherwise, it is going to oxidise and it is going to get only powder. And because of a very narrow weld zone, the cooling rates can be very high. Okay. Cooling rates can go up to you know 10,000 Kelvin per second, even higher. So that is why you know when you have a material which has phase transformation, specially low carbon steel for example, then you will end up getting very fine (())(22:03) microstructure. Okay. So and that may lead to cracking. Good.

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So this we have seen.

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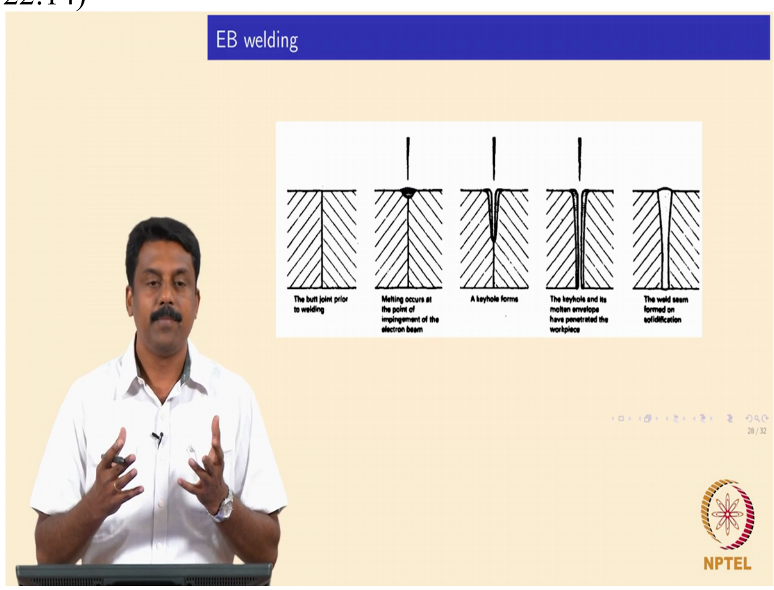

So this is the basic the sequence of weld formation. So first we need to make sure that the edges are prepared nicely. There should not be any mismatch. The bolts would be coplanar, absolutely perfect. Dimension tolerance is less than a micron what you achieve. Otherwise suppose if this is some back up, something like this, it is not going to work out. Okay. So because if it is not fit properly, if they are not if they are misaligned, then you are not going to make a joint. Similarly, the surface preparation roughness, so if it is not done properly, and it is also not going to work out. Right?

So the moment you have the beam, you are melting up ends. Once the welding happens, obviously the beam pressure and the vapour pressure would start forming at keyhole. Right? So the keyhole would form because the moment you melt, it will start reprising. Is not it? So the vapour pressure, the beam pressure and the recoil pressure would start developing the keyhole by pushing the liquid surface away. Okay. So the keyhole is formed here because of the beam pressure which is acting in this direction and the vapour pressure and the recoil pressure.

Right? So then you will have a keyhole formation at the edge. And then you keep on focusing the beam. So obviously, the keyhole wall will be extended and you will have a full penetration keyhole. And the molten volume wouldencompass the keyhole because the surface tension would never close the keyhole because the keyhole formation forces like beam pressure, vapour pressure, recoil pressure is so high your keyhole will never be closed. Okay.

So and then, so the moment the beam is off, obviously it will have (())(24:20) and then surface tension would make the liquid interface to coil us and ultimately it will solidify. Yes? It is clear? So the sequence of the weld formation. Any questions? Okay.

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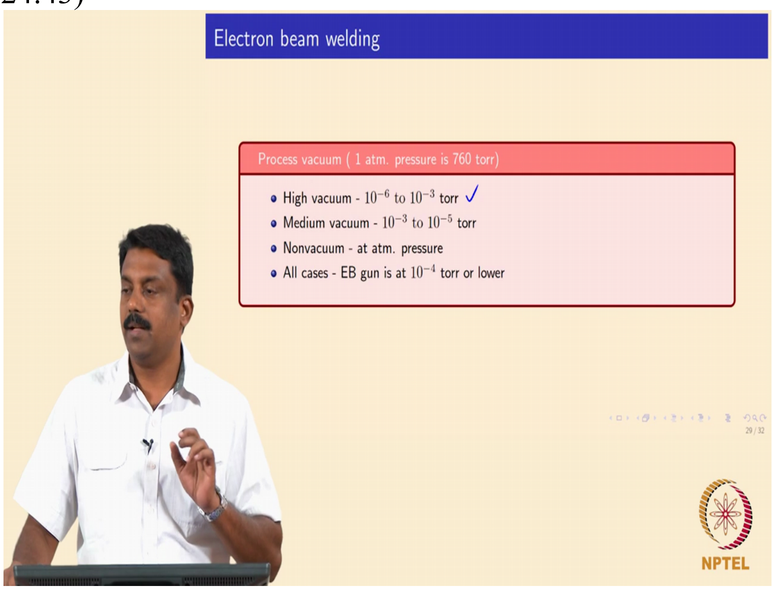

So in the most of the cases we need to maintain a very high vacuum. So nowadays we also have an atmosphere system. So but it is not really atmosphere system. The we still have electron gun but the Sample can be in atmosphere. So the in all cases, the electron gun should be at a very high vacuum. Okay. But you can make sure you can develop a system in such a way that the sample can be outside (())(25:10) vacuum system. Right? So that you know you can achieve a good keyhole stability and you can also manipulate the Sample. Okay.

So suppose if you are doing it in a very large volume of material and you cannot keep it inside the vacuum chamber, say for example weld I showed you, 150 centimetre slab and if you want to keep it inside the vacuum chamber and you need to have a big, huge setup. Now in fact, there are setups in which you can do in a meter component as well but then the installation cost will be very high. Okay. So in that applications and if you have a non-vacuum or low vacuum system, then the sample can be kept at desirable, yes, atmosphere inside low vacuum, then (())(26:00) beneficial. Yes, it is good. Nice.

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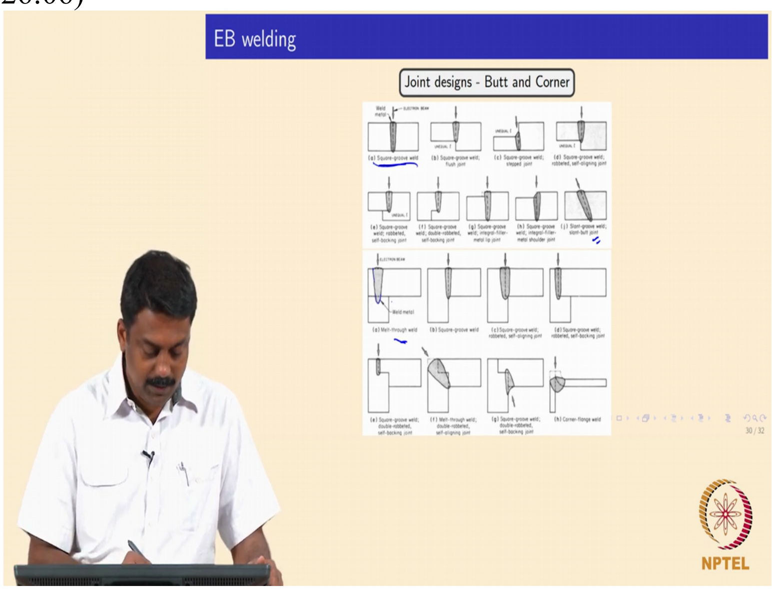

So the most preferred joint design is the square groove butt joint. Okay. And all the configuration if you look at it, it is the manipulation of the butt joint only. Okay. So we can have a slightly inclined butt joints but in most of the cases all these butt joints in varying configurations you can achieve. And we see over here, melt through weld and this is can be this can be achieved only by electronbeam. Okay. So it is like you know you join two and you are not doing filled weld.

Filled weld, you do in a melt through weld. So we can because the electron power is so high and they can achieve deeper penetration, so the beam can be penetrated and then molten and we make a joint between 2 interfaces, the melt through weld. And this is better than having enough filled weld because in a filled weld, you add extra material and you also have a cess concentration points. Is not it? So when you are using a filled weld on the joint, so you also have a cess concentration and then you also add extra material to make a filled joint in the configuration.

So in that application you can use in melt through weld. So you can have an electronbeam passed and then you can make a joint between these 2 surfaces. It is clear? (())(27:43) configuration, if you look in most of them are butt welds.

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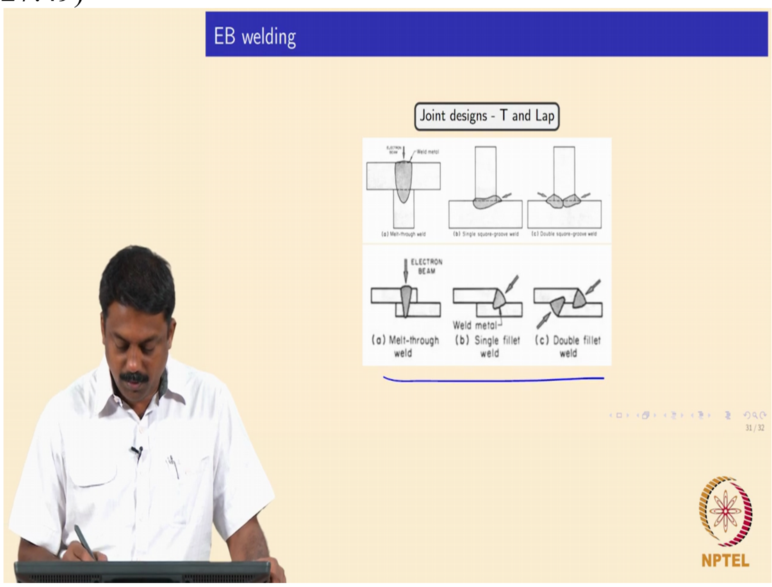

And some other configurations, so ya the T joint and L joint and it is very well done in electronbeam welding using a melt through configuration. Whereas in other joints, so you will have to do a single groove or double groove T joints. In electronbeam, you can achieve a simple melt through welds. So if you want to use GMAW, so you will have to use a single filled welds or double filled welds to achieve similar weld configuration. Yes. It is clear? Any questions?

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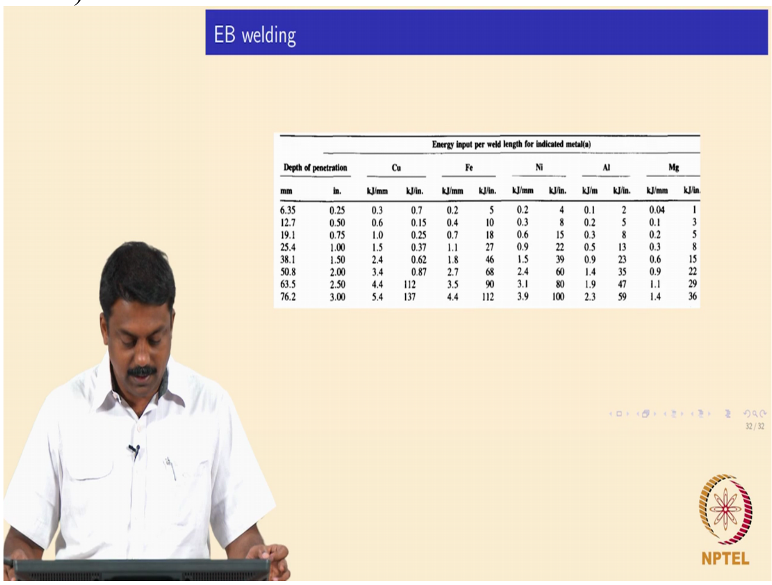

Depth of penetration		Energy input per weld length for indicated metal(a)									
		Cu		Fe		Ni		Al		Mg	
mm	in.	kJ/mm	kJ/in.	kJ/mm	kJ/in.	kJ/mm	kJ/in.	kJ/m	kJ/in.	kJ/mm	kJ/in.
6.35	0.25	0.3	0.7	0.2	5	0.2	4	0.1	2	0.04	1
12.7	0.50	0.6	0.15	0.4	10	0.3	8	0.2	5	0.1	3
19.1	0.75	1.0	0.25	0.7	18	0.6	15	0.3	8	0.2	5
25.4	1.00	1.5	0.37	1.1	27	0.9	22	0.5	13	0.3	8
38.1	1.50	2.4	0.62	1.8	46	1.5	39	0.9	23	0.6	15
50.8	2.00	3.4	0.87	2.7	68	2.4	60	1.4	35	0.9	22
63.5	2.50	4.4	112	3.5	90	3.1	80	1.9	47	1.1	29
76.2	3.00	5.4	137	4.4	112	3.9	100	2.3	59	1.4	36

So this table shows the energy input we use and what depth of penetration we achieve for a given ya composition of material. So for example in copper, the energy we what we need is kilojoules per millimeter. Okay. So (())(28:46) reference table which you can use it.