Joining Technologies of Commercial Importance
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Lecture – 15
Laser Beam Welding

Hello, I welcome you all in this presentation on the laser welding related with the subject joining technologies for the metals. You know this is one of the radiation based processes, another is the electron beam welding and both these processes are known to offer the higher power density wherein right from the heating to the melting and evaporation can be achieved by adjusting the power density suitably.

So in this presentation, mainly I will be talking about the laser welding.

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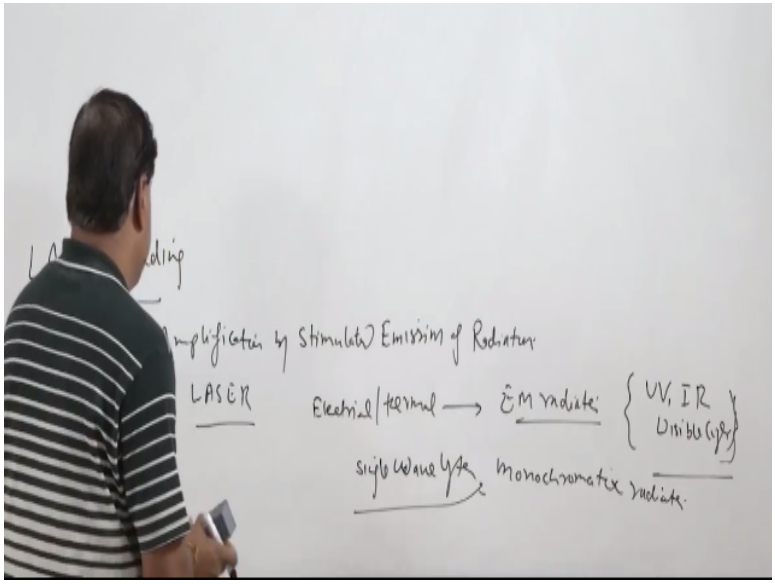

Laser welding is basically the abbreviation of like light amplification by stimulated emission of radiations. So this process basically sources of energy using laser basically one of form of energy is converted into the radiation energy or the electromagnetic radiations. So energy may be in form of electrical or thermal that is converted into the electromagnetic radiations. These radiations include all types of like ultraviolet radiations, infra-red radiations and also the visible light radiations.

So from these radiations basically the single wave length radiations are obtained, which are called monochromatic radiations, which are used for processing of the material. So how it is

done and how it is achieved that is what we will try to see.

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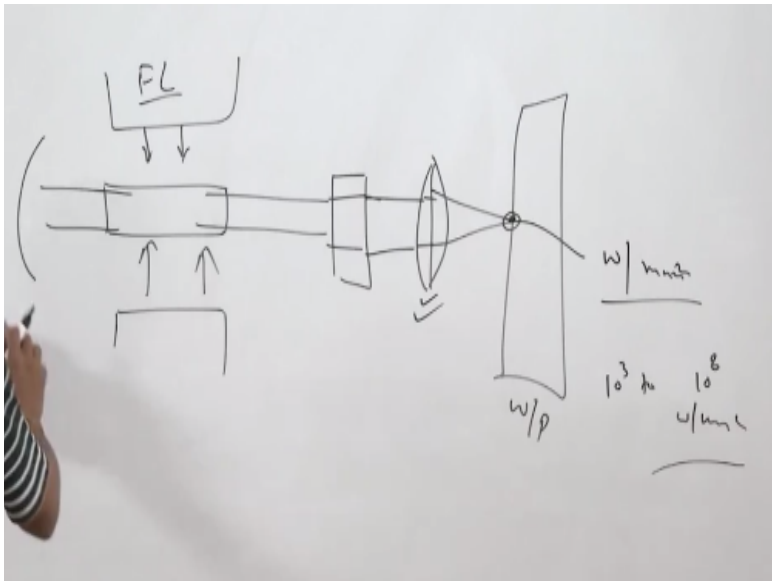

In this one basically the most common way is to that the lamps mainly called flash lamps are used to excide the material mostly in the form of ruby crystal and from this after the excitation the laser radiations are emitted like this, then they are reflected back using suitable reflectors. Here like this and then they are brought to the parallel then through the lines it is focussed at the desired point and this point becomes the workpiece.

So when they are targeted or applied or directed over the surface of the workpiece, so using flash lamps light energy is directed, which excites the material which may be in form of the gases or the ruby crystal gases like helium or argon or carbon dioxide can be used. These are the reflectors which will be reflecting and focussing all these things towards the lenses and these lenses will finally be converging it onto the surface of the workpiece.

And whenever it is directed over the surface of the workpiece, a kind of energy density or the power density that we get becomes extremely high, which may range from like say 10 to the power 3 to say 10 to the power eight power mm square or more. So in that case, there is lot of flexibility to achieve a wide range of the power density and this feature is exploited for the various purposes in processing of the material which includes.

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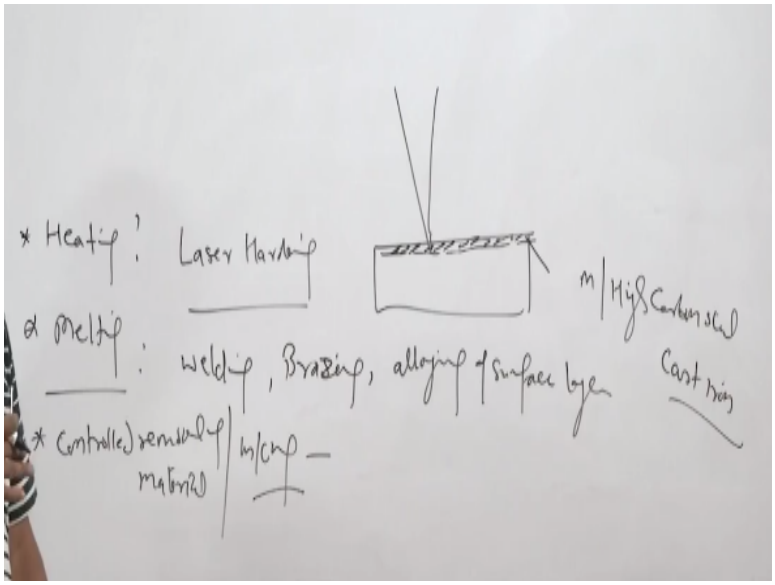

So by regulating the energy density we are in position to use it for the heating purpose, which is basically used for the like say laser hardening material is heated rapidly at the surface and then by auto-quenching or by external quenching it can be harden like say, the surface is directed with the laser and here it gets heated, reaches to the rising temperature and then it is quenched off as laser moves away from the directed surface.

And then this quenching results in the hardening of the surface layer, but for this it is necessary that material has a hardening characteristics which is primarily say for medium or high carbon steels and cast iron so this method is found to be suitable. Similarly, this is also used for the melting purpose. Now melting, when the laser is used for the melting purpose, we need much higher density as compared to that for the heating.

And this can be used for the welding where fusing of the, fusion of the faying surface is achieved, may be used for the brazing purpose or may be used for the alloying of the surface layers like this and it is also used for the controlled removal of the material, which we can say that machining.

So this is what we normally call as a machining and in this one basically the evaporation or ablation of the material over the directed surface is achieved so that the controlled removal of the material takes place in order to obtain the desired geometry and the sizes with surfaces of the material. So the machining, welding or the melting and heating all can be achieved by adjusting the power density of the laser being applied over the surface.

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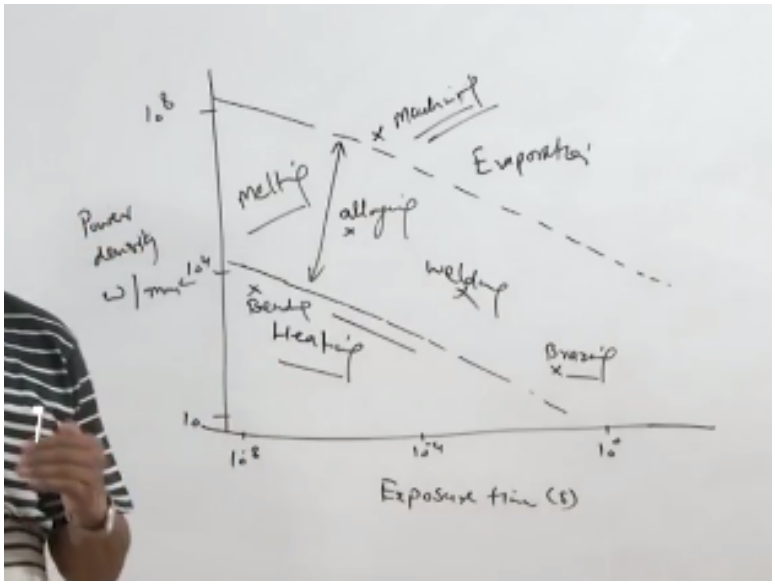

So there is one very general guideline kind of the diagram, which will help us to see the kind of approach, which is used. Here in the x axis we have the exposure times means the time for which the laser is applied. So here extremely a small say -10, 10 0 – 10, 10 to the power -4 and 10 to the power 0 and in the y axis, we have power density or energy density, which is in watt per mm square.

So here say 10, 10 to the power 4, 10 to the power 8. So if we see this is the band for the band which is used for the purpose of the heating goes in like this and the band for the purpose of the metal. So they are three zones basically combination of the power density as well as x to the time can be used for the different purposes, this is the zone for the heating purpose means it is used for the heat treatment purpose or softening of the material like bending.

So this location lies for the say bending purpose where very short period the laser is directed so material gets soft and then it is after softening bend by applying suitable pressure. Similarly, these are the bends for the heat treatment purposes as for as the power density and the exposure combination is concerned and then we have the like say welding. So welding lies somewhere here like slightly more than 10 to the power -4 seconds and here 10 to the power 4 or more power density.

And further higher power density and shorter exposure periods are used for the purpose of alloying of the surface wherein the material to be alloyed is led or over the surface and then laser beam is passed over the surface, so that the fusion control, fusion of the base material and the material over led on the surface fused together and results in the alloying of the

surface.

And the brazing is used here for the lower power density for the longer periods like say this is the kind of a zone for the brazing purpose and then this is the area where, so this band between the two corresponds to the melting and then evaporation or ablation, so here the lower power density for longer period and higher power density for shorter period. So more than 10 to the power 8 power density is normally used for the evaporation and machining purposes.

So that somewhere here for the machining the power density and exposure time combination for the machining purposes. So basically if higher is the power density we need the shorter exposure time for generating the heat depending upon the purpose of the using laser, we may use it for very short period like suggest for softening purpose, higher power for soft purpose for short period.

And somewhat the high power density for somewhat longer period for the machining or the cutting purposes and for the brazing purpose, lower power density and the longer period similarly somewhat moderate power density and the longer exposure period is used for the welding purpose. So this is how this diagram gives the broad idea about the kind of the exposure period and the power density is to be used for the different purposes.

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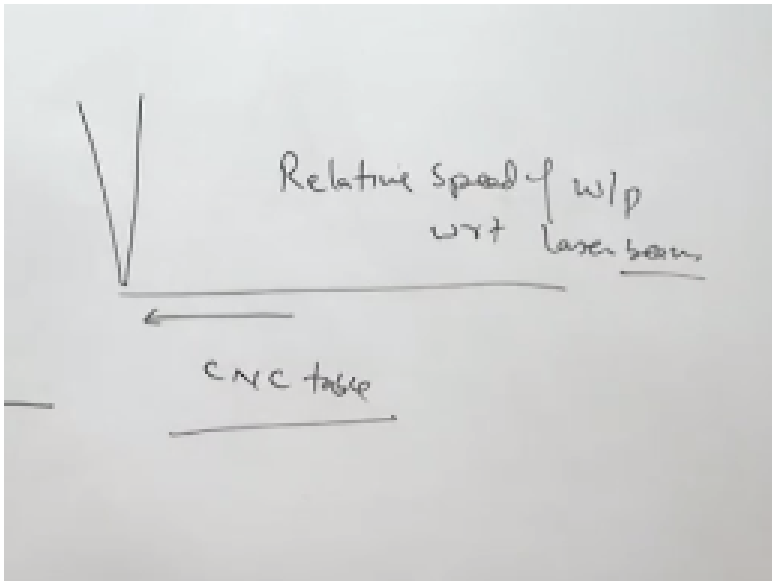

Now how to get the suitable exposure time for this purpose, now we say this is the surface of the workpiece, so now we can direct the laser at particular point. Normally, the using the

CNC table, over which workpiece is mounted is moved with respect to the laser. Laser is now directed at one location and position of the workpiece is adjusted using the control movement using the numerically control machine tool.

So now the speed of the movement can be adjusted suitably in order to have the required exposure time, it may be very slow for longer exposure period and it may be very fast for the shorter exposure period. So basically, the speed of the movement means the relative speed of workpiece with respect to laser beam determines the exposure period. So normally what we do higher scanning speed, laser scanning speed or the workpiece is speed with respective laser is used for the short exposure periods.

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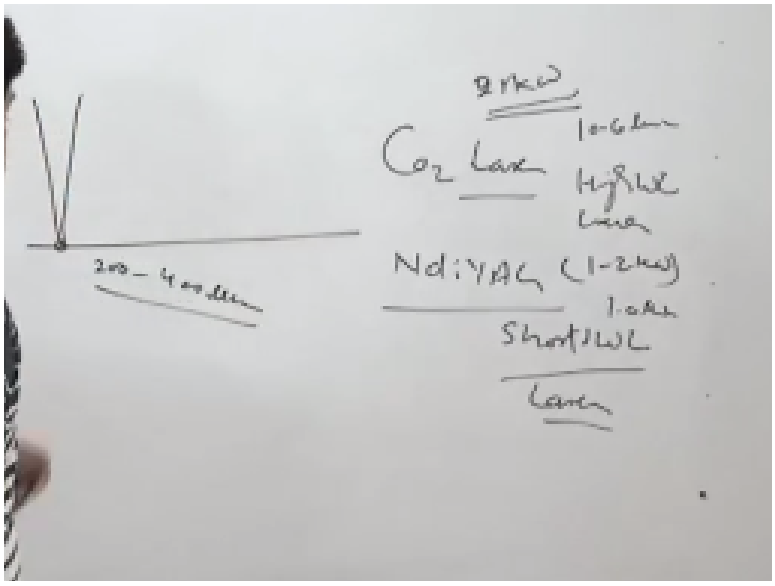

So depending upon the combination of the power density and the scanning speed suitable joints are made. For example, like say the laser we may use of the Co2 laser or ND YAG laser, this offers the short wavelength laser and this is of the Co2 laser is the high wavelength laser which is about 10 to the power 6 micrometer and here it is 1.0 something micrometer. So the short wavelength lasers, they reflect less as compared to the high wave length lasers.

So here if this is the surface of the workpiece and we are directing the laser over the surface, so the diameter over which laser can be focussed is very small say in case of ND YAG laser typically say 200 to 400 micrometer. So the beam is focussed over the surface, it may be of a say it is common to have 1-2 kg watt lasers, while Co2 laser can be as high as 25 kg watt capacity.

So what is of the laser metals allot in delivering the power over the surface, so higher is the power which is available with the laser, it can deliver lot of energy over the smaller area in short period.

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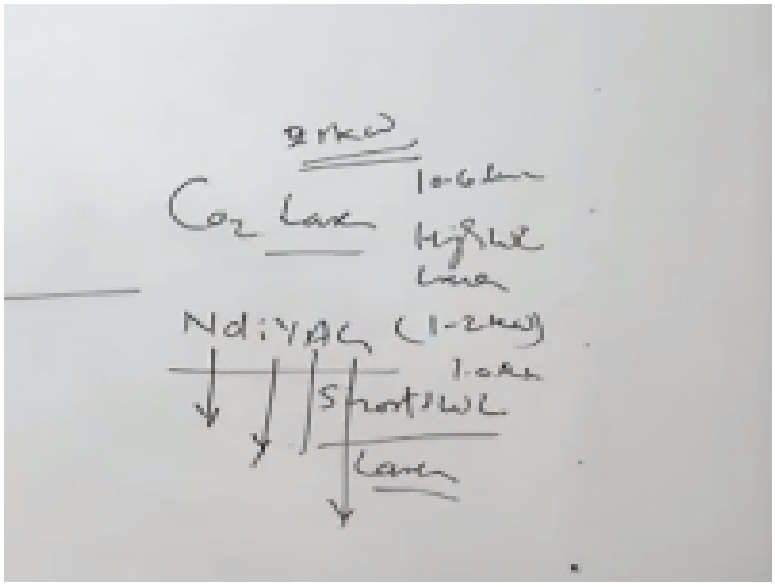

So say for 1 kg watt laser or 500 watt laser, if it is focussed over the surface of the area over, which it can be focussed say 200 micrometer for say typical value for the ND YAG where here ND is neodymium yttrium garnet aluminum garnet, so these are the three abbreviation for the neodymium yttrium garnet aluminum garnet, laser this is one typical laser and in this case, what we do laser is directed over the very small, so the melting takes place.

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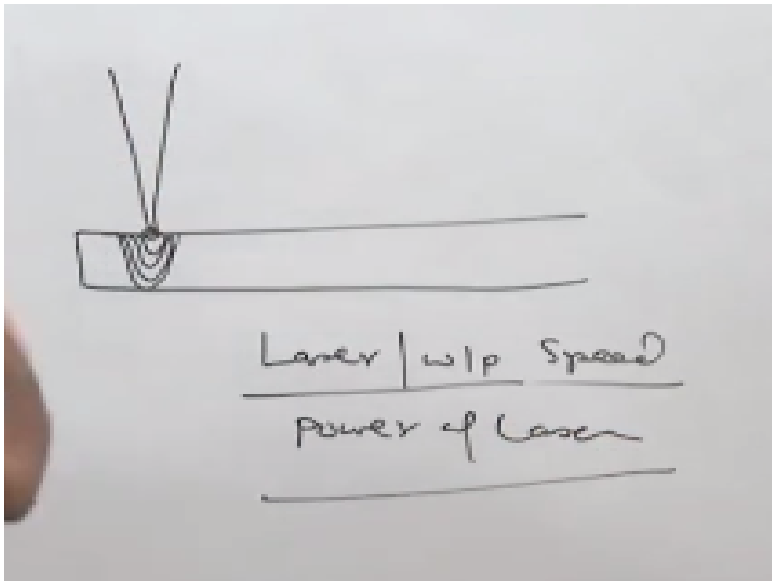

So you see melting will be taking place like this. So if it keeps on increasing the duration of this state, the depth penetration will keep on increasing up to certain limits. So we have to

identify that how to adjust the scanning speed, so that we get the suitable depth which will be sufficient for penetrating through the thickness and once this depth is achieved, we can start moving the laser as per the required speed.

So the speed of the relative movement, like the relative movement between the laser and the workpiece is determined using suitable. So you can say the laser or workpiece speed whatever is used, so it will help us in determining how much energy is being delivered in unit length and then the power of the laser certainly matters power of a laser. So, increase in power and decrease in speed will increase the power being delivered or energy being delivered to the work piece.

And so it will increase the depth of the penetration and the size of the weld which will be made. Now as I have said, since the laser is directed over a very small area and very lot of large amount of the energy is delivered in very short period.

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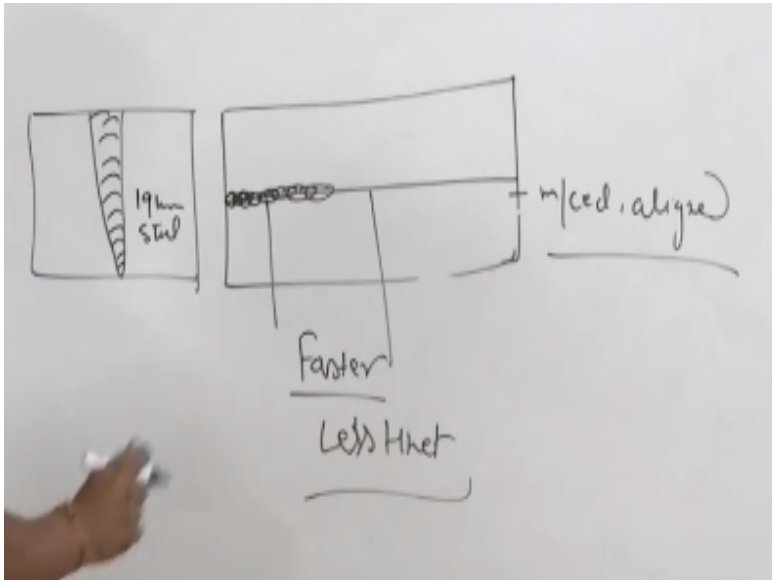

So amount of heat actually required for the welding purpose or for fusion purpose is very small. So here you see these are the two sheets to be welded and the two sheets to be welded must be properly machined aligned. This is very important in case of laser accurately machined and aligned if any gap is left between the 2 plates to be joined, like see the gap is if say 300 micrometer between the plates due to the machining accuracy or misalignment.

If the gap of 300 micrometer is left between the 2 and we are using the laser of 200 micrometer than at that location, you will see that laser will just pass through the surface of

the workpiece, pass through the gap between the plates to be welded without causing any heating. So it is very important that the edges of the plates must be properly machined, they should be straight and aligned.

So that the gap between the plates to be joined is very less or rather smaller than the diameter of the laser which is to be used. So here if the diameter is larger than the gap which is there than of course it will result in the continuous melting of the faying surfaces and this melting will be so fast, faster melting using very less heat input. So H-net is very small in case of the laser welding.

And if the H-net is very small means the fusion is taking place like say this one, if this is the side view here and the laser will be generating very you can say not the volume of the weld metal produced is very small and we can say aspect ratio is very high it means depth to the width ratio is very high and the thickness for which the laser welding is normally used is 19 mm of the steel.

However, using the high capacity lasers, efforts have been made to weld in single pass up to 32 mm also but it is not so common. Mainly up to the 19 mm thickness plates have been welded in single pass, so here the thing is since it works very fast, it melts very fast and using even very less heat input.

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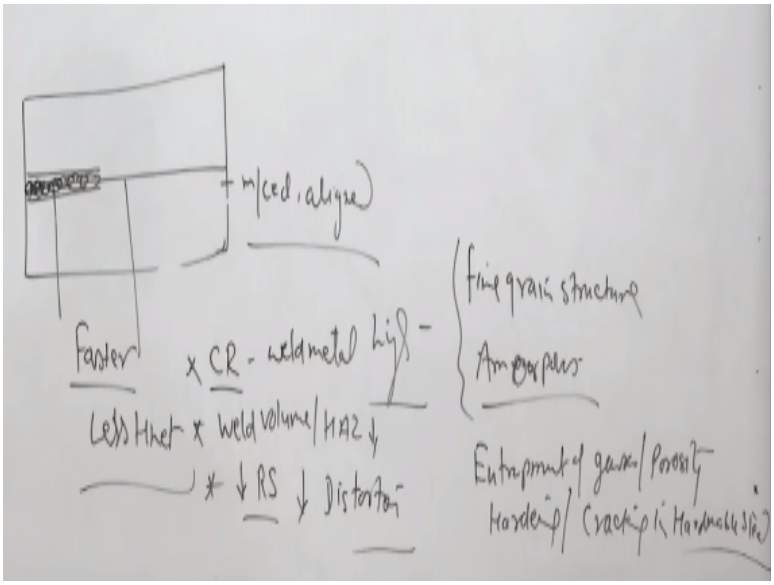

So the cooling rate experienced by the weld metal is very high, so high cooling rate results in certain favourable things and unfavourable things also. Favourable things like high cooling

rate results either very fine grain structure which is good from the mechanical properties point of view. Sometimes even amorphous structures also obtained but sometimes too high cooling rate can lead to the entrapment of the gases in form of ferocity or if the material is hard enable, then excessive hardening can cause the cracking tendency in the hard enable steels.

So this is another problem related to the high cooling rate fine. It is good to have the fine grain structure for improve mechanical properties. Sometimes it results in the amorphous structures also, but since the cooling rate is very high, so there is a possibility that the gases will get interrupt or in case of the hardening steel materials may harden too much so leading to the cracking tendency due to the residual tensile stresses.

Other effective features of the process are like reduced heat input like one vector is this cooling rate another is since the weld volume and HAZ both are less due to the reduced heat input so this is the, so that related expansion and contraction (()) (22:26) the volume of the metal which is heated during the welding and then contacts during the cooling is the small. So these in turn reduces the residual stress volume.

So reduction in the residual stress decreases the distortion tendency. This is one thing since this entire volume is extremely heated volume of the well metal which is produced and the heat effected zone which is produced in case of laser welding due to the limited heat input for the fusion purpose is less so it results in the reduced residual stresses as well as the distortion tendency.

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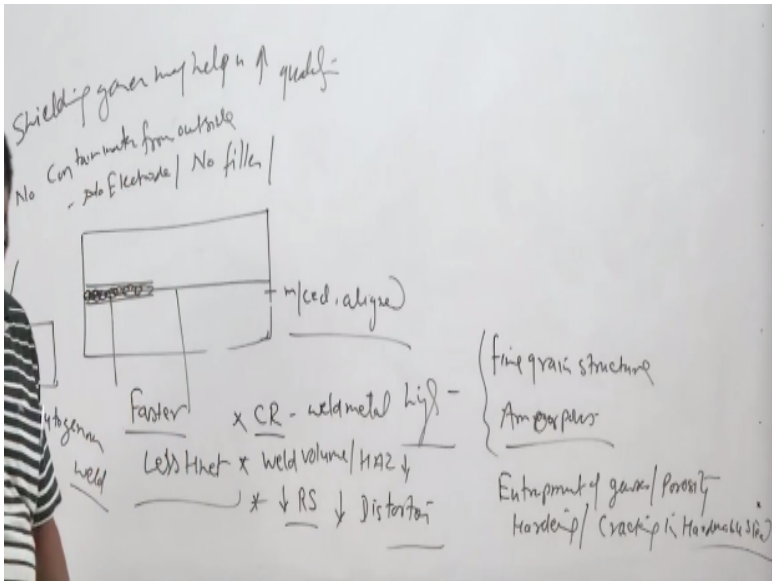

Further most of these joining in case of the laser welding does not use the external filler, just the fusion of the faying surfaces has achieved. So mostly it is autogenous weld. In this case, there is no use of no contamination from outside in which form, like no electrode, no filler, or no external gases, however, for the good quality purposes, we may use the shielding gases. So, shielding gases may help in improving the quality of the weld joint by avoiding the interaction of the atmospheric gases with the molten metal.

So these are some of the positives of the laser welding, apart from this we need to see the capability and the limitations of the laser welding from the welding point of view.

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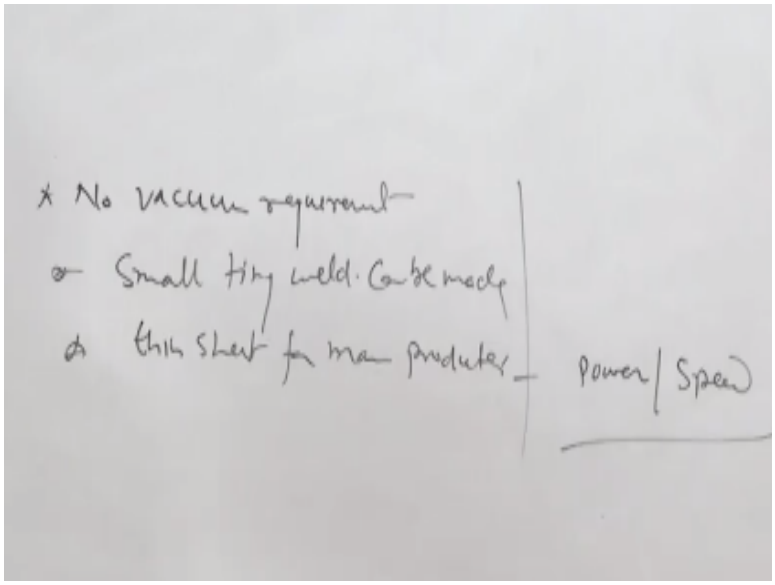

So further no vacuum requirement in this process and a very small tiny welds can be made. This feature is extremely exploited in joining of a very thin sheets for mass production

purpose because the welding speed is high, thin seats in the controlled conditions can be welded effectively once the process parameters. So of course the power and speed, these two need to be optimised properly so that we get the required depth of the penetration and depth of the fusion.

However, the depth of penetration and depth of the fusion are significantly influenced by the process conditions and the molten being welded, therefore, we need to ensure that the consistent penetration is consistently acute.

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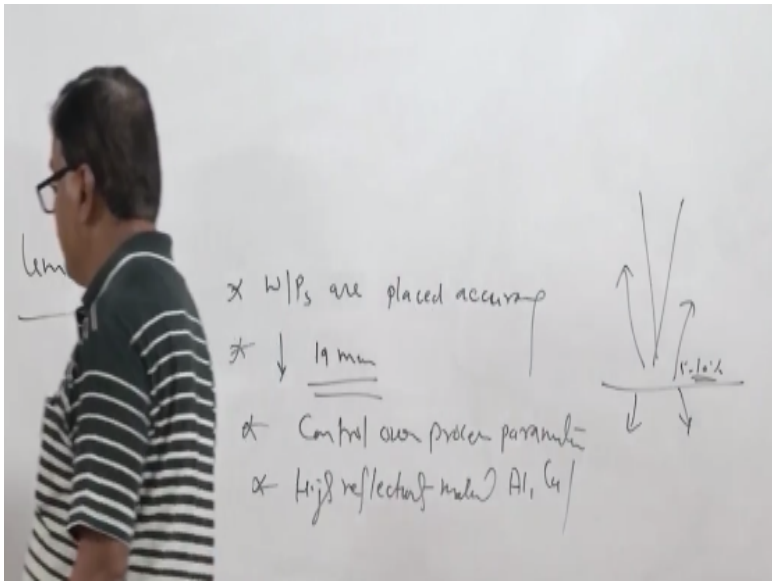

Now some of the limitations are also they are related with this process since the laser beam diameter is very small, so it is important that the workpieces or sheets or plates to be joined are placed very accurately. Otherwise, we will find that the beam has passed from somewhere else, so workpieces are placed very accurately to ensure that the beam passes through the centre line of the welds and very limited penetration.

It is normally up to 19 mm only the true thickness penetration weld can be made. It is very common so it is like up to the 2 cm only it can be welded and very good control over the process parameter is needed otherwise we may get inconsistent penetration and another the issue related with these is that high reflectivity materials like aluminium and copper. These impose lot of difficulty related with the reflection.

Because whatever beam is directed over the surface, it gets reflected and hardly say 5-10% of the energy is absorbed. So the melting is very difficult and high thermal conductivity further

makes this melting of the copper and aluminium difficult, so that these materials require especial precaution in order to improve the absorptivity and reduce the reflectivity. It is common for this materials that efficiency is very less like say 10% only.

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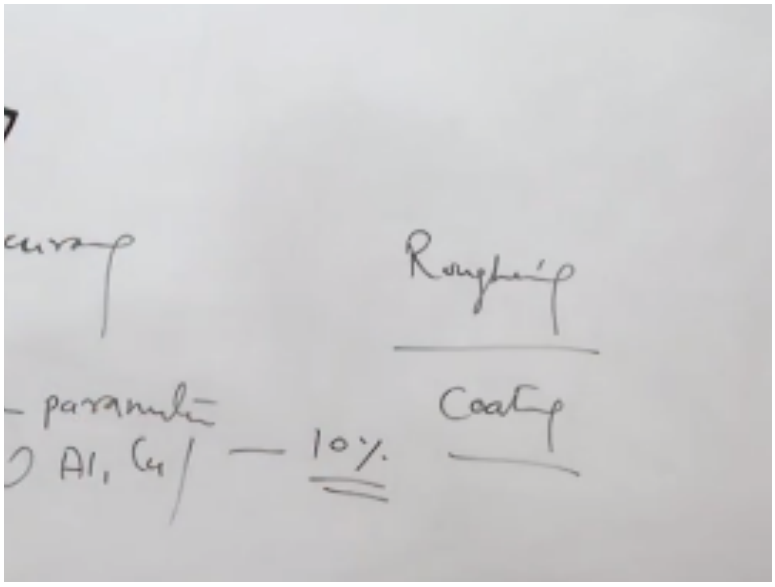

So that is why some roughening of the surfaces or application of the coatings like the black prints, etc help in increasing the absorption of the laser in case of the aluminium and the copper. Now we will see it from the penetration or performance point of view.

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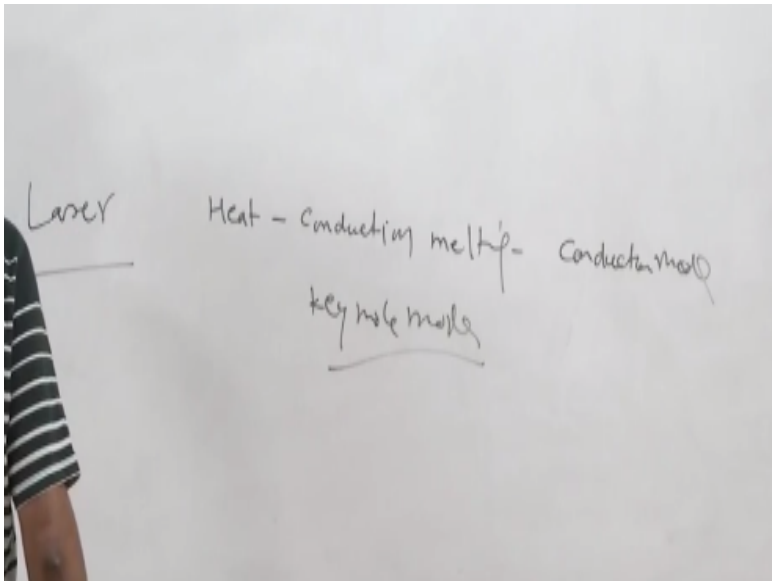

We know that the laser is used in two ways for the welding purpose one is the heat applied is transported through the conduction and then melting takes place this is called conduction mode and another is key hold mode. So what is the difference in these and what happens when the laser is directed on the surface of the work piece.

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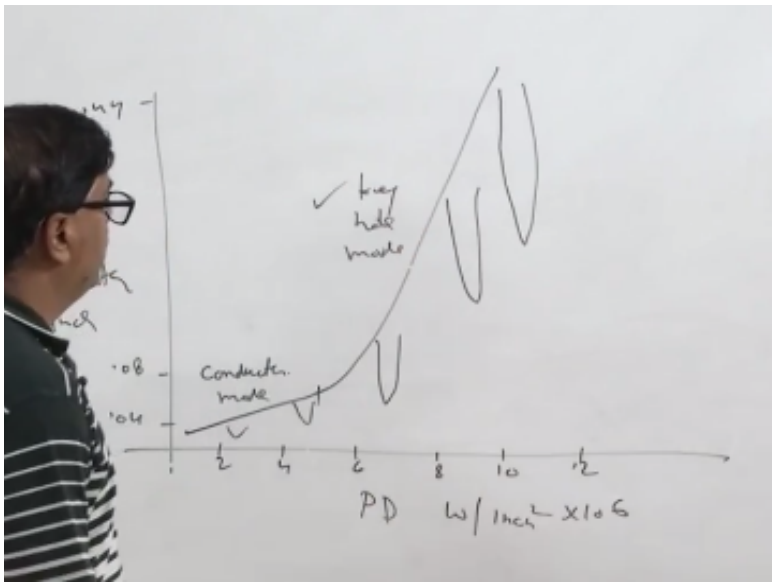

So for this purpose, what we need to see is one diagram, here we have power density in terms of the watt per square inch in 10 to the power 6. Here like say 2, 4, 6, 8, 10, 12 like this and on the other hand, the penetration depth which is achieved in inches it is like 0.4, 0.8 and like this 0.44. So when the power density is increased what we get like initially it keeps on increasing linearly like this and then it jumps fast.

It increases rapidly with the increase in the power density. So this is the zone for the conduction mode and this is the zone for the key hole mode. So here the penetration, the width is large and penetration is limited, width and penetration increases, width is also high but thereafter will see the penetration width does not increase much but the depth of penetration increases.

So this depth of penetration will keep on increasing without increase in the width of the weld.

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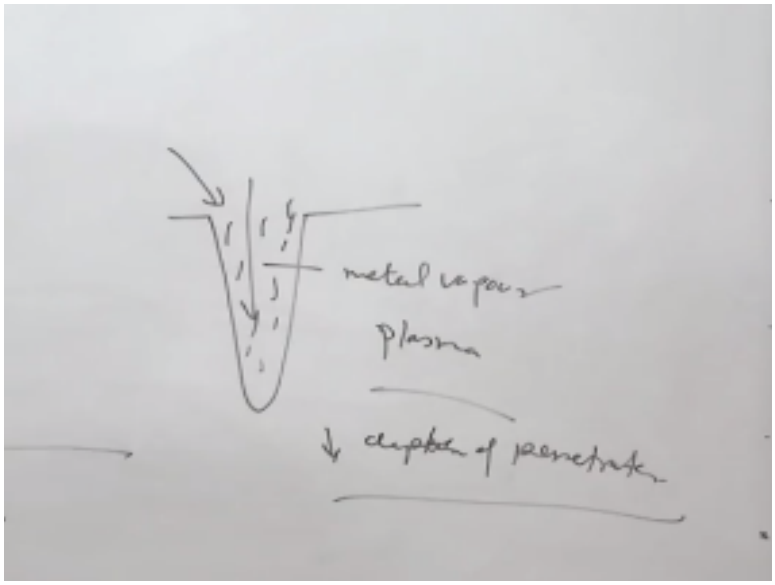

So this is what is obtained in key hole approach, but it imposes certain problems like high energy density results in the evaporation of the metal and a metal vapours, actually ionised, an ionisation of the metal vapours forms the plasma and this plasma absorbs the laser. So whenever plasma is formed in this gap the plasma absorbs the last and which in turn reduces the actual energy being delivered at to the base metal and that in turn reduces the depth of penetration.

So depth of penetration is reduced due to the plasma formation. So this plasma formation must be taken care of or it must be suppressed. So either the energy density and the scanning speed parameters are controlled in such a way that the plasma formation is avoided or if it is being formed in any case, then the flow of the inert gases during the welding is ensured in such a way that the plasma is expelled from the whole, which has been formed.

So a proper care is taken during this process, means directing the inert gases in such a way that the key hole is not disturbed otherwise it will get collapsed, it will adversely affect the weld joining process or the welding process. So this is what we have seen the depth of the penetration is affected by the energy density and the formation of the plasma also affected. So the difference metals of course all of the different kind of the depth of the penetration.

So here now I will conclude this presentation. In this presentation, I have talked about the basic principles, how the laser beam can be effectively used for the welding purpose, what are the positives or the advantages of laser welding and in what way it offers certain disadvantages for the laser welding and what are the points must we kept in mind while using

the laser welding for the consistent and uniform penetration during the welding. Thank you for your attention.