Advanced Manufacturing Processes

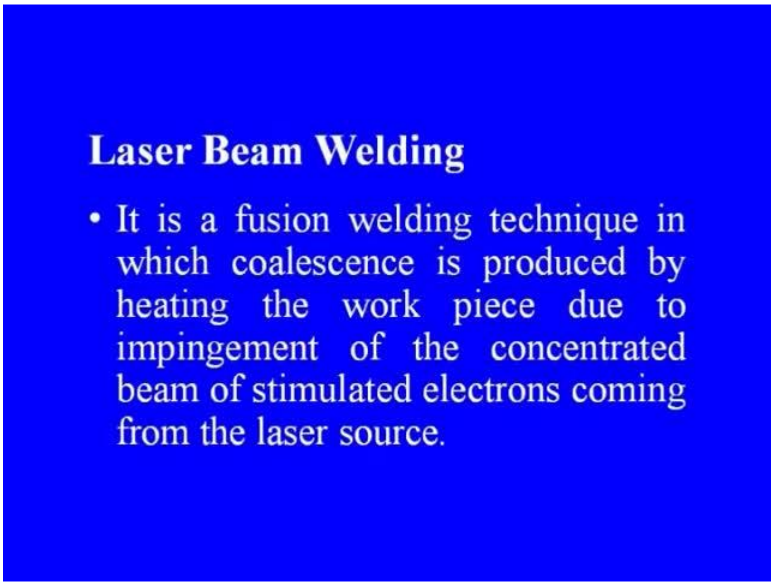
Prof. Dr. Apurbba Kumar Sharma
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Module - 4
Advanced Welding Processes
Lecture No - 6
Laser Beam Welding and Diffusion Welding Process

Welcome to this session on laser beam welding process under the course advanced manufacturing processes. In the last few sessions we have discussed about the solid state welding processes, then the electron beam welding process and plasma arc welding process. We have also seen the working principles, process requirements, advantages, limitations and applications of these processes. Moving on let us see another advanced welding process namely laser beam welding process. We have already discussed about the laser beam machining process in the module 3.

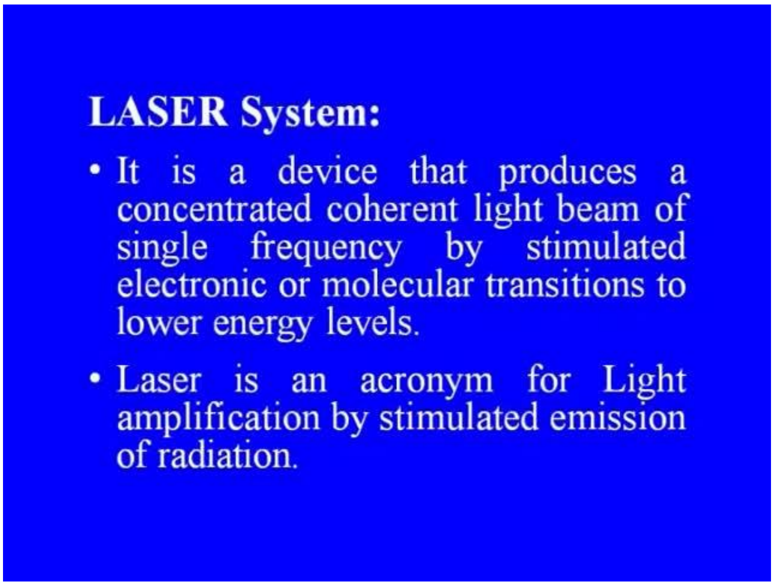
So, this laser beam welding process is also similar to that process in the sense that the same kind of laser will be used, and here instead of cutting or removing material we will confine the laser beam power into just melting the materials and fusing the two materials. In the previous lecture we have discussed about the principles of laser formation, then some unique characteristics of lasers and their applications. However, in this session we will confine our discussion to the welding aspects along with a brief description of the basics and features of and applications of laser beam welding process. The process principles, advantages, limitations, and applications of some other important welding processes like forge welding and diffusion welding will also be covered in this session.

(Refer Slide Time: 02:56)



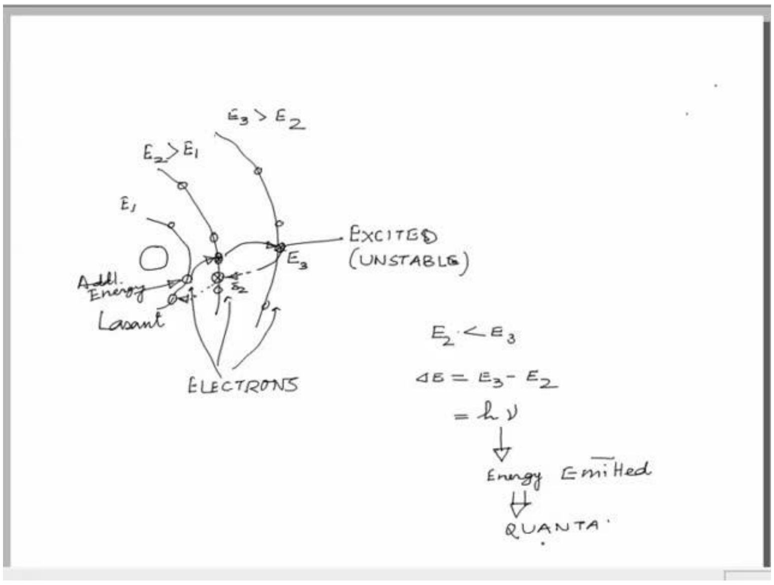
Now, let us move on to first the laser beam welding process. As we have indicated already, so this is also a thermal based process in which heat will be generated by the application of laser beam. The coalescence of the surfaces of the material will be produced by heating the work piece due to the impingement of the concentrated beam, laser beam which will be coming out from the laser generating device or we call as laser source. Let us refresh our self with the laser system. Although we have already discussed quickly let let us have a recap of the process what we have discussed already.

(Refer Slide Time: 03:57)



It is a device that produces a concentrated coherent light beam of single frequency by stimulated electronic or molecular transitions to lower energy levels. Laser is an acronym for light amplification by simulated emission of radiation.

(Refer Slide Time: 04:39)

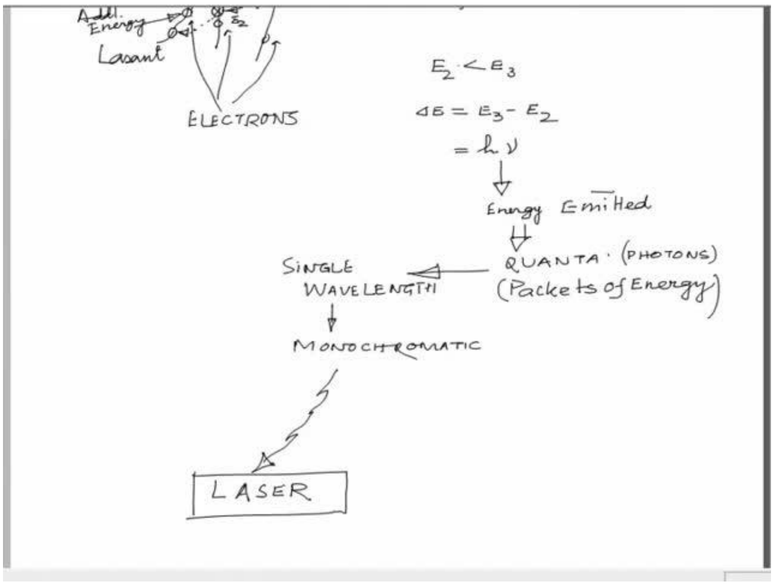


If we recall the, our earlier discussions we can see that this is, for producing laser one material which is called say lasant. This lasant material has to be excited or in other words the electrons in the orbits of low energy so here energy is E 1 and here energy is E 2 which is higher than E 1. Similarly, if we go on to the other orbits so energy level will be higher subsequently. Therefore, if we if we apply some or or if we supply some energy, this is additional energy to the low energy electrons. So, these are nothing but electrons with different energy levels as we have indicated.

Now, if these electrons at relatively lower energy level is shifted to or knocked up to another level which is at higher energy and this is shifted to further shifted to another level which has got further energy then they will they will come to an excited status or excited state which is very, very unstable for them to remain for a longer period. Therefore, these electrons will always try to jump to the next lower energy level. They will always keep on trying this; in turn again they will try to come to their original energy level.

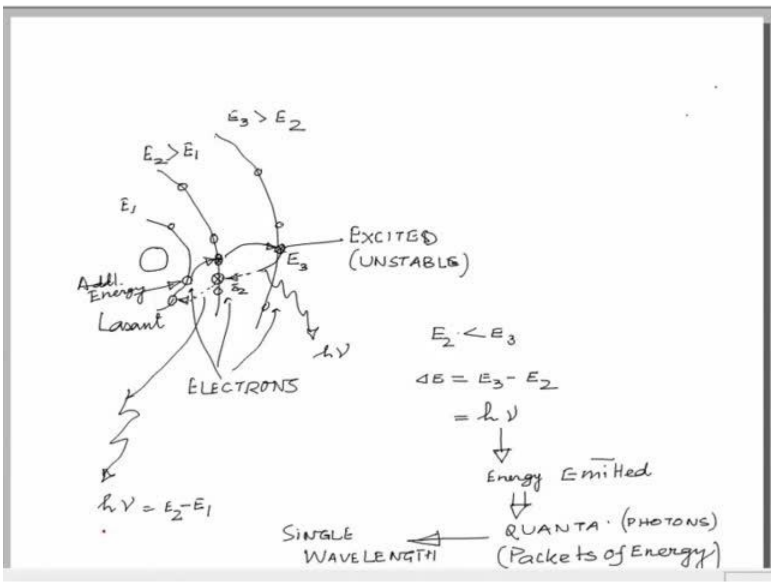
While doing so at this moment when it was here say they were at this E 3 level. Now, while coming back to E 2 level where E 2 is less than less than E 3 the difference in the energy del E is nothing but E 3 minus E 2. This energy or delta E is equivalent to h nu and this is nothing but the energy and this energy will be emitted in the form of emitted in the form of some packets or also called as quanta.

(Refer Slide Time: 07:45)



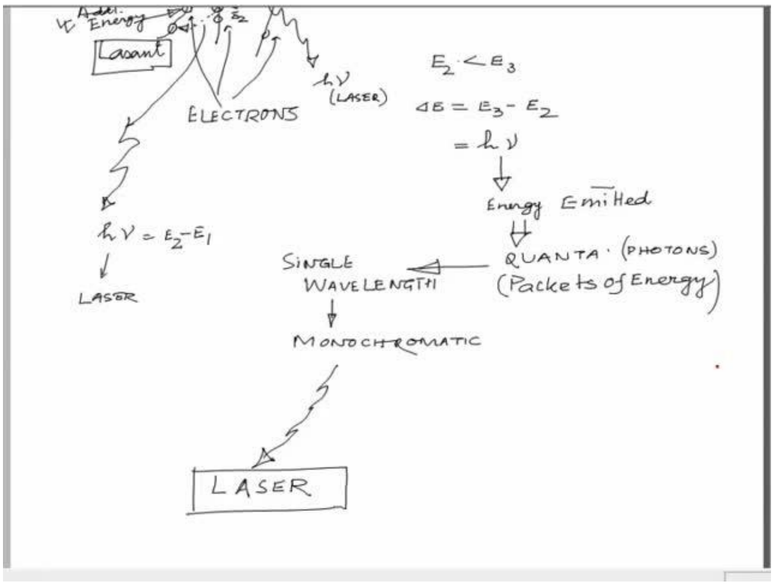
Or these are in very simple meaning it can be known as packets of energy. These quantas are also called photons. So, they have single wavelength and therefore, they are we can say monochromatic, monochromatic in nature and these quantas are nothing but what we call as laser.

(Refer Slide Time: 08:57)



Therefore, while coming back here. So, they will emit some radiation this is nothing but h nu. Similarly, while coming out from here they will emit some radiation this is nothing but h nu which will be now equivalent to E 2 minus E 1 again it will be delta E.

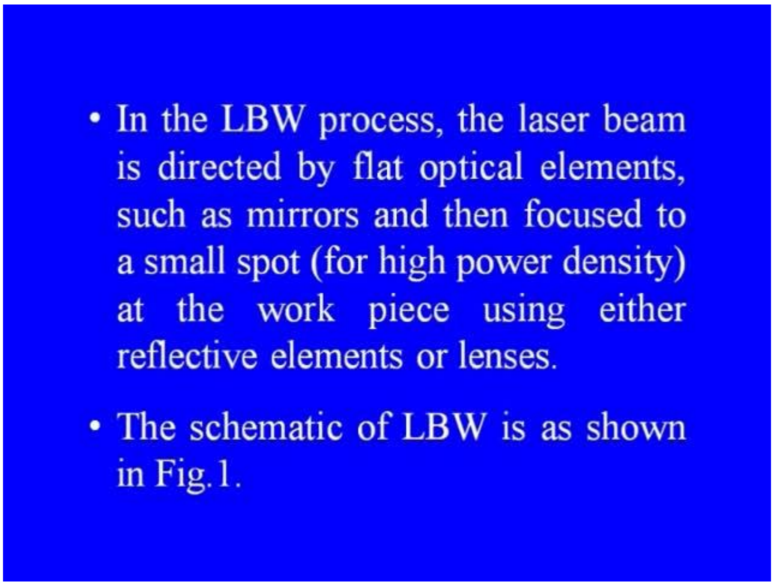
(Refer Slide Time: 09:23)



So, this is nothing but what we call as laser, what we call as laser here. So, this is the basic principle how we produce or we can get laser from a lasing material or a lasant, that is lasant. So, for this we need an external source of energy that we call as additional source or this we call as excitation energy which will be generally in the form of some additional UV light or some other arrangement. And the material in the excited state will emit this laser energy or the photons, this will be allowed to reflect, get reflected several times inside the device or inside the lasing device.

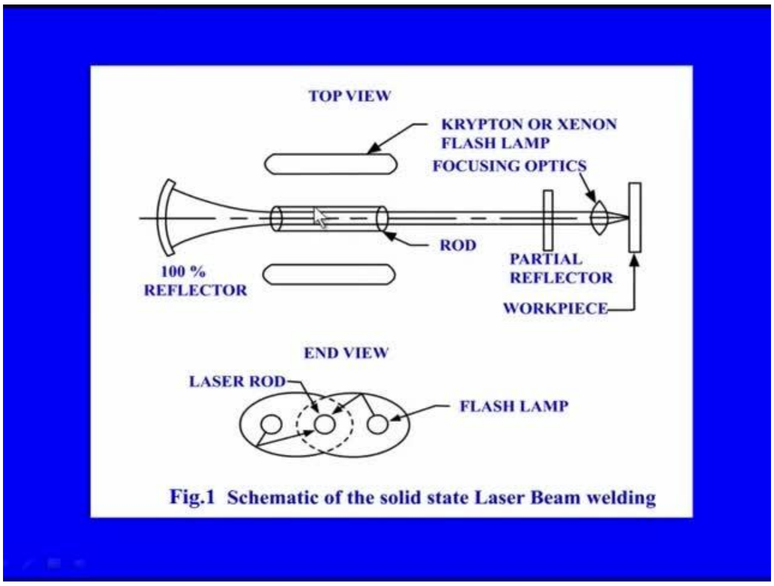
And after it gets amplified to a certain level then they will be allowed to come out from the device or the lasing environment from the system through special mechanisms and that will be taken away or collected for different applications. So, this is the basic principle of laser production that we will see how they are being manipulated further for different applications.

(Refer Slide Time: 11:15)



In the laser beam welding process laser beam is directed by flat optical elements such as mirrors and then focused to a small spot for high power density at the work piece where we want to do the welding operation using other reflective elements or some special lenses. This is the schematic of the laser system. This is what just we were discussing just now, it is schematic is on the screen.

(Refer Slide Time: 11:53)



This is the lasing material I was talking about or also called as lasant. So, here it is shown as a rod which can be say ruby rod, if it is a solid state material or neodymium atrium aluminum granite rod. So, these are some of the lasing material or lasant, solid state lasant. Apart from that we can use some gases also like a argon system, helium argon system or carbon di oxide is a very popular lasing material. Now, this lasant is being excited by some additional energy. So, this is the energy supply system, additional energy supply system.

Generally, these are like krypton or xenon flash lamps. So, they pump energy, pump energy in the form of some light waves which will be responsible for causing the population inversion. What is the situation called population inversion? Like just we have discussed just now the electrons from lower energy level to higher energy level will be knocked up that means that will create a very unusual situation of electron densities at the cells, outer cells where generally the number of electrons will be different from that of inner cells or for that matter we can say each cell has got some fixed number of electrons because owing to its electronic configuration.

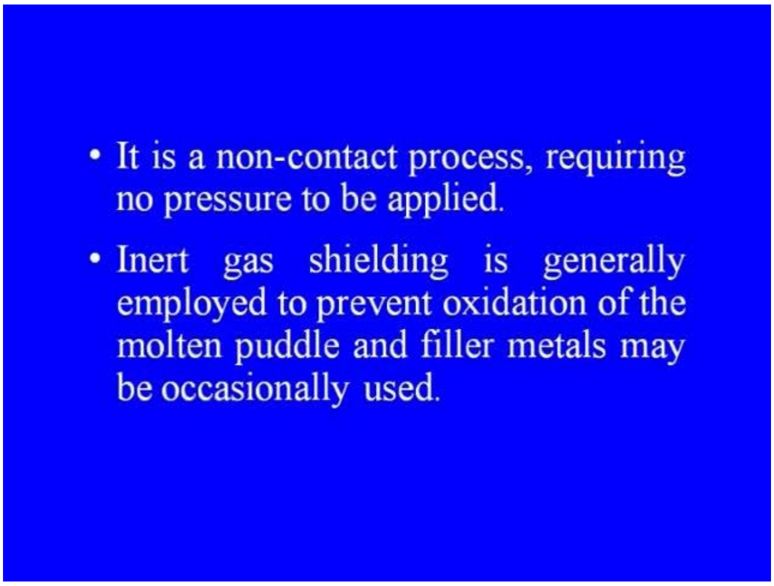
Now, if we disturb that number which is naturally occurring say for example, in the outer cell if there were four electrons. Now, if we knocked up few more electrons on to the outer cell say for example, it has come to eight then it is called a situation that is population inversion. We have created an abnormal situation of different abnormal population in the outer cell. Now, at this state as I have already told the electrons are in a unstable condition and they will always try to jump to the near, nearer cells or low or low orbits to come to, in order to come to their normal conditions.

Therefore, they will always try to jump down to the next orbits, next lower energy level orbits and thereby making the population inversion condition going back to the original condition. However, because of this, this additional source this population inversion will be kept on creating or will be maintained over a period. And therefore, these electrons although they will jump back to the next electron energy, next lower energy level cells some more electrons will be again brought back to or knocked up to the other higher energy level cells.

However, this while jumping down to the smaller energy level cells the energy released will be in the form of some photons or we can say in the form of some radiations which will be as shown in the in the figure will be continuously being reflected in this system. This is a, is shown as hundred percent reflector system. So, in between, in between the chamber or the enclosure so some specially placed mirrors are there which will be responsible for their continuous reflection of these beams and after getting amplified to a certain or required level they will be allowed to come out through this lens or the mirror through this mirror system which is partially reflective.

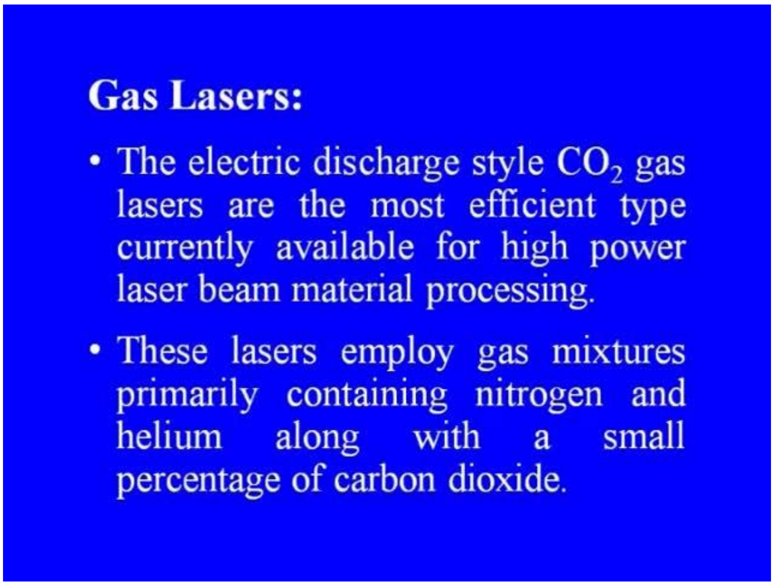
That means some portion of the amplified energy or the beam in the form of laser will be allowed to come out from this system. And this amplified energy which is called laser will be used for industrial purposes or for other purposes which can be for say medical purposes as well. It is as we have already seen the schematic or the principle this laser welding device is a non contact device in which there is no conventional electrode and work piece contact or the tool work piece contact situation and therefore, there is no question of applying any pressure as well.

(Refer Slide Time: 17:34)



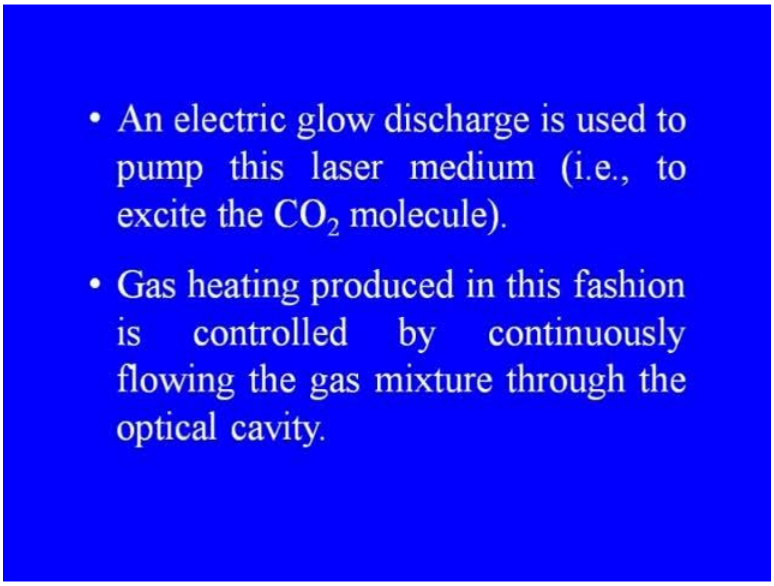
Inert gas shielding is generally employed to prevent oxidation of the molten puddle and filler metals may be occasionally used, as we have already spoken about, this is a thermal based process and causes material to get melted. Therefore, it is prone to oxidation if the environment is not controlled properly.Therefore, some shielding gases for certain materials which are very easily oxidisable where susceptible to oxidation should be used. Some shielding gases should be used for protecting the weld pull from this oxidizing essence. Now, let us talk about the gas lasers which is generally widely used in case of laser beam welding and as we have already indicated the carbon di oxide is the most popular gas laser.

(Refer Slide Time: 18:44)



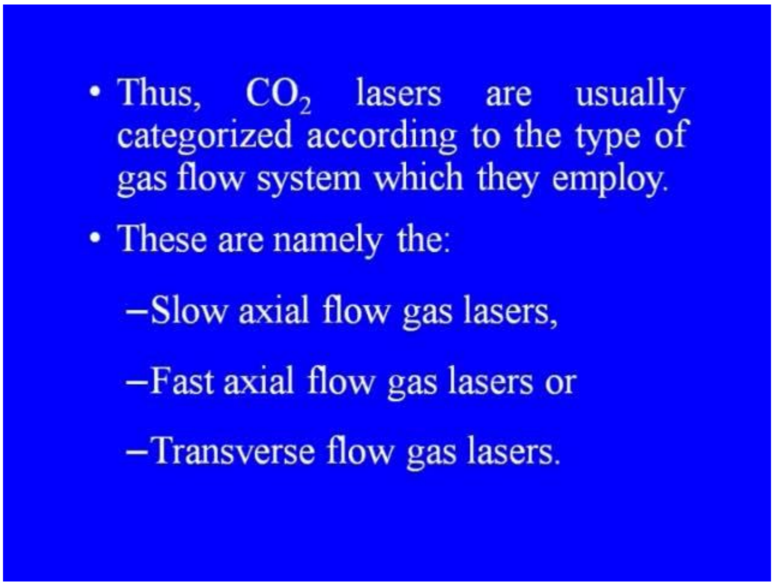
The electric discharge style of carbon di oxide gas lasers are the most efficient type currently available for high power laser beam material processing. These lasers employ gas mixtures primarily containing nitrogen and helium along with a small percentage of carbon di oxide.

(Refer Slide Time: 19:12)



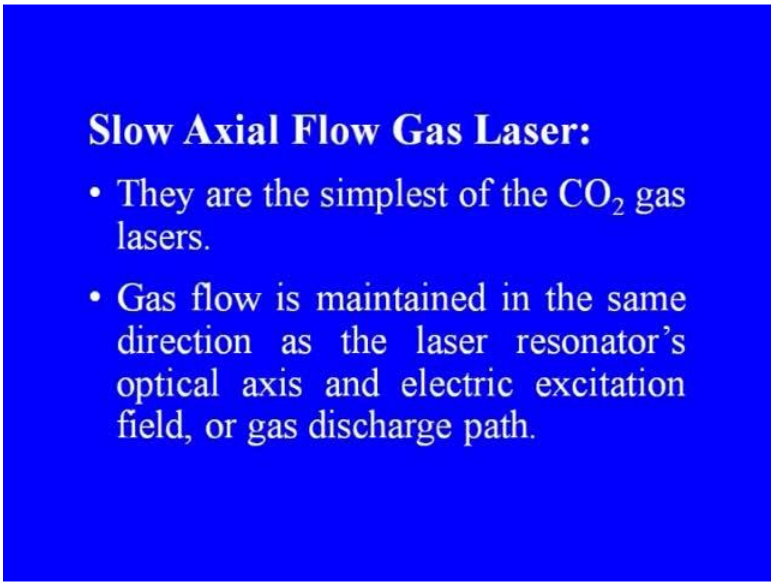
An electric glow discharge is used to pump this laser medium that is to excite the carbon di oxide molecules. Gas heating produced in this fashion is controlled by continuously flowing the gas mixture through the optical cavity.

(Refer Slide Time: 19:32)



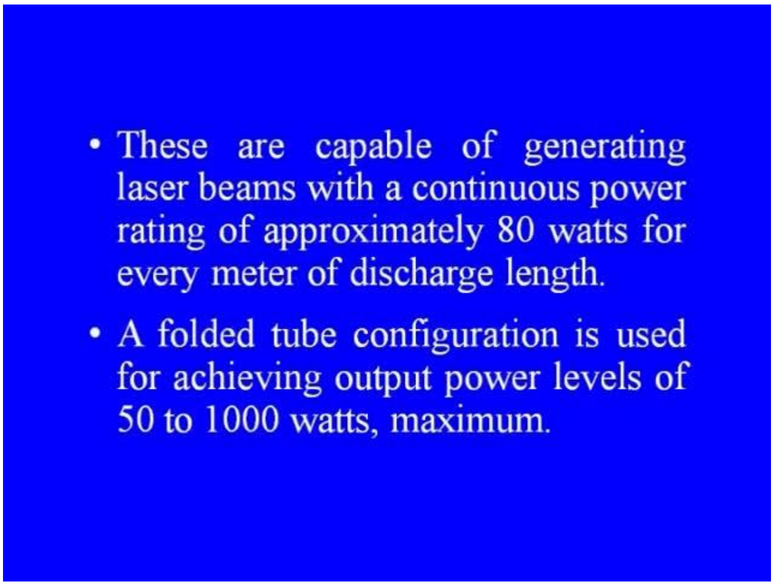
Thus, carbon di oxide lasers are usually categorized according to the type of gas flow system which they employ. These are namely the slow axial flow gas lasers, fast axial flow gas lasers and transverse flow gas lasers. Let us see this slow axial gas flow lasers.

(Refer Slide Time: 20:08)



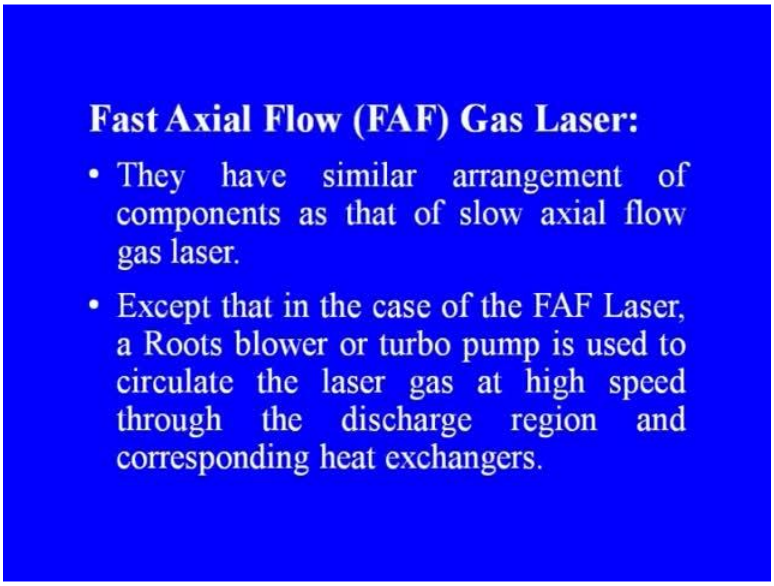
They are the simplest of the carbon di oxide gas laser family. So, gas flow is maintained in the same direction in this case as the laser resonator's optical axis and the electric excitation field or the gas discharge path in the same direction.

(Refer Slide Time: 20:34)



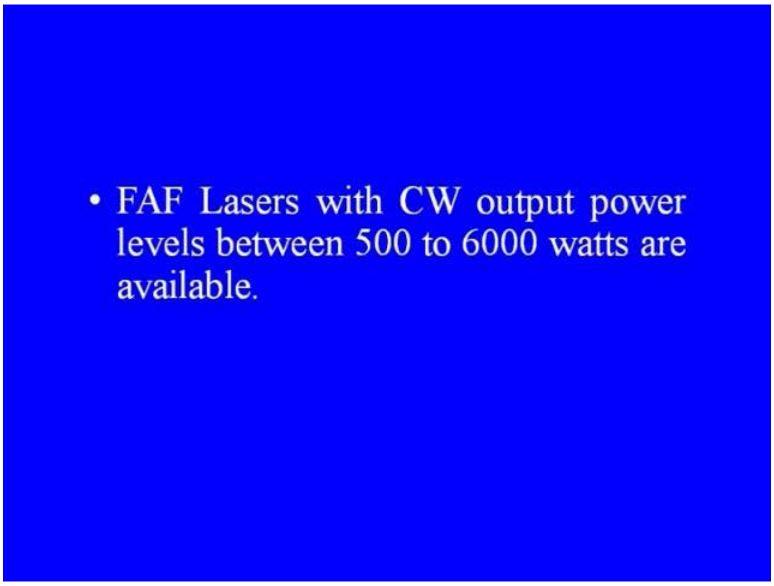
These are capable of generating laser beams with a continuous power rating of approximately 800 watts for every meter of discharge length. A folded tube configuration is used for achieving output power levels of 50 to 100 watts maximum.

(Refer Slide Time: 21:05)



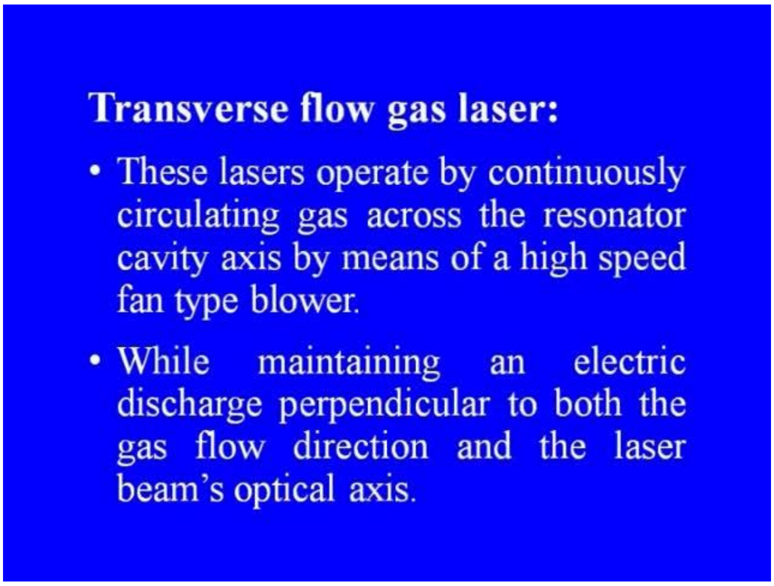
And in case of fast axial flow FAF in short gas lasers, they have similar arrangement of components as that of the slow axial flow gas laser. Except that in the case of fast axial flow gas lasers a root blower or turbo pump is used to circulate the gas at high speed through the discharge region and corresponding heat exchangers.

(Refer Slide Time: 21:38)



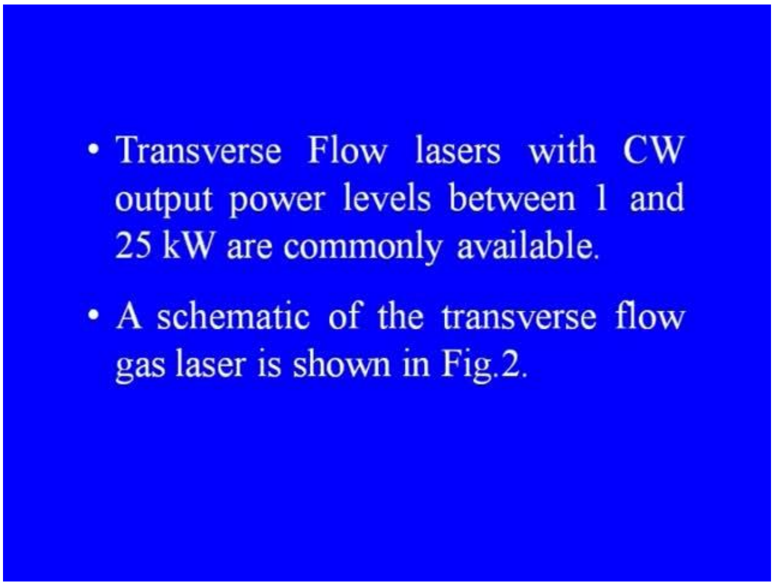
Fast axial flow gas lasers with continuous output power between 500 to 6000 watts are easily available.

(Refer Slide Time: 21:55)



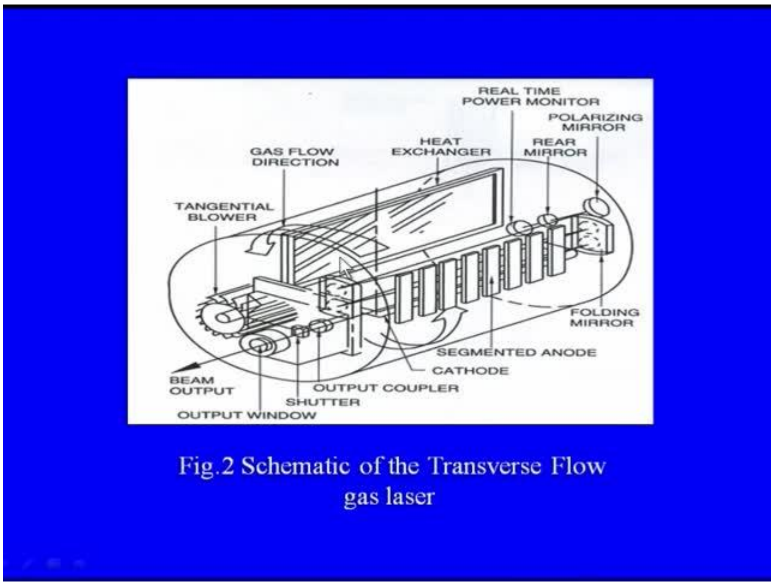
Then comes the transverse flow gas lasers. These lasers operate by continuously circulating gas across the resonator cavity by means of a high speed fan type blower. While maintaining an electric discharge perpendicular to both the gas flow direction and the laser beams optical axis.

(Refer Slide Time: 22:21)



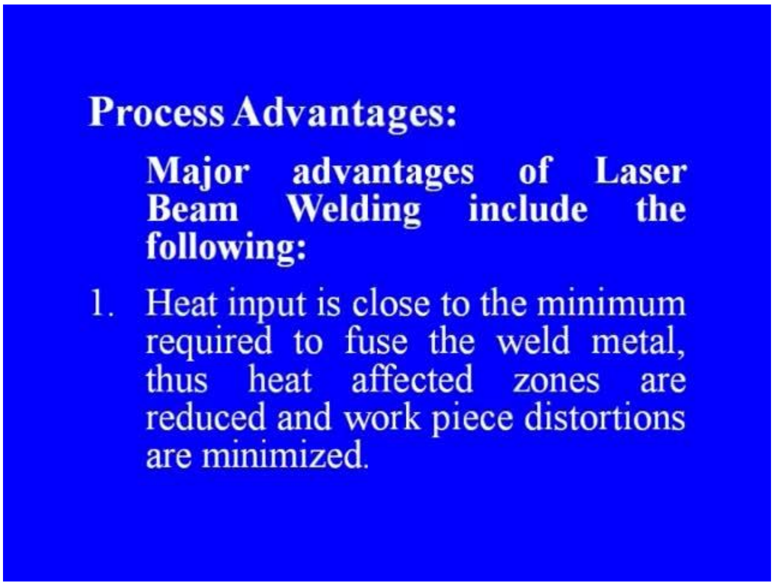
Transverse flow lasers with continuous wave output power levels between 1 and 25 kilo watt are easily available. A schematic of this type of flow gas laser is shown here in the screen.

(Refer Slide Time: 22:45)



So, here this is the mechanism. So, all the requirements or the components like polarizing mirror, rear mirror all these components are integrated in this system and this is where, this is the device through which we can have the beam output. This gas flow direction etcetera are also been shown in this figure. Now, let us look at the advantages, major advantages of laser beam welding process.

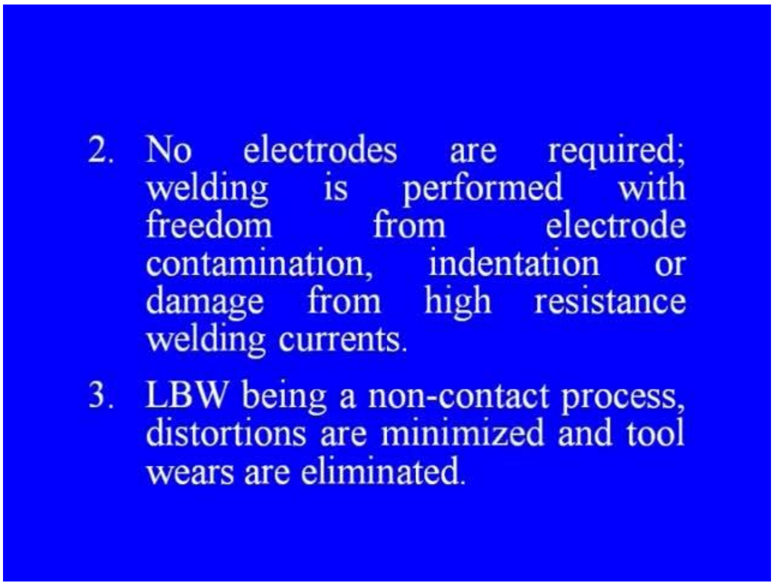
(Refer Slide Time: 23:26)



So, this includes the following, number one, heat input is close to the minimum required to fuse the weld metal, thus heat effected zones are reduced and work piece distortions are minimized. As we have already spoken about so this is also another thermal based process and heat effected zones is most likely. However, because of the characteristics of laser that it can be just focused to a very narrow zone.

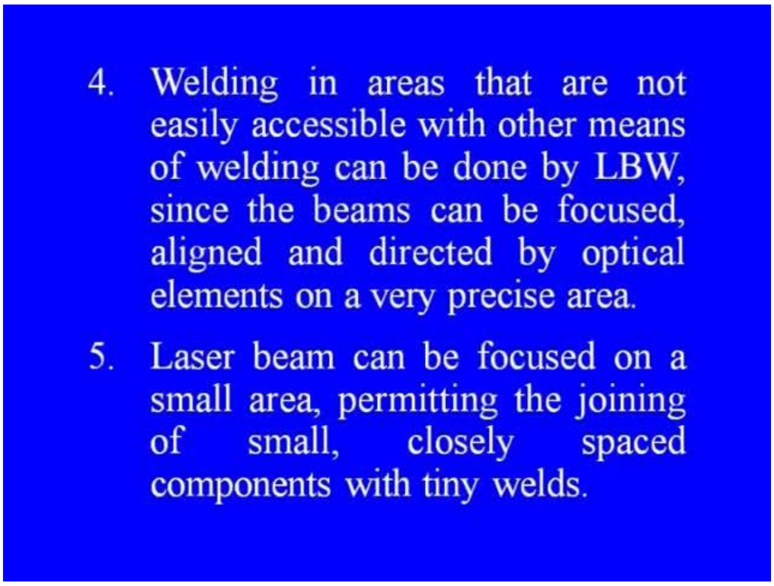
Therefore, the heating effect through the nearby material of the weld point will be much less. This is clearly an advantage of this process like we have seen in the electron beam welding process also in that case also the beam can be concentrated to a very small diameter spot. And therefore, the heat affected zone nearby to this working zone will be much less.

(Refer Slide Time: 24:46)



Number two, no electrodes are required in this case. Welding is performed with freedom from electrode contamination, indentation or damage from the high resistance welding currents. In fact there is no current being applied to the work piece or the system. In that system only the laser production system does need the power supply that is different. Laser beam welding being a non contact process distortions are minimized and tool wears are eliminated.

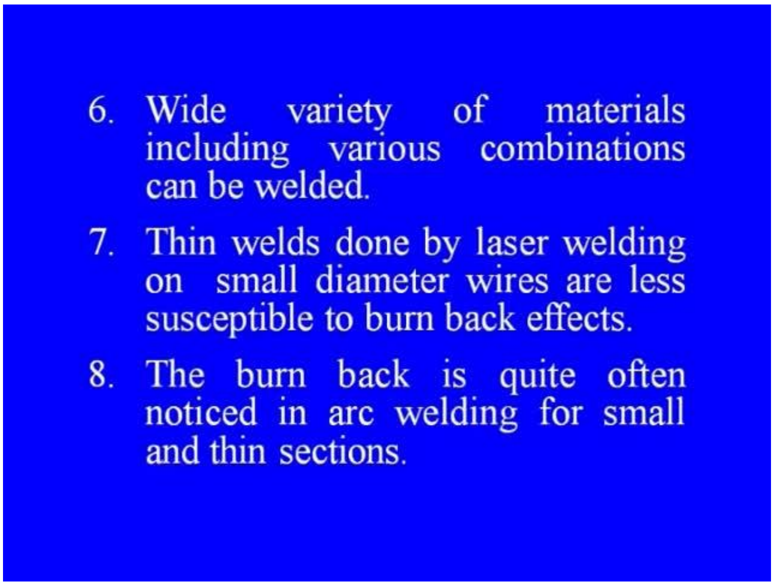
(Refer Slide Time: 25:28)



Welding in areas that are not easily accessible with other means of welding can be done by laser beam welding. Since, the beams can be focused, aligned and directed by optical elements on a very precise area. This we have spoken about in in case of electron beam welding as well. So, even if there is a small constriction so this laser beam being very very thin in diameter or the diameter of the beam is very less, can be guided to a very restricted area as well and welding can be done.

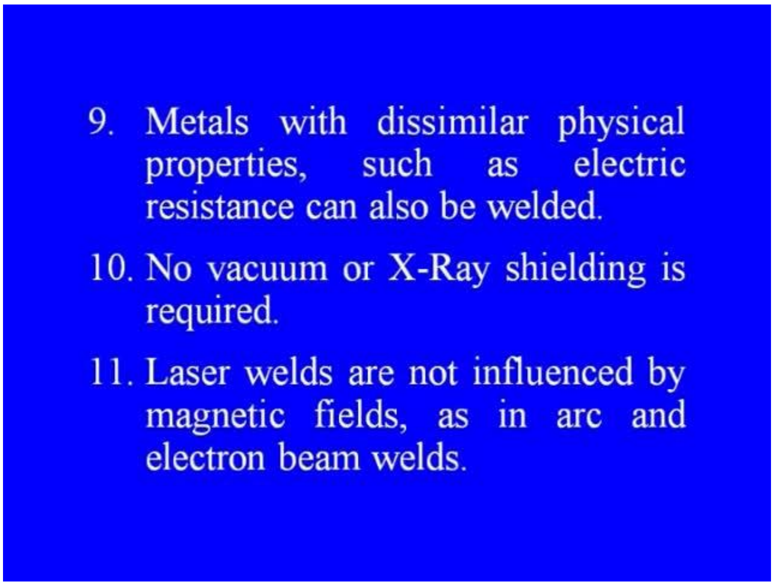
In which case perhaps the conventional welding electrons could not be inserted to reach that particular area and of course, the conventional welding rods will give a a macro level welding spot which can be reduced to a very, very narrow or small zone in case of laser welding. Therefore, it it is suited mostly for for micro joining or micro manufacturing applications. Laser beam can be focused on a very small area, permitting the joining of the small and closely spaced components with tiny welds. That is usually ideally it is suited for most of the micro fabrication purposes.

(Refer Slide Time: 27:09)



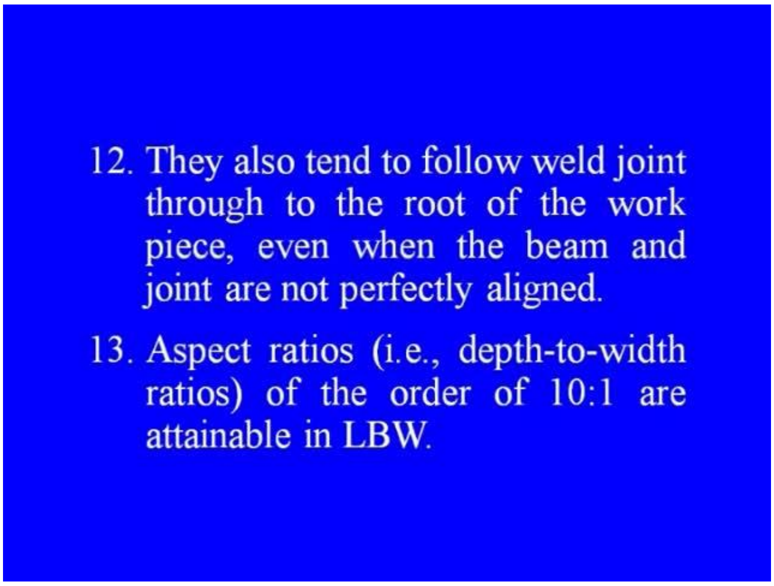
Then wide variety of materials including various combinations can be welded by laser beam welding method. Thin welds done by laser welding or small diameter wires are less susceptible to burn back effects. This is clearly an advantage. The burn back is quite often noticed in arc welding for small and thin sections which can be easily avoided in case of laser welding system.

(Refer Slide Time: 27:48)



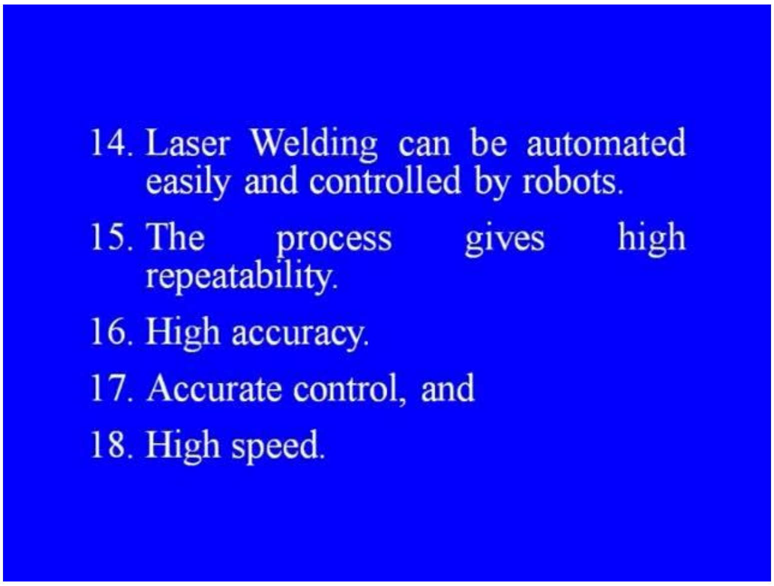
Metals with dissimilar physical properties such as electric resistance can also be welded very effectively here because electric resistance, electrical resistance does not come into the picture in case of laser beam welding process. And no vacuum or X ray shielding is required in this case which is clearly an advantageous situation. Laser welds are not influenced by magnetic fields as in the case of arc and electron beam welds where a magnetic field influences the beam itself and it can deflect the beam from the actual point of focus etcetera, but here in this case it is not so.

(Refer Slide Time: 28:39)



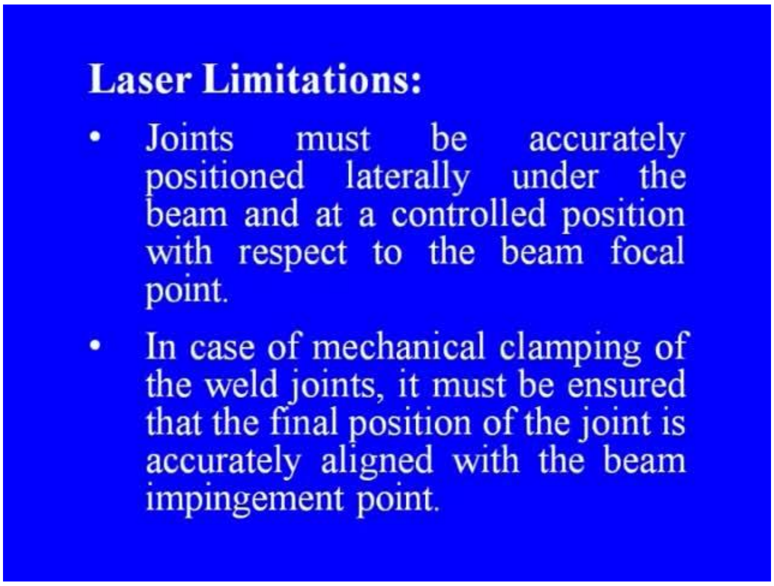
They also tend to follow weld joints through the root of the work piece, even when the beam and the joint are not perfectly aligned. Then the aspect ratios which is nothing but depth to width ratios of the order of 10 is to 1 could be attainable in this laser beam welding process. This process can be automated very easily and controlled by robos also.

(Refer Slide Time: 29:14)



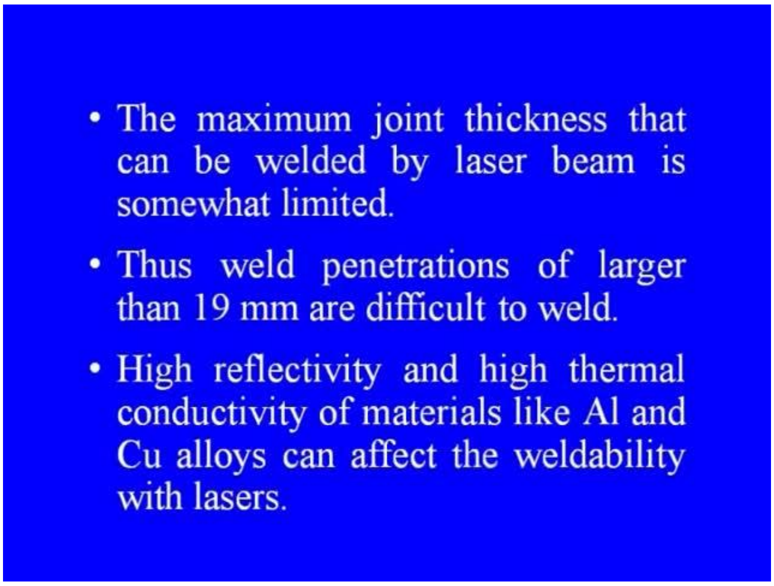
The process gives very high repeatability which is very important as far as the process performance is concerned. It provides very high accuracy, this provides very high control, accuracy of accuracy of control is very high and high speed can be obtained. Let us at the same time note few limitations of this process as well.

(Refer Slide Time: 29:44)



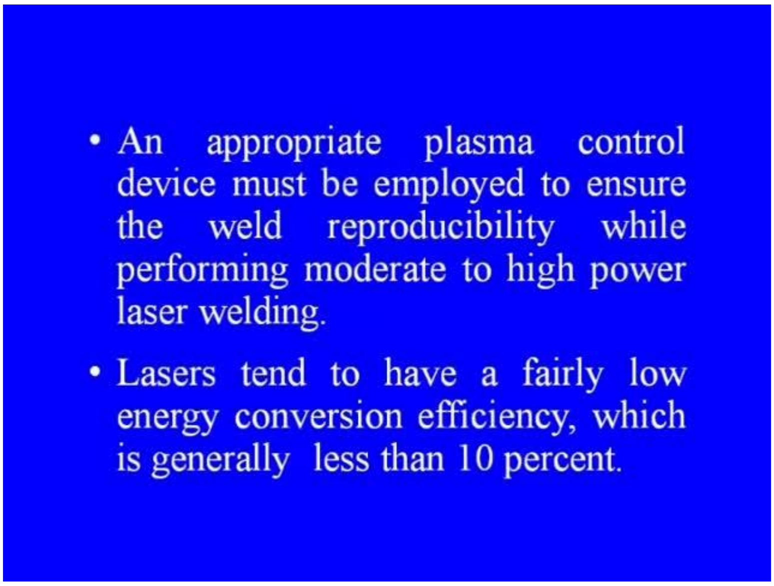
The joints that are obtained by laser beam welding must be accurately positioned laterally under the beam and at a controlled position with respect to the beam focal point. This is very critical for accuracy of the welding process. In case of mechanical clamping of the weld joints it must be ensured that final position of the joint is accurately aligned with the beam impingement point.

(Refer Slide Time: 30:24)



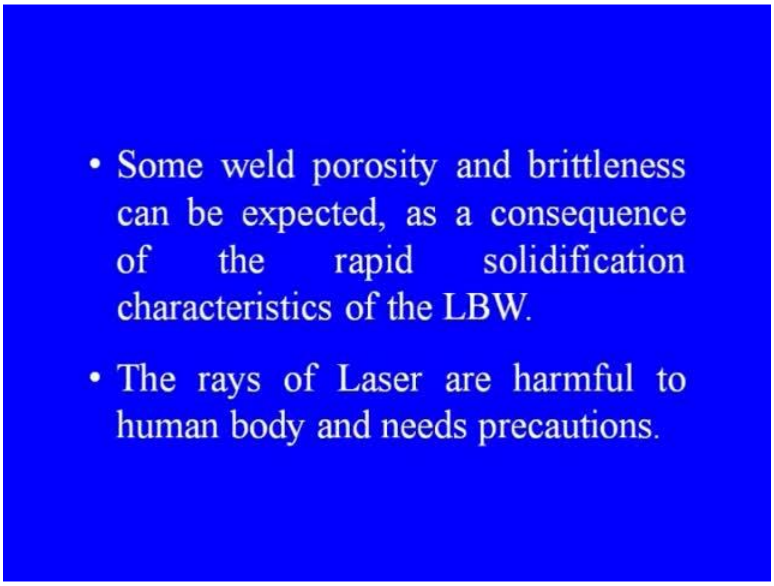
The maximum joint thickness that can be welded by laser beam is somewhat limited. The weld penetrations of larger than 19 millimeter are difficult to weld. High reflectivity and high thermal conductivity of materials like aluminum and copper can affect the weldability of lasers. This we have of course, we have seen in case of laser beam machining as well where it is difficult to machine those materials which has got very high reflectivity particularly that of like copper and aluminum and their alloys. These materials have got very high reflectivity and lesser assets, it does not work very well with these type of materials.

(Refer Slide Time: 31:22)



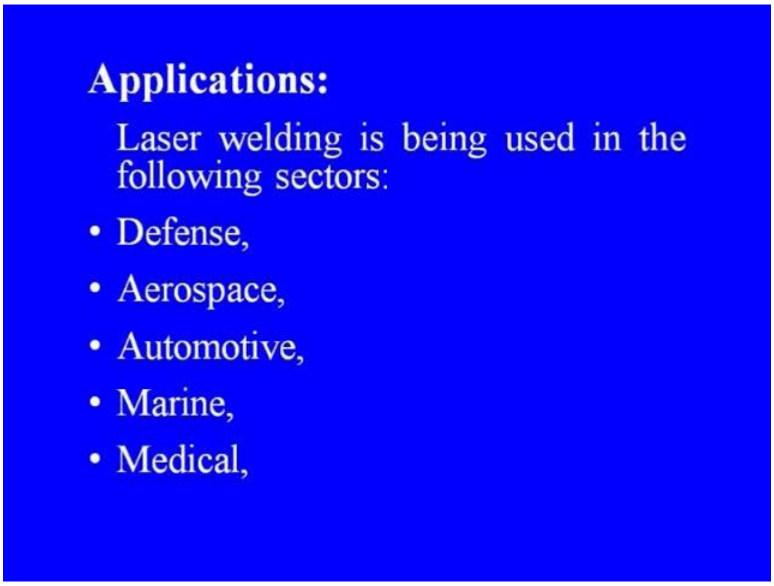
An appropriate plasma control device must be employed to ensure the weld reproducibility while performing moderate to high power laser welding. Lasers tend to have a fairly low energy conversion efficiency which is generally less than 10 percent. So, this is a point of concern as far as the economics of the system is concerned or economics of the process is concerned.

(Refer Slide Time: 31:55)



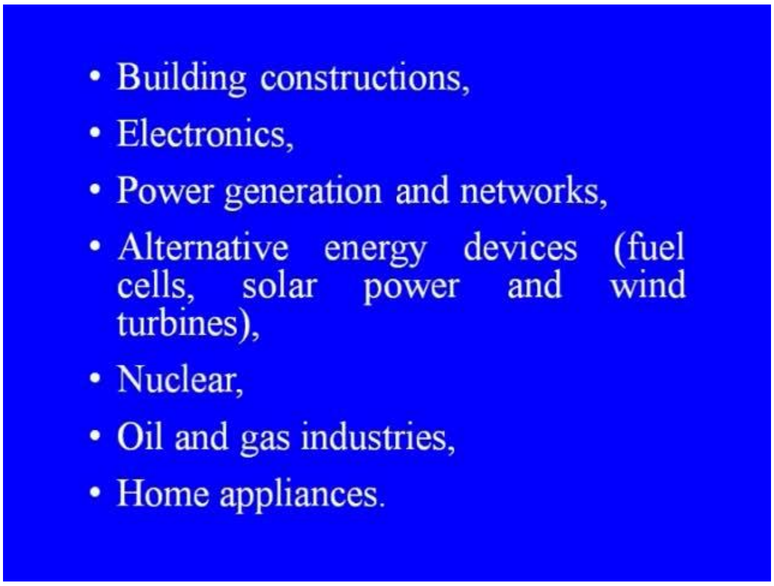
Some weld porosity and brittleness can be expected, as a consequence of the rapid solidification characteristics of the laser beam welding. The rays of laser are harmful to human body and needs precautions. Now, let us see few applications of this process.

(Refer Slide Time: 32:23)



It is being used in the following sectors like in defense applications, aerospace applications, automotive applications, marine applications medical applications…

(Refer Slide Time: 32:29)

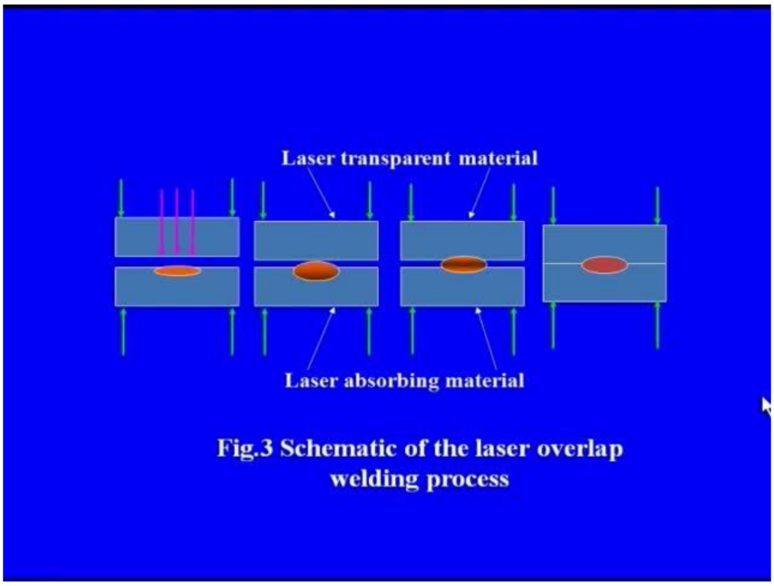


Building constructions, electronics, power generation and networks, alternative energy devices like fuel cells, solar power and wind turbines, nuclear applications, oil and gas gas industries and in many home appliances. Now, let us move to few new trends in laser welding which is transmission or overlap welding.

(Refer Slide Time: 33:08)

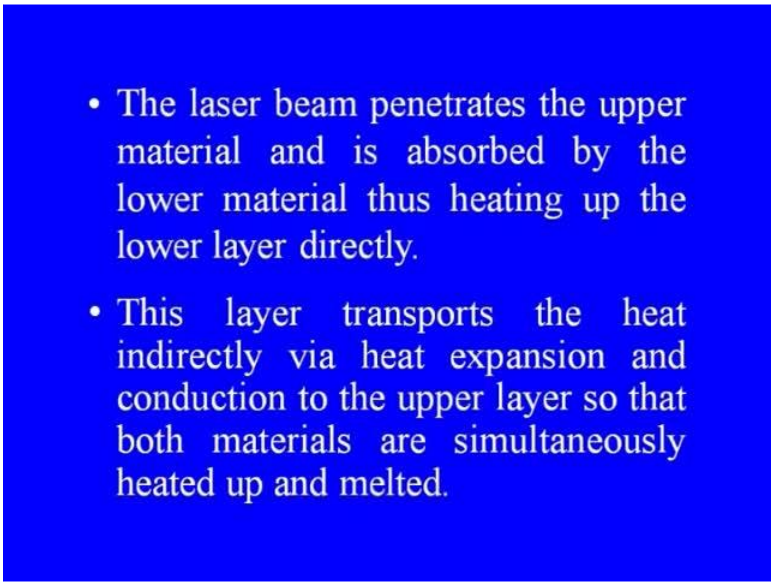
Joining of polymers by lasers is a relatively new area which is achieved using a laser transparent material and laser absorbing material. The schematic is shown in the screen here.

(Refer Slide Time: 33:27)



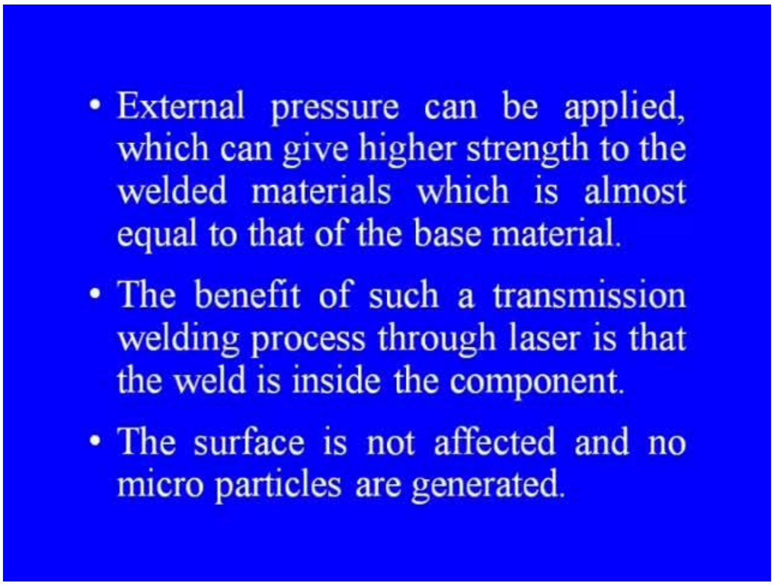
So, here as shown in the screen there are two materials that upper material this is transparent to laser so laser can penetrate this material and fall on the harder material. And this material the bottom material is laser absorbing material. Therefore, the material here gets heated up upon this incident of this laser material, and therefore this heated material then gets fused to or gets bonded to the top material, because of the application of the light pressure on them. And this molten material can get both the halves bonded. So, this is called laser overlap welding process.

(Refer Slide Time: 34:33)



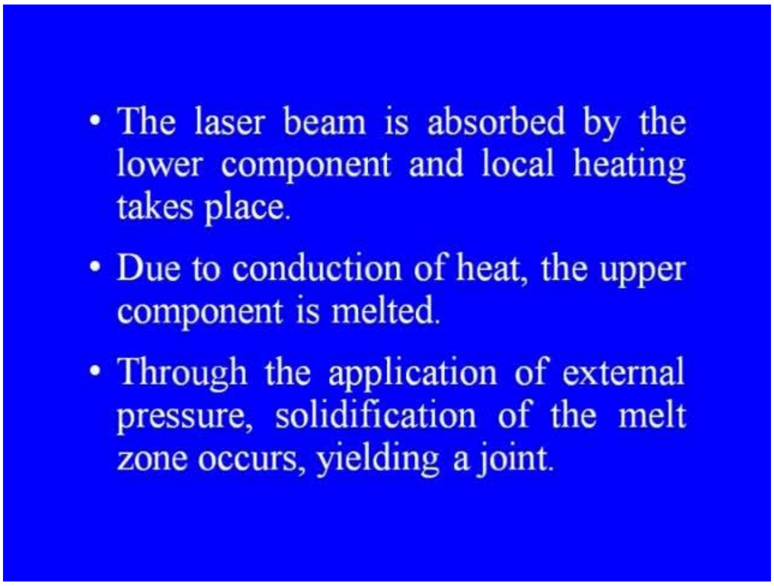
The laser beam penetrates in this case the upper material and is absorbed by the lower material, thus heating up the lower layer directly that we have seen in the screen in the figure. This layer transports the heat indirectly via heat expansion and conduction to the upper layer so that both materials are simultaneously heated up and melted.

(Refer Slide Time: 35:07)



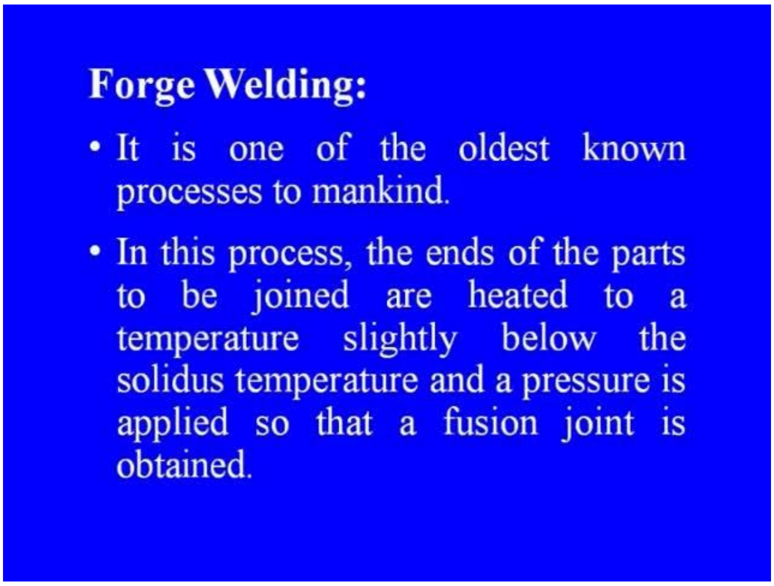
External pressure can be applied to make them get intimated which can give higher strength to the welded materials which is almost equal to that of the base material. The benefits of such a transmission welding process through laser is that the weld is inside the component, this is very important that is not exposed to the environment or outside we can see anything. The surface is not affected and no micro particles are generated in the joint.

(Refer Slide Time: 35:40)



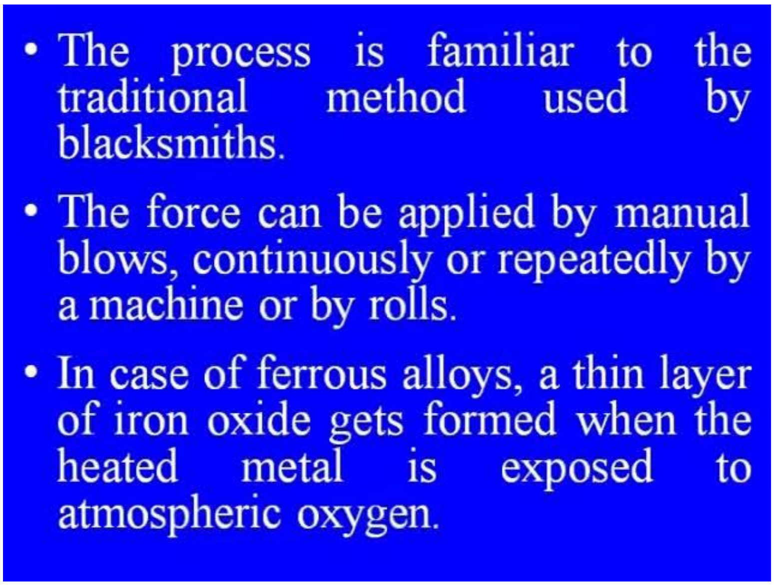
The laser beam is absorbed by the lower component and local heating does take place. Due to conduction of heat the upper component is melted. Through the application of external pressure solidification of the melt zone occurs yielding a joint. In brief, in this laser welding process we have studied the process and the features of the laser beam welding, laser applications and new trends in this category. Let us discuss some other welding processes.

(Refer Slide Time: 36:30)



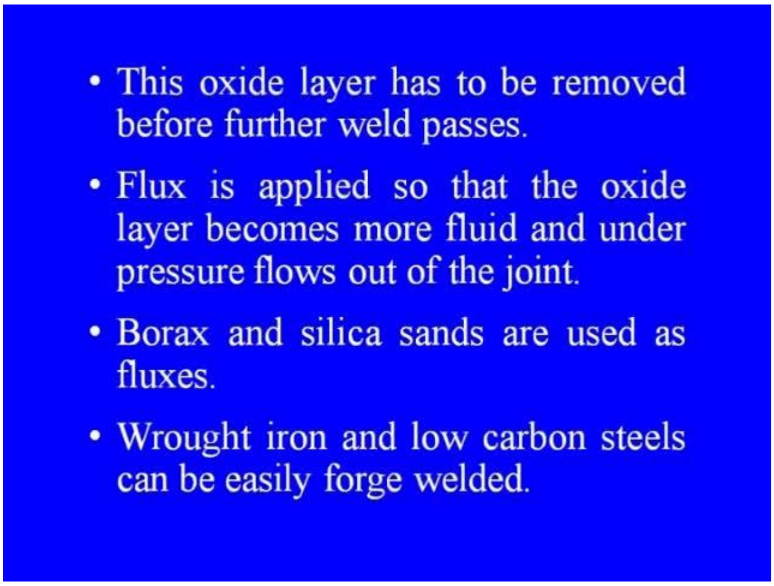
First of all the forge welding process, it is one of the oldest known processes to mankind. In this process the ends of the parts to be joined are heated to a temperature slightly below the solidus temperature and a pressure is applied so that a fusion joint is obtained.

(Refer Slide Time: 36:54)



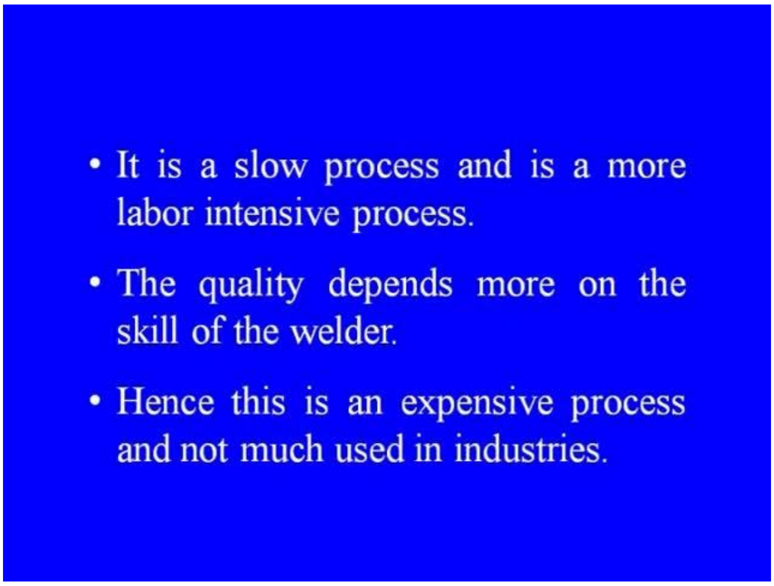
The process is similar to the traditional method used by blacksmiths. The force can be applied by manual blows, continuously or repeatedly by a machine or by rolls. In case of ferrous alloys, a thin layer of iron oxide gets formed when the heated metal is exposed to atmospheric oxygen.

(Refer Slide Time: 37:32)



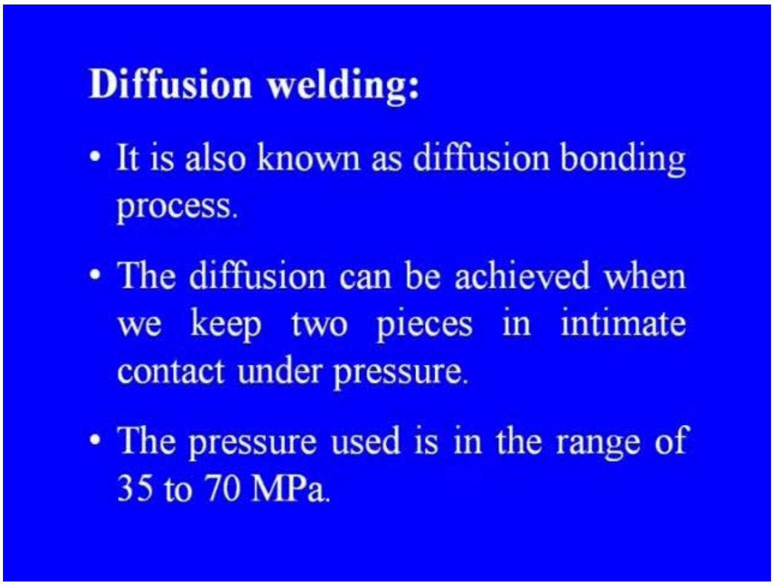
This oxide layer has to be removed before further weld passes. Flux is applied to that so that the oxide layer becomes more fluid and under pressure flows out to the joint. Borax and silica sands are used as fluxes. Wrought iron and low carbon steels can be easily forge welded.

(Refer Slide Time: 37:59)



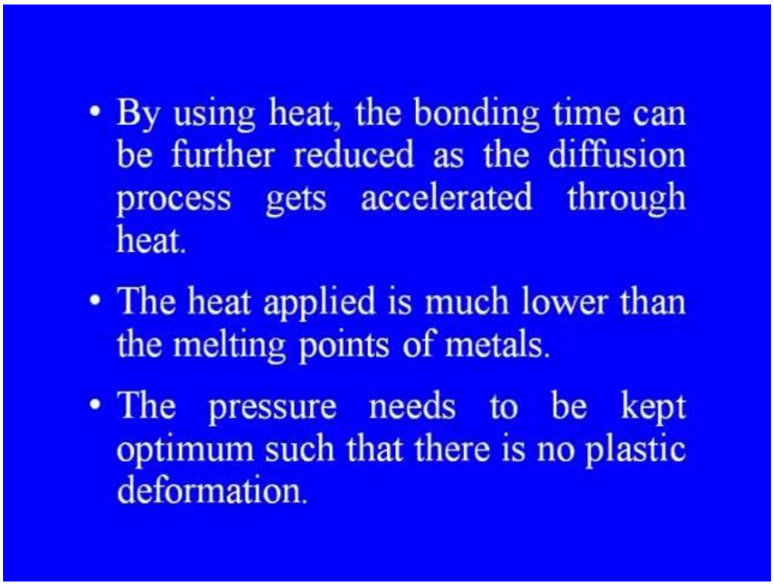
It is a slow process and is a more labor intensive process. The quality of this weld depends more on the skill of the welder rather than the process. Hence, this is an expensive process and not much in use in industries. Another process is diffusion welding process.

(Refer Slide Time: 38:30)



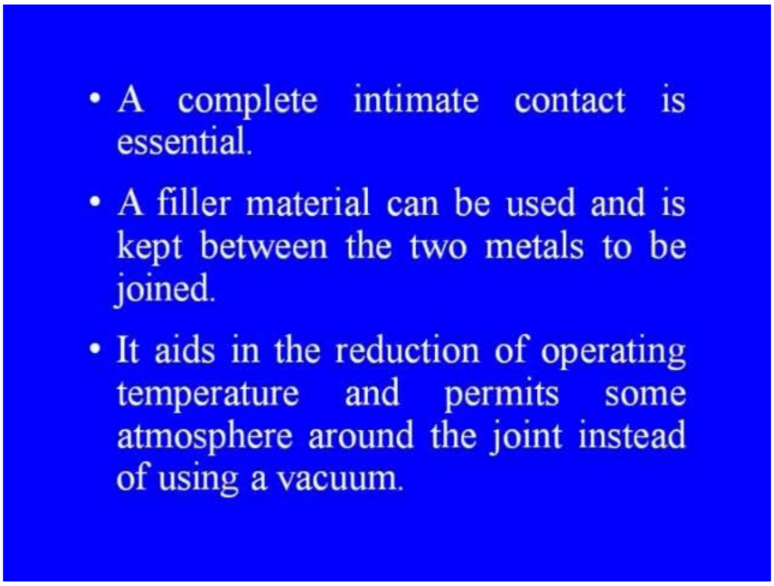
Diffusion welding process is also known as diffusion bonding process. The diffusion can be achieved when one keeps two pieces in intimate contact under pressure. The pressure used in the range of 35 to 70 mega pascal.

(Refer Slide Time: 38:58)



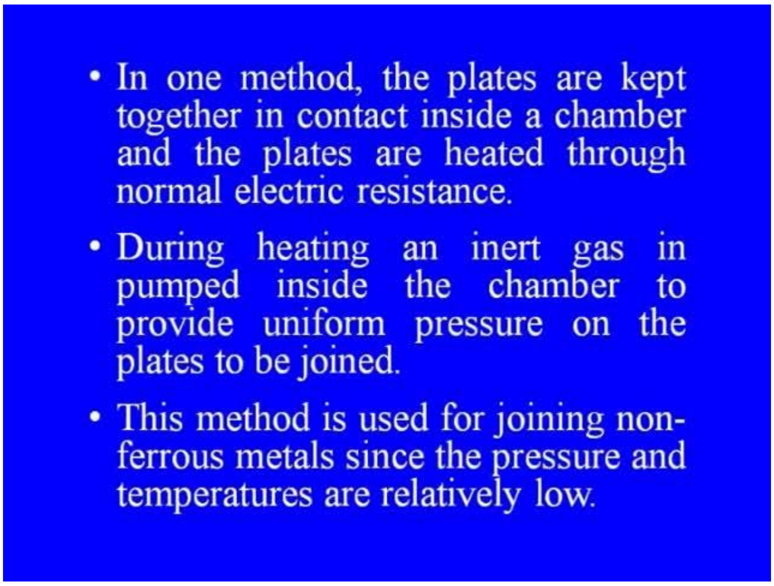
By using heat, the bonding time can be further reduced as the diffusion process gets accelerated through heat. The heat applied is much lower than the melting points of metals. The pressure needs to be kept optimum such that there is no plastic deformation.

(Refer Slide Time: 39:31)



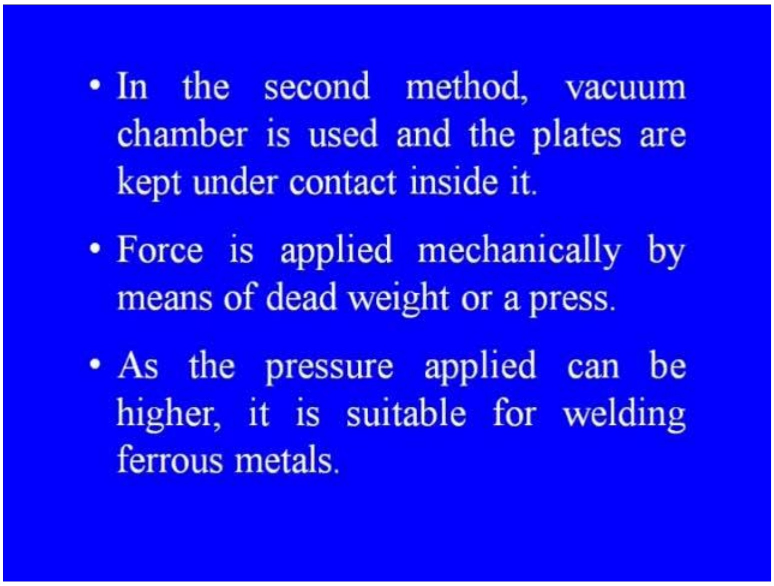
A complete intimate contact is essential in this process. A filler material can be used and is kept between the two metals to be joined. It aids in the reduction of operating temperature and permits some atmosphere around the joint instead of using a vacuum.

(Refer Slide Time: 40:01)



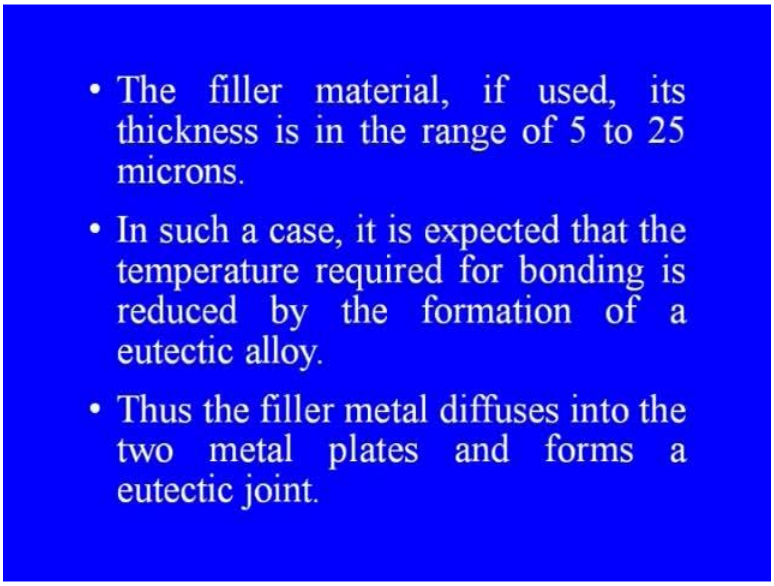
In one method the plates are kept together in contact inside the chamber and the plates are heated through normal electric resistance. During heating an inert gas is pumped inside the chamber to provide uniform pressure on the plates to be joined. This method is used for joining non ferrous metals since the pressure and temperature are relatively low.

(Refer Slide Time: 40:37)



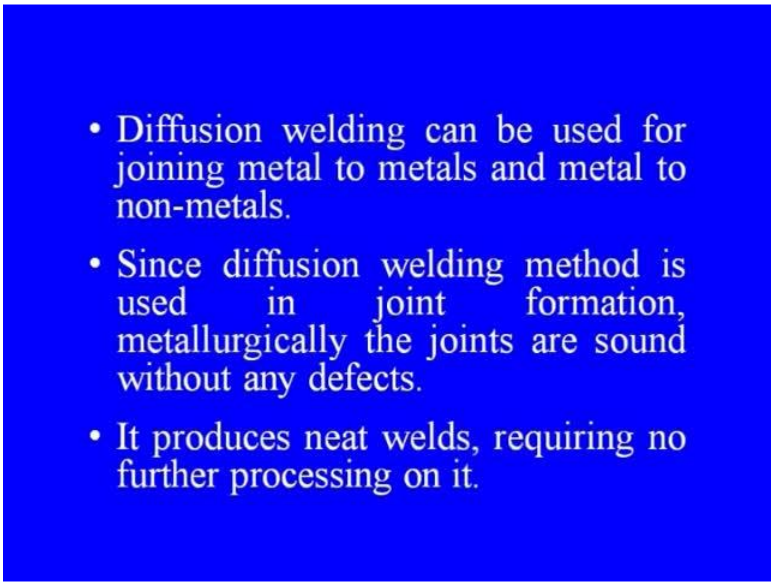
In the second method vacuum chamber is used and plates are kept under contact inside it. Force is applied mechanically by means of dead weight or a press. As the pressure applied can be higher, it is suitable for welding ferrous metals.

(Refer Slide Time: 41:01)



The filler material if used its thickness is in the range of 5 to 25 microns only. In such a case it is expected that the temperature required for bonding is reduced by the formation of a eutectic alloy. Thus, the filler metal diffuses into the two metal plates and forms a eutectic joint.

(Refer Slide Time: 41:35)



Diffusion welding can be used for joining metals to metals and metal to non metals as well. Since, diffusion welding method is used in joint formation, metallurgically the joints are sound without any defects. It produces neat welds, requiring no further processing on it unlike many other processes. Now, let us summarize what we have studied in this session. We have a discussed about the laser beam welding process first, then briefly we have refreshed how the laser is being produced and different requirements, applications and limitations of the laser beam welding process. We have also discussed the forge welding process and diffusion welding process. The potential applications of these processes have also been discussed. We hope this session was informative and interesting.

Thank you.