Laser Based Manufacturing

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Module # 03

Lecture # 07

Mechanisms of Laser Welding Part I

Hello everyone. I welcome you all in the third week of NPTEL online course on Laser Based Manufacturing. This is our first lecture of Week 3. Till now in our previous weeks, we have seen the fundamentals of lasers in the first week of this course and in the second week we started using the lasers for cutting operation for material removal operation. We have also seen how exactly the lasers are used in the industry by watching a video which is demonstrating the actual laser cutting of mild steel.

Let us begin our lecture. This week we will be studying the various laser welding processes, their mechanisms, process characteristics and their applications basically in the industry.

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This is a week 3, that is a laser based welding as I mentioned and today we are looking at the mechanisms of laser welding operation.

Well, my friends welding is an important manufacturing process. It is a fabrication process which is generally used to join the materials together for various parts, for various sub-assemblies in the product development.

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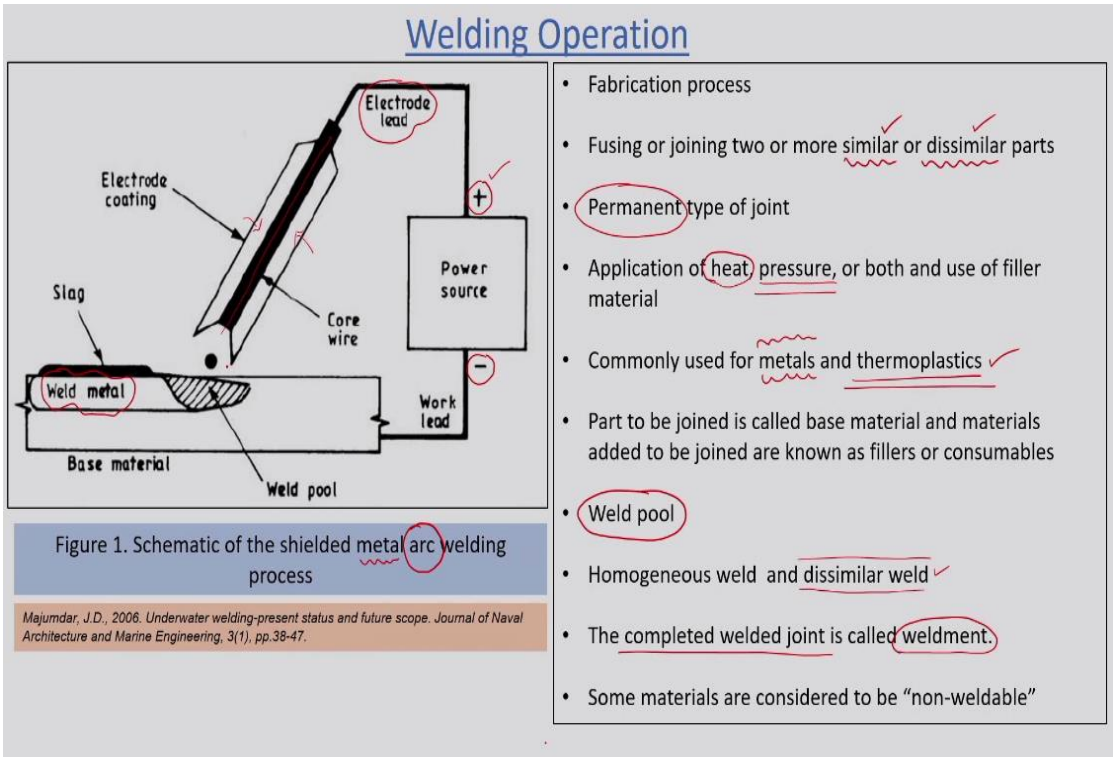

When we fuse or join two materials together, it may be similar materials or the dissimilar materials by using a permanent joint. In welding operation we are joining either similar materials or dissimilar materials and the type of joint is permanent joint. In fabrication process, we can join two different materials as temporary as well, by using the fastening methods such as screws and nuts or rivets.

However, when we fuse two materials together permanently that is the welding process. How we weld or how we join these two materials together? we have to use the heat, thermal energy and we use the pressure or we use both simultaneously to join the two materials together and then we get the bonding strong joint of two materials which is further being used.

Welding we can find everywhere around us in our domestic life as well, in the industrial life, in academic life, our furniture, grills, construction purpose, everywhere we are using the welding. In a similar way in manufacturing operations as well we use welding very often.

We can join metals and thermoplastics as far as the industry is concerned. Metals are widely used and there is need to join these metals. In the industry we are also using thermoplastics as well. There is also need to join the thermoplastics, so we need to go for the welding operation. When we join these two materials together in some of the cases, we are using an additional material for fusing these two materials, we are using filler material. These filler materials are may be of the same type or maybe the different type for joining these two materials.

We generate weld pool, weld pool is generated during the welding operation.

A schematic is there in front of you this is a very common process that we can see around it is arc welding process: it is a metal arc welding process, it is used to join the metals together. To join these metals together we need to generate an electric arc. To generate an electric arc we

need a power source. Here we are using a power source. The work is attached to the cathode, that is the negative terminal of the power source and the electrode - this is the electrode which we are using for welding operation and this is connected to the positive terminals that is anode of the power source. The electrode is also having a coating. This is the core wire it maybe of same material and it is having a coating. This is the coating material - this coating material is working as a shielding material.

During the process of welding there are chances of oxidation of welded spots or welded surfaces and this oxidation is not desired in the welding operation. To protect the welded surface we are using some sort of flux, some sort of protecting material and that coating of that protecting material is given to the electrode.

When the joining, is getting occurred the coated material will also get melted and that coated material will be deposited on the weld material and it will save, it will protect the welded material from the environment.

This is the weld metal which is generated during the welding operation. We are applying power across, we are applying electrical field across these electrodes: that is electrode lead and the work piece is also an electrode.

During the application of electrical field, there is generation of electric arc and that electric arcs are generating intense heat which is melting the electrode rode as well as it is melting the materials. When the materials are getting melted there is a deposition of the electrode material in between the gap of these two materials which we want to join. All the three parts here are melted: the parts which are to be joined as well as the electrode rod we are using as the filler material.

When these two parts are melted, the filler material will get deposited and it will generate a homogenous joint if all the three materials are of same type. If suppose we are using a mild steel electrode rod to join two materials of mild steel only, we are generating the homogenous weld - all the three materials are same, the materials which are getting joined together and the material of the electrode as well.

When we use dissimilar materials for welding this is also possible. Here we are using either the electrode rod of different material or the materials which are getting joined maybe of different nature then also it is possible to have the welding operation.

The completed welded joint is called as the weldment. Here this completed welded joint when we joint two parts together the joint which is completed is called as the weldment.

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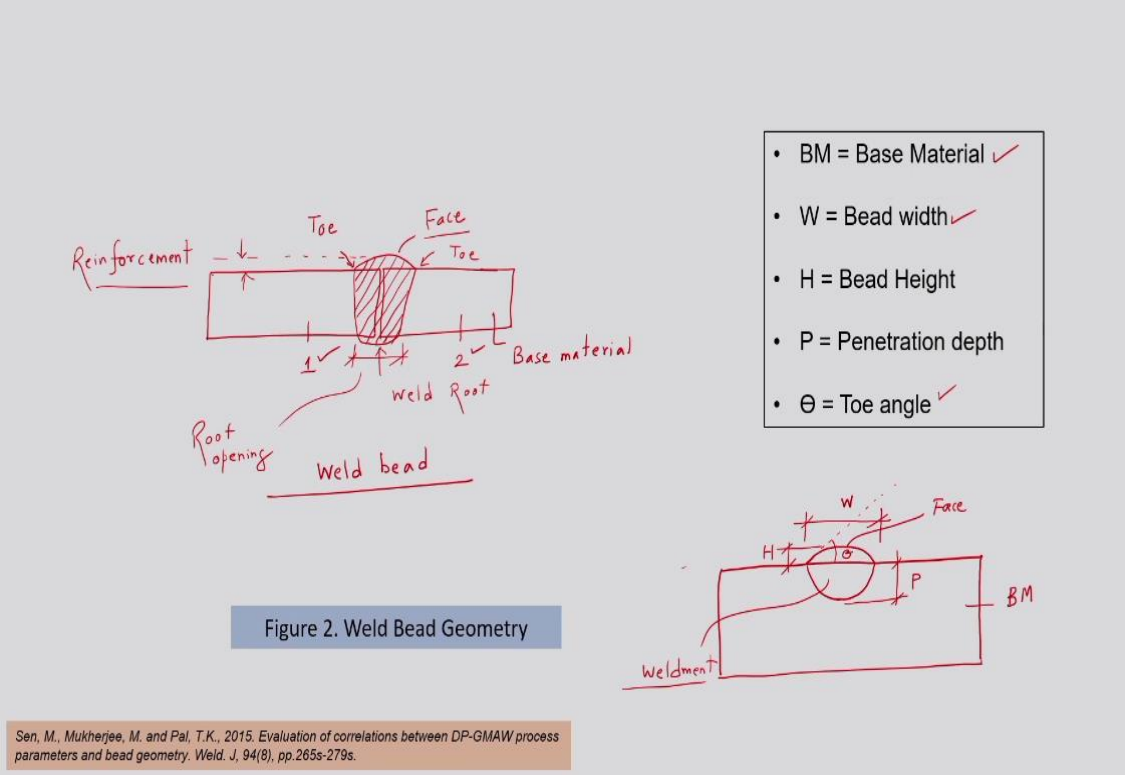

Figure 2. Weld Bead Geometry

Sen, M., Mukherjee, M. and Pal, T.K., 2015. Evaluation of correlations between DP-GMAW process parameters and bead geometry. Weld. J, 94(8), pp.265s-279s.

Now, when these welding is getting occurred, there is a generation of weld bead. Now, let us look at the geometry of the weld bead.

Consider we want to join two metallic parts together. This is part one and there is another part two here: two parts are there and we want to join them together by using any source of heat maybe an electric arc or lasers. During the formation of the joint, we are getting some sort of geometry something like this. This much of portion is getting melted and there is the re-solidification of melted material together and then we are having together unified joint of part number one with part number two and if we are using a filler material by using the electrode. When we try to figure out the various terminologies of the weld bead. This is weld bead. This is called as the face of the weld bead. There are two base materials, base material number one and base material number two and when these two materials are joined together we get a shape something like this. It has a swollen portion at its top that is called as the face. The point at which the face is getting connected with top surface of metal one or metal two, that is called as toe. This point is called as toe of the weld. There are two toes; one toe for part number one and there is another toe for part number two.

The bottom portion of the weld is called as weld root and the weld root has certain width and it is called as root opening.

The swollen portion or the portion which is above the plate one and plate two is called as reinforcement of the weld. This is the reinforcement of the weld. This is giving the strength to the weld - reinforcement. If you look at the geometry in much more details about the weld bead. We can draw another diagram over here. We are having a top surface, this is the top surface of the work part and let us consider that we just applied an electric arc over the top surface to generate the weld bead and we get the geometry something like this.

The width of the bead is called as the bead width - here it is mentioned. Some of the portion of the bead will get penetrated inside the base material: this is base material BM and this is called as the penetration of the weld bead inside the base material. This is penetration depth. The bead also is having the height. This height is called as bead height and the angle made by the tangent to the face - this is the face. Angle made by the tangent - this is the tangent to the face and it is making certain angle with the top surface of the base material it is called as theta (toe angle). It is designated by using theta and it is called as the toe angle.

This entire geometry or entire weld bead, it is also called as weldment and the ultimate objective during the welding operation is to get the ideal geometry of the weldment during the processing. It maybe any sort of welding process.

Now after looking at the various bead geometry parameters now let us see what are the various types of joints being used in the welding operation.

Welding is being used for joining two parts may be thin parts, thick parts, maybe plates, pipes, rods, all sort of materials in any form can be utilize to join together. However, there are various types of joints used in the industry and five basic types of joints that we are going to see today.

The first important joint is the butt joint. These joints are decided based upon the manner in which these materials are fitting to each other.

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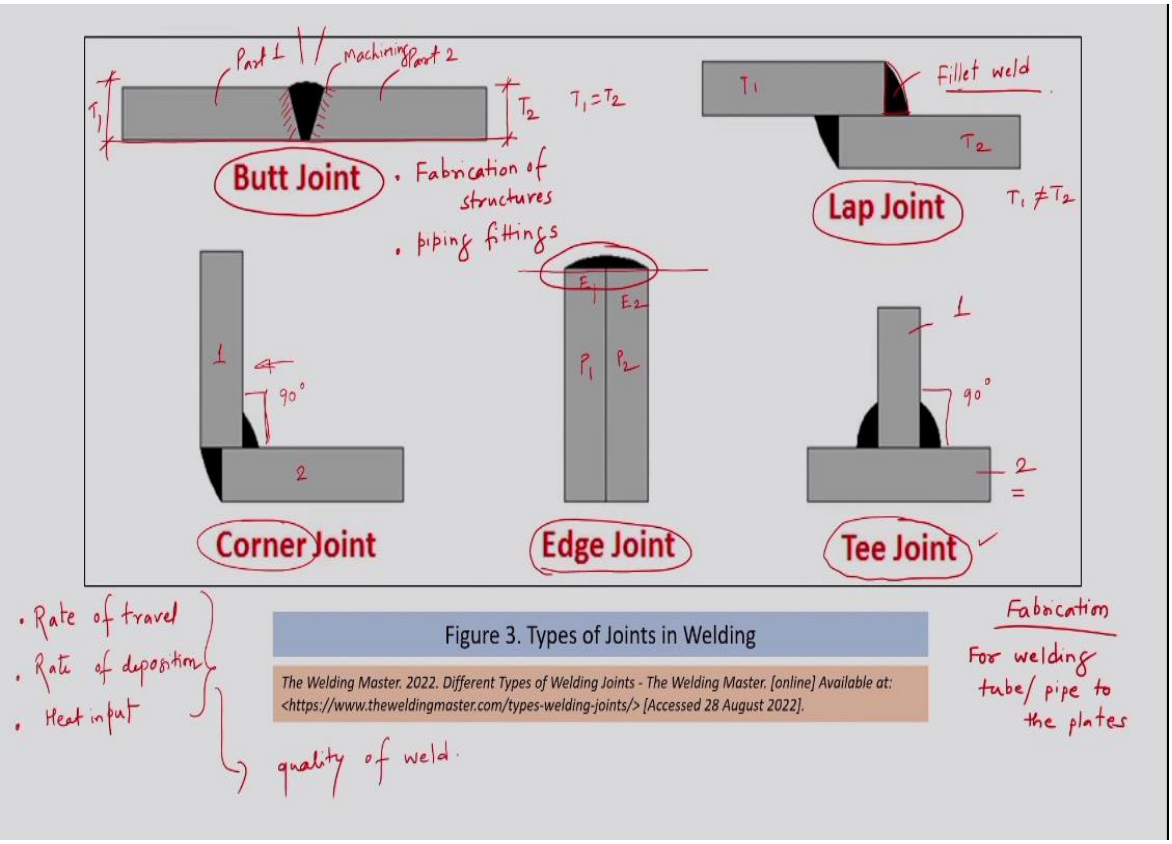

Figure 3. Types of Joints in Welding

The Welding Master. 2022. Different Types of Welding Joints - The Welding Master. [online] Available at: <https://www.theweldingmaster.com/types-welding-joints/> [Accessed 28 August 2022].

The first type of joint is the butt joint which is there on your screen. Here you can see we are using two different parts. This is part number one and part number two. Part one and part two are lying in the same plane. These two parts are lying in the same plane, their ends are adjacent to each other. We are processing these edges of these ends, we are processing the ends by carrying out some sort of operation that is the machining operation. We are giving a specific shape that is a V shape to create some sort of a gap here in between these two joints and then we are applying the arc energy or the thermal energy which is generated by electric arc or by using the laser here and by using the filler material we are developing a joint. This is called as the butt joint. Here two materials are adjacent to each other they are in the same plane.

These types of butt joints are basically used in fabrication of structures and piping systems. These are used commonly for a fabrication of structures and they are also used to join the piping systems.

There is another joint here, now, instead of having these two parts in a same plane can these parts maybe orthogonal to each other or at a 90 degree with each other.

Consider part 1 is at 90 degrees inclined to Part 2 and the Part 1 is exactly at the middle of Part 2. When such configuration is there then we are calling these as the tee joint.

If we take Part 1 at the edge or at the end of the Part 2. Here if we take or if we just offset the Part 1 and if we take at the end of Part 2 then we can get the corner joint. Again the angle between Part 1 and part 2 is 90 degree only. This angle is 90 degree. However, the relation or the position of Part 1 with Part 2 is different in tee joint and corner joint.

Of course, the applications are different. Tee joint is again used for the fabrication purpose to join two parts and the corner joint is also used to make some sort of boxes, some sort of closed structures we are using the corner joints. The tee joints are also used for welding tube or pipe to the plates.

In butt joint, we required to have both the sheets of same thickness. This T2 and T1 are same. In this case T1 = T2.

Now, consider we are having two different parts of two different thickness. Consider T1 here and T2 and T1 is not equal to T2. When we want to join two different sheets of different thicknesses, butt joint is not sufficient. In that case we have to have some sort of overlap between the sheet number one or part number one with part number two and then we can carry out the welding operation. That kind of operation is called as a lap joint and filling that we get is of this shape which can be there on your screen and this is called as fillet weld. This is fillet weld.

Now, in certain situation we are joining the ends of two different parts together. In the configuration which is there on your screen. This is called as edge joints. Here Part number 1 and Part number 2, their edges are aligned in same plane. This edge number one of Part number one and edge number two of Part number two are aligned in a same plane and then we are applying the heat energy to melt the material and to get re-solidified and to have a strong joint

between these two parts. This is called as the edge joint. Here, whatever the stresses are coming on the weld will get shared.

There are various parameters which are affecting the quality of the weld. And these parameters are the rate of travel of the electric arc or the source of heat with respect to the work piece. It is also dependent upon the deposition rate by what rate the material is getting deposited between the two joining materials. Heat input, these are all parameters which are affecting the quality of the weld and the geometry whatever we have seen is a function of all these parameters.

I will just write over here: the rate of travel, rate of deposition and heat input are controlling the quality of the weld.

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Now, we have seen various types of joints in welding operation. Now see what are the various types of processes being used in the industry and then we will study about the laser welding process.

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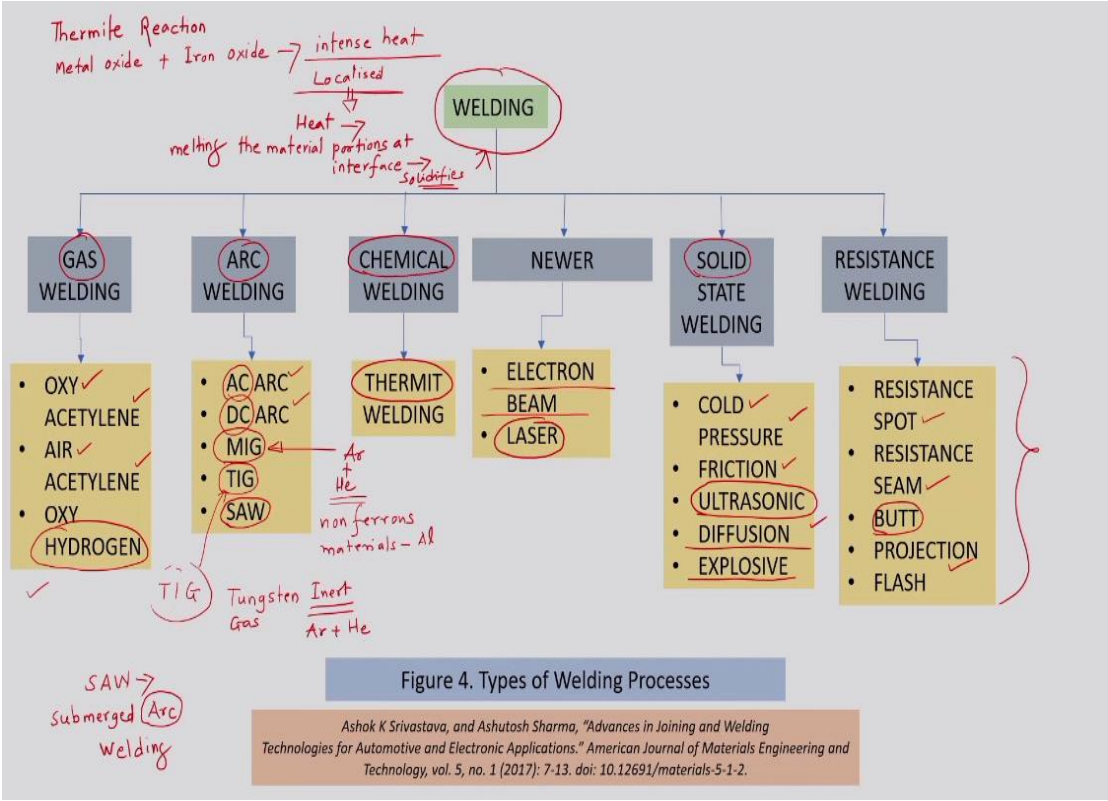

Figure 4. Types of Welding Processes

Ashok K Srivastava, and Ashutosh Sharma, "Advances in Joining and Welding Technologies for Automotive and Electronic Applications." American Journal of Materials Engineering and Technology, vol. 5, no. 1 (2017): 7-13. doi: 10.12691/materials-5-1-2.

We will have a quick look at these processes. Welding in broad sense can be classified into variety of classes. There are many versions of classification. Here we will just look at it in a broad sense of manufacturing.

When we use gas for joining these two materials that we called the gas welding. In this case various types of gases such as oxygen, acetylene are used to generate the thermal energy, heat and that heat or thermal energy is used to melt the materials. When we use oxygen and acetylene that is called as oxy acetylene gas, we are generating a flame of oxy acetylene gas mixture and then that flame will be utilized to melt the materials which are need to join together. Instead of oxygen if we are using simple air along with the acetylene gas that is called as air acetylene gas welding or instead of acetylene if we are using hydrogen along with oxygen that is called as oxy hydrogen gas welding.

The principle of operation is very simple. You have a mixture of various gases, burn them, you will get a high energy flame and that high energy flame will be applied at the point of application wherever we want to join the materials together they will get melted and then will get re-solidified and we are getting the required welding done.

If we are using electric arc: we are using an arc during the operation and that is called as the arc welding. Either we can generate the arc by using alternating current or direct current or we are using some sort of inert gases during the operation that we call the metal inert gas (MIG) welding. In AC or the DC arc welding we are using the electrode with flux materials, either it is coated or an additional flux material for the protection of the weldment that we have already seen in our previous slide.

In metal inert gas (MIG) welding we are using an inert gas to protect the weldments. What kind of gases we are using during this metal inert gas welding: the gases are argon and helium. Here a mixture of argon and helium is used as an inert gas mixture to protect the weldment and MIG is widely being used to weld nonferrous material such as aluminum.

Now, when we are using tungsten, Here this is TIG, the TIG is quite popular in the industry. It is tungsten inert gas welding and here the tungsten is non-consumable: it is not getting melted during the operation. In the arc welding the electrode is getting deposited, it is getting consumed however in TIG type of welding the tungsten is generating the arc only, it is generating the heat energy and we have to add an extra material in this case.

However, the advantage of the TIG is that: we can control the heat energy, we can apply the heat energy, we can get intense arcs wherever it is required by using tungsten filament. In this case as well we need to apply the inert gas and the same argon plus helium can be utilized to carry out the arc welding using tungsten filament.

Then the next one as far as the arc welding is concerned is submerged arc welding. SAW is acronym of submerged arc welding. Here the electrode is submerged inside a flux material. We get the substrate material then we apply a layer of flux and then we submerged the electrode inside that and then the heat energy will be generated by using the spark. During the process

of applying the heat energy the flux material will also deposited at the spot of the application of heat, at the spot of welding itself.

When we use chemical energy, the heat energy which is generated due to the chemical reaction, that is called as the chemical welding and very popular and useful chemical welding process is thermit welding which is popularly used or very useful in joining the rails which are using for a locomotive, to join the rails of locomotives or train we are using this thermit welding process.

Now, how does it work? Here we are generating a thermite reaction, this thermite reaction is occurring when we are using two different materials and these two different materials are metal oxide and iron oxide. When we have the reaction between metal oxides and iron oxides, an intense heat get generated. This is leading to intense heat; however this intense heat is localized. We are applying it at the required location. Since, it is a localized intense heat, it is melting the substrate and then we can have the required joining done. This is generating heat and that is melting the interface. It is melting the materials portion which are at the interface and when these molten material is getting cooled down, then there is solidification - solidifies and that leads to the welding. This is about the chemical reaction that we use during the welding operation.

There are certain processes in which we are not using the material in its liquid form to get fuse together. Here we are using the material in its solid form. These types of processes are cold pressure, friction, we are using ultrasonic energy, diffusion process and explosive welding process.

In explosive welding process we are generating compression forces by detonating the explosives and then that compression forces are applying on the sheets and these two sheets are getting joined together under the action of compression forces and they are getting joined together at atomic level. That is the solid-state welding.

We can apply pressure that is a cold pressure. When we apply the friction which is quite popular among industry nowadays, that is friction stir welding process. It is a solid-state welding process where the friction energy is getting used to join the parts together at a solid state only.

When we use the resistance, the electrical resistance of the parts, to generate the heat energy for joining the parts together, joining different systems together that is called as the resistance welding. This is the resistance welding can be of spot type or seam type or we can have a butt type of resistance welding or we can even have the projection welding as well.

The details about all these processes it is not in the scope of this lecture.

We will have to look at the newer technologies being used in the welding operation. And the newer technologies or newer processes are: laser welding process and the electron beam welding process.

During the application of all these different types of energies for joining the material together they are having inherent limitations: such as it is difficult to join two materials which are of dissimilar nature they are not similar. Second, there is a problem of high heat affected zone that

we call HAZ, so that high heat affected zone may lead to more cracks and some of the welding processes are having many welding defects as well.

To minimize the welding defects, to minimize the HAZ and to join various materials of different nature newer processes are being used. And one of the process is the laser process where we are using laser power or laser beam to generate the thermal energy which will be used to join two parts together.

There is another process that is electron beam. High speed electrons are impinged on the workpart and the kinetic energy of these high speed electrons will be converted into thermal energy and then we are using it for the actual joining operation.

However, the scope of electron beam is low because the energy required, specific energy consumption as far as EBM is much, much higher, it is very high. However, in laser beam operation which is very common and nowadays we can have lot of lasers available with us and as far as the conveyance is concerned and we have seen many advantages of lasers in our previous class. All these advantages are getting carrying forward for this important application of lasers in welding as well.

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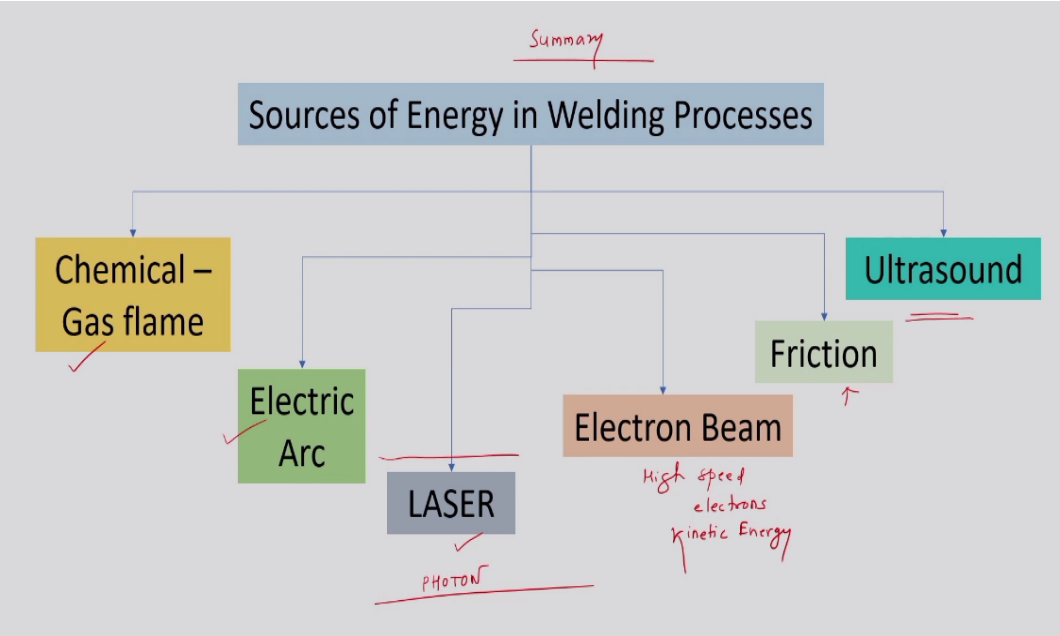

This is again a summary of the various energy sources. As I mentioned chemical gas flame-based energy, electric arc which is again further converted into thermal energy, laser here we are using the photon energy we have already seen that, electron beam - high speed electrons and kinetic energy of the electrons and friction again the thermal energy which is generated due to the friction, ultrasound or ultrasonic vibrations are also used.

Now, let us see how the lasers are useful to join the parts together.

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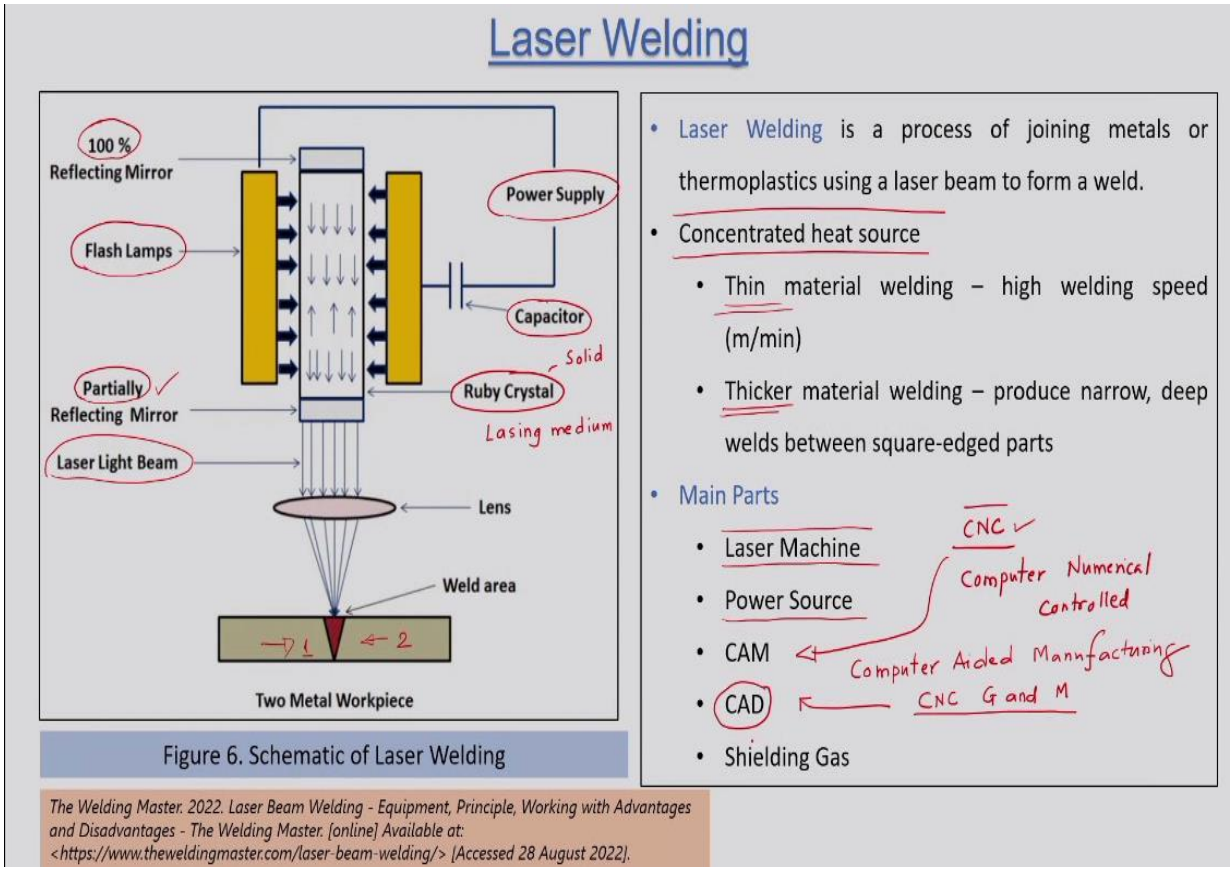

Figure 6. Schematic of Laser Welding

The Welding Master. 2022. Laser Beam Welding - Equipment, Principle, Working with Advantages and Disadvantages - The Welding Master. [online] Available at: <https://www.theweldingmaster.com/laser-beam-welding/> [Accessed 28 August 2022].

Laser welding process is a very simple process. Here we are joining two different parts together by using the heat which is generated by lasers. We apply the lasers at the location of the interface of two parts and by using the photon energy which is converted into thermal energy at the laser material interaction site where we are melting the work parts, some portion may also get vaporized and after melting and vaporization there would be re-solidification of the melted parts then we are getting the required welding done.

As we know that the lasers are providing us concentrated heat source, that is the peculiarity of the lasers we are using over here, we are getting the controlled energy through collimated, coherent and monochromatic beam of light and then by using these concentrated heat source we are joining thin metals, even we can join the thick materials as well by using the keyhole-based laser welding, we will see in our coming slides. Thicker materials also can be joined.

To get the thin material welding we have to control the welding speed, we have to control the interaction time of the laser with the workpiece. If the speed is low then there is a chance of having cutting of the thin sheets and will not get the welding done, there may be vaporization and the thin sheets may get cut, they may get separated, they may get parted off. We have to increase the speed of the laser material interaction that there should be enough heat that is transmitted for only the melting operation not the vaporization operation.

In thicker material it is other way round we can have low speed of operation so that more energy is put in to get deeper welds. We have to reach in a deep during the thick metal laser welding process.

A typical laser machine or typical arrangement of laser which is used in welding operation can be seen on your screen. This is Ruby crystal laser. Ruby crystal is a solid-state laser medium. This lasing medium is solid state. We need the excitation source. Here we are applying excitation energy through flash lamps. These flash lamps are getting energized by using a power supply and capacitor.

When we apply the photon energy, when we apply the light energy on the Ruby crystal then the laser beams are getting generated and these laser beams are getting reflected by using a pair of mirrors. If both the mirrors are of 100% reflectivity, then we will not get any output. Deliberately we are making one of the mirrors partially reflecting. When we used such kind of mirror we can get the laser light beam. We are getting the laser light beam and these laser light beam, then, we are focusing on the workpart.

These are the two workparts which are placed very near to each other with certain geometry at their ends. When we apply the laser beam energy over this interface of these two workparts, Part 1 and Part 2, this portion will get melted and then re-solidified. In this way by having a concentrated heat source which is generated due to the laser beam we can join these two parts together.

And for this purpose we required a laser machine, we required a power source. This is a power source or power supply is essential. The laser machines, all these parts are required. The Ruby crystal or any lasing medium. CO_2 is also being used during the lasing welding operation. Gases material or the solid material can be utilized. Nd:YAG is also used for welding operation.

When we talk about a typical laser machine, nowadays, these are CNC controlled - computer numerical controlled and to operate the CNC machine we should have computer aided manufacturing software. Computer aided manufacturing software is generating the CNC code: G and M code. But these CNC, G and M mode is generated based upon the CAD drawing of the feature that we want to machine.

CAD system is essential, CAM system is also essential and by using CAD and CAM systems with CNC machine tool we can have very accurate, precise CNC based laser welding operation.

We also required shielding gases or inert gases to protect the weldment. With this we stop for today’s class. Thank you.