Manufacturing Process-I
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Module - 03
Lecture - 02
Welding Process Classification

Welcome students. This is second lecture based on the Welding Process Classification. We will start this lecture. The classification of the welding process can be done on the basis of the many criteria.

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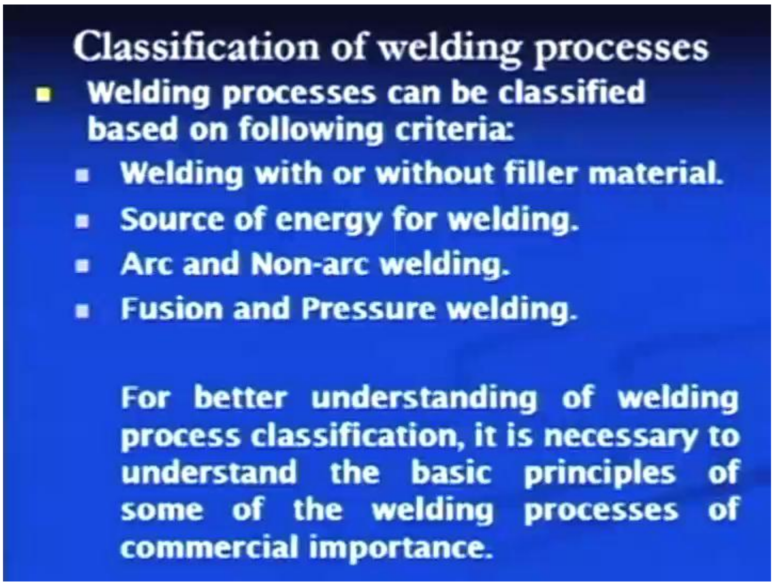

The welding processes can be classified on the basis of the four main parameters: the welding with or without filler metal; the source of energy be used for the welding; welding may be arc or non-arc types; fusion and pressure welding type. To classify the welding processes based on these four factors, it is necessary to understand the welding processes and their basic principles, so that we can have a better understanding of the Welding Process Classification.

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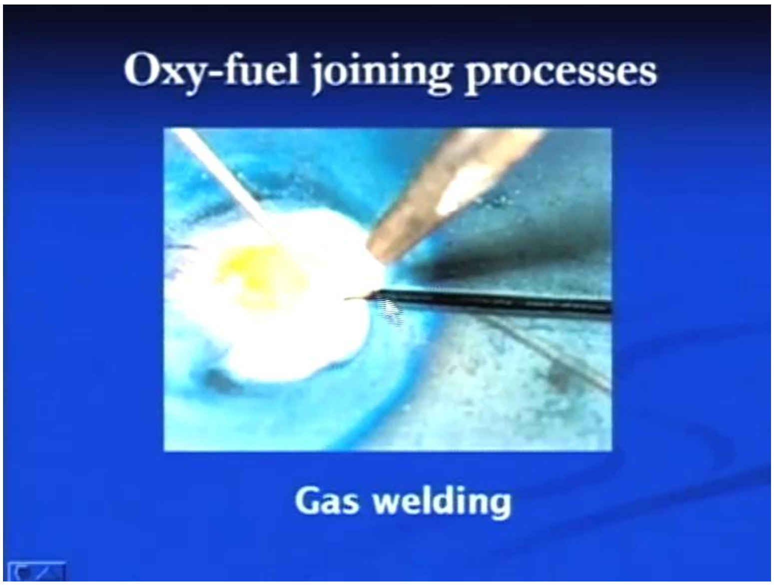

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And for a better understanding of the common welding processes we will start with oxy-fuel joining processes. The oxy-fuel joining process is largely known as oxy acetylene welding processes, in which a measure of oxygen and acetylene is used to produce a mixture, which is ignited, and the combustion of gaseous mixture produces heat, this heat is applied to melt the faying surfaces, and the filler metal in this processes may be used or may not be used. This process is normally used for thin welding processes; thin welding sheets, not for the thick welding sheets. The flux is normally used in these processes to protect the molten metal from the atmospheric contamination and remove the impurities. In this welding process, the fusion of the base metals takes place and sometimes filler material is also used in joining of the thick sheets.

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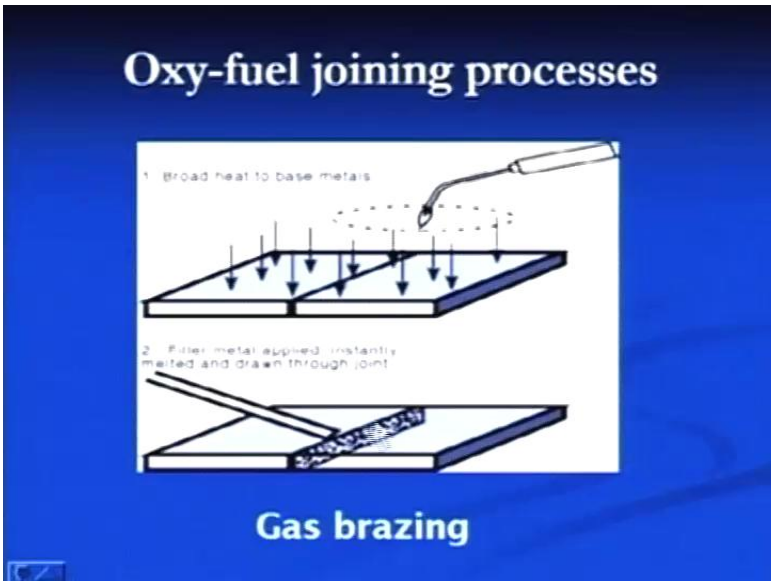

The next process, which is oxy-fuel joining processes, is the gas brazing process, in which oxy acetylene flame is used for heating of the faying surfaces to be joined, and then, brazing material or the filler material is placed near the heated zone. And because of the heat, the filler material melts, and by capillary action it is sucked into the areas where the joint is to be produced. The similar principle is used in soldering process also, in which comparatively low melting point filler metal is used for producing the joint.

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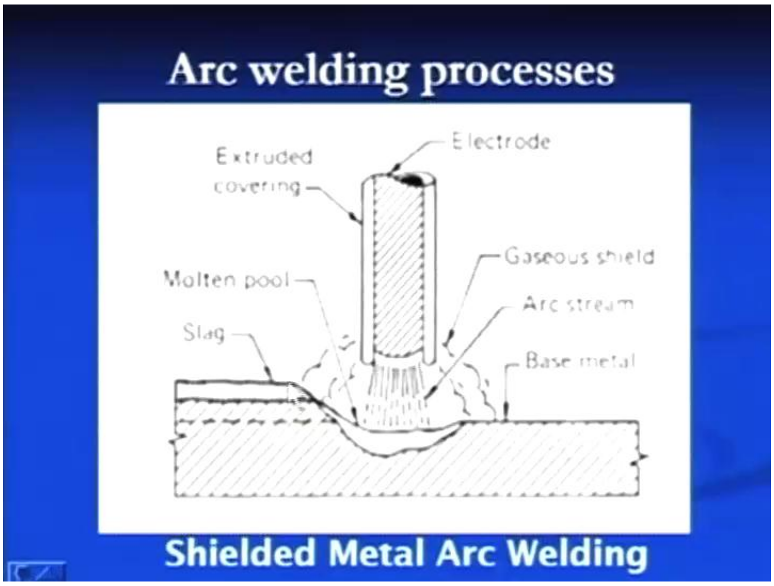

The arc welding based processes are many. And some of the arc welding processes of the commercial importance are like this: the first one is shielded metal arc welding processes, in which the joint is produced by developing the heat, and the heat is developed by an arc; arc is established between the consumable electrode and the base metal; and the molten metal is then allowed to solidify. So, coalescence or the joint in this welding process is produced by melting of the base metal and the consumable electrode. And after that the molten metal is allowed to solidify freely. In this welding process, the electrode is normally coated, and this coated electrode - the coating provided in the electrode - performs numbers of functions like: it increases the electrode stability, and develops the shielding gases, which protect the molten metal from the atmospheric contamination. And after reacting with the impurities - after reaction with impurities - these coating fluxes form a slag, which becomes lighter one, so that it floats on the surface of the molten metal. That slag can be seen at the upper surface of the deposited weld bead.

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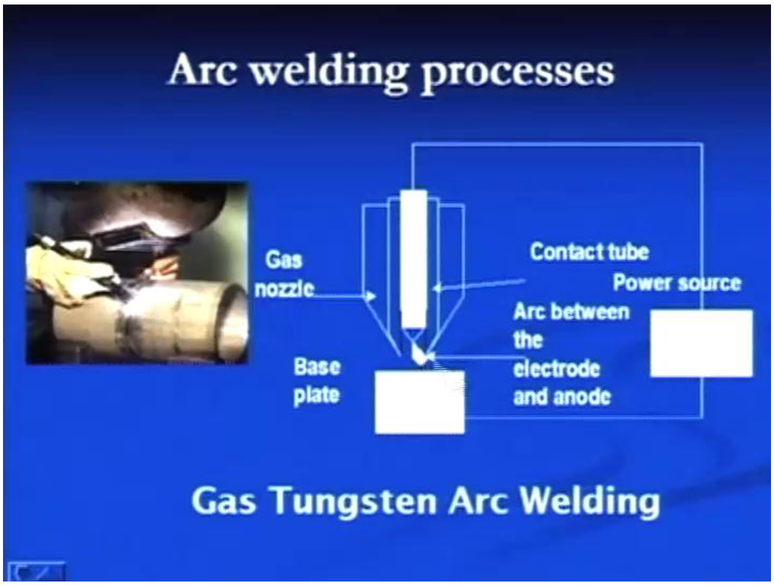

The next joining process in the arc welding processes is the TIG or tungsten inert gas welding process. In this process, the joint is produced by developing the heat between - by developing the heat from the arc, which is established between the non-consumable tungsten electrode and the work piece. And the molten pool which is generated by the arc heat is allowed to solidify to produce a sound joint.

In this case electrode does not provide the filler metal, but separately or another filler rod may be used to fill up the gap. So the filler metal in this process, may be used or may not be used. For jointing thick plates filler metal is normally used, but not for the thin sheets. So the molten weld pool is allowed to solidify freely in this welding process and to produce the sound joint.

In this figure we can see that thin pipe is being joined with the help of a TIG process. This process is a very low heat input process, provides a high energy density; and that is why it helps to join thin sheets and produce high quality weld joints.

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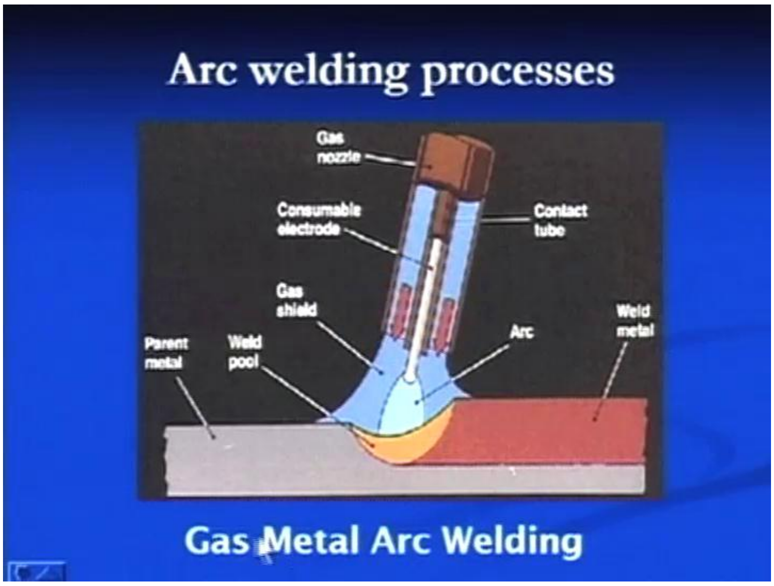

The next process, which is normally used for the mass production purpose - for producing the joints of the metals, which are active to the atmospheric gases. In this one, a consumable electrode is used, and the arc is established between the electrode and the work piece. And to protect the molten weld pool which is generated, an inert shielding gas is normally used, and when inert shielding gas is used, we call it as a MIG process or metal inert gas welding process. And when active gases like CO2 is used, then it is termed as GMA process or the metal active gas welding process. In this case, metal is allowed to solidify freely and to produce the sound joint

The deposition rates, which are obtained in the MIG welding process, are much higher than the TIG welding process. And that is why its application is more justified for the mass production purpose.

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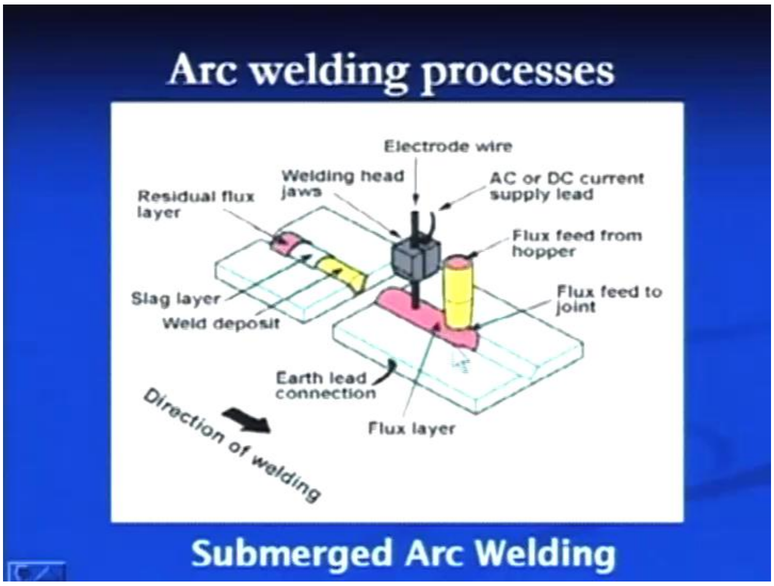

The next welding process is the submerged arc welding process, where a joint is produced by developing an arc between the base metal and a consumable electrode. And arc is submerged below the granular flux, which becomes fusible, and fusible flux melts and surrounds or covers the arc and the molten weld pool, to protect it from the atmosphere. And the molten metal is then allowed to solidify to produce the sound joint.

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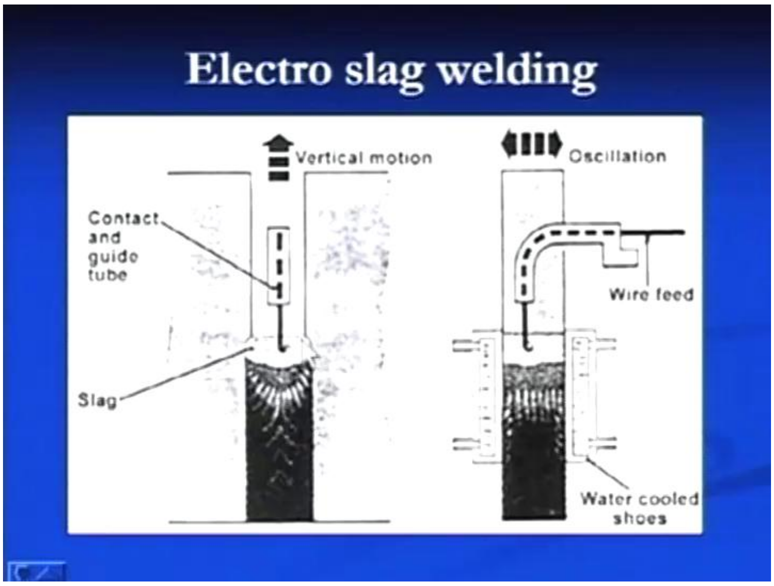

In electro slag welding process - this is a single pass welding process normally used for a jointing of thick sheets. Here, initially, an arc is established between the blanking plate and the consumable electrode. The heat generated by the arc is used to melt the flux - granular flux. And when the molten flux forms a pool arc is extinguished, and then, heat it generated by the electrical resistance heating principle, and which develops a temperature to the tune of 2000 degree centigrade, and this high temperature helps to melt the electrode and the faying surfaces of the base metal.

Gradually, the copper shoes, which are acting as a mold between the plates to be welded, are moved in upward direction, and the entire joint is completed in one pass. So, here a combination of arcing and the heat electrical resistance heating is responsible for producing the joint in electro slag welding.

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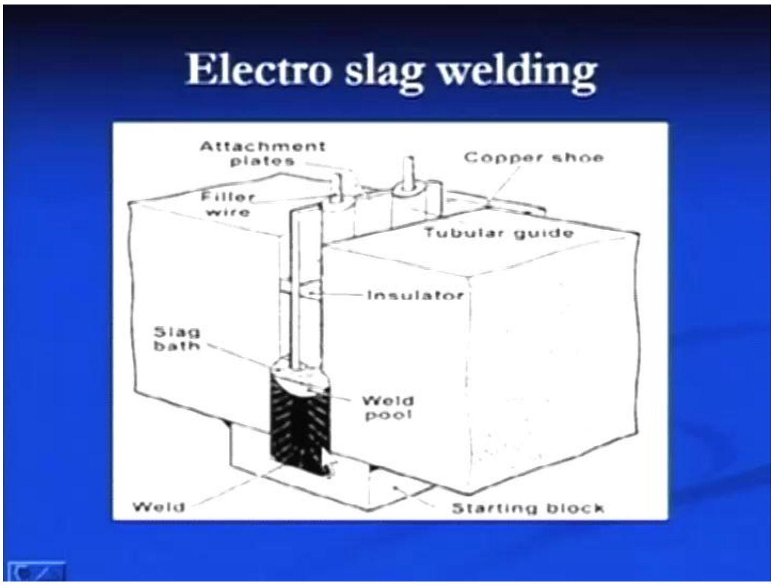

The three-dimensional diagram of the electro slag welding can be seen here. These are the two consumable electrodes at different locations; and here the copper shoes - one in this side, another can be in this side; here we have weld pool; this is the blanking plate; and this copper shoes are moved in the upward direction.

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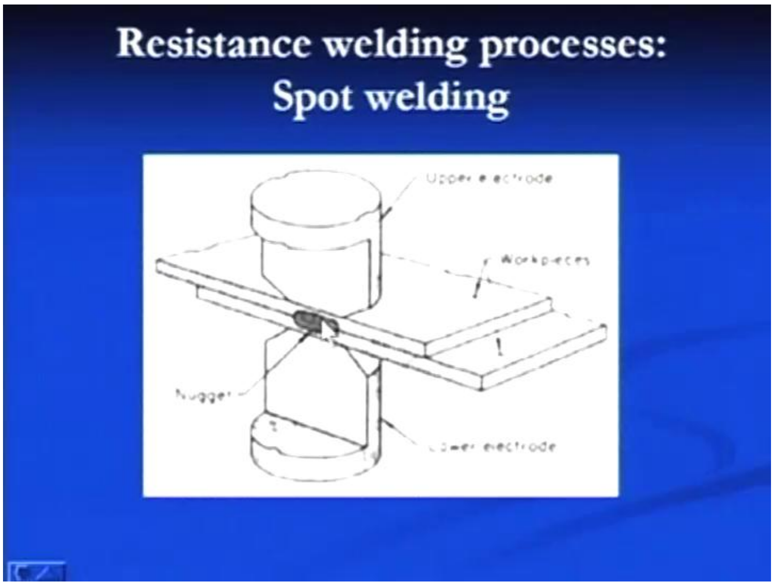

Now, we will the resistance welding processes. And there are many welding processes in the resistance welding processes category. First one is the spot welding processes. In spot welding process, the joint is produced in form of a spots. Here we have two electrodes and electric current is passed through the areas, through the plates, which are to be jointed. And by electrical resistance heating, heat is generated. And amount of heat generated depends on the I square RT, where I is the current flow in amperes; R is the electrical resistance in ohms at the contact surfaces; and T is the time in seconds. So that amount of heat required for producing the joint depends on the material to be joined and the thickness of the plates. And here the spots like or the nuggets like this at the interface of the two plates is formed, because of electrical resistance heating. Here no fusion or significant fusion of the base metal takes place.

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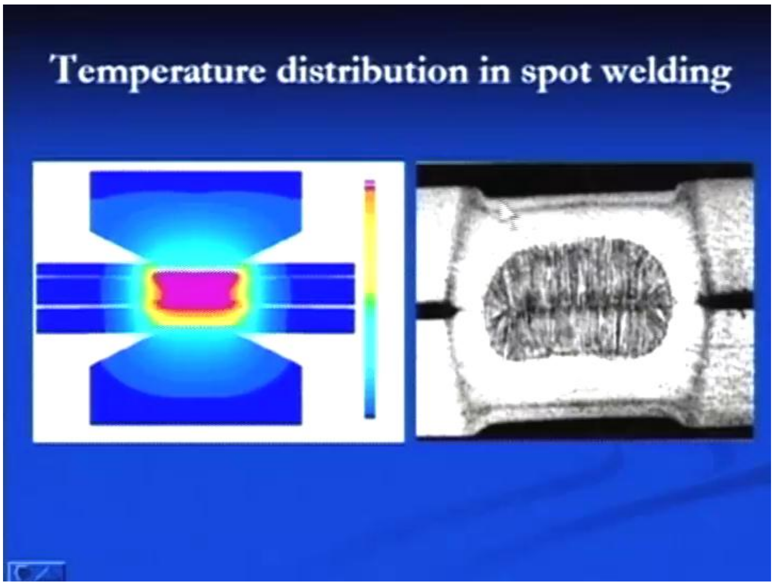

We will see the temperature distribution in the spot welding. Temperature - maximum temperature - is generated at the interface and that is why nugget is also formed at the interface; but some effect due to the heat and the pressure is noticed at the surfaces of the component, which are in contact of the electrodes. Like here, this diagram shows the electrical shape nuggets having the columnar grain structure and these are the two plates, which have been joined by the spot welding; but here we can see that some sort of the deformation has taken place at the surface, because of the electrode pressure on the work piece. And then, similar deformation can be seen here also.

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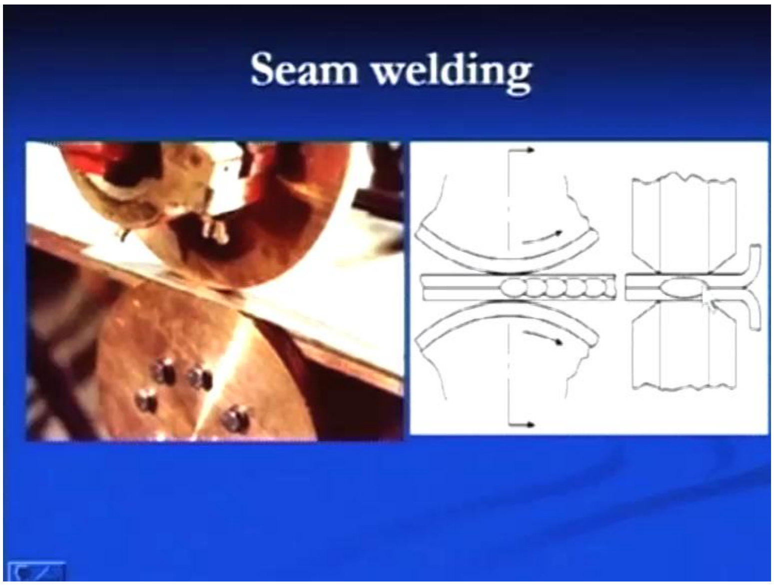

Next is the seam welding process in which the electrodes in form of… this is also a resistance welding process, in which electrodes in form of rollers are used. The electrodes - both the electrodes may be in form of rollers or one of them may be in form of rollers. The plates to be joined are passed through the rollers, and electrical current is passed through these roller shaped electrodes, which produces number of nuggets in series; that we can see from here. These are the two roller shaped electrodes, and when the plates to be joined are passed through the rollers, a series of nuggets are formed at the interface. And this figure shows the cross section where this is one of the rollers, and this is another roller, and the nugget is formed in between at the interface between the two plates.

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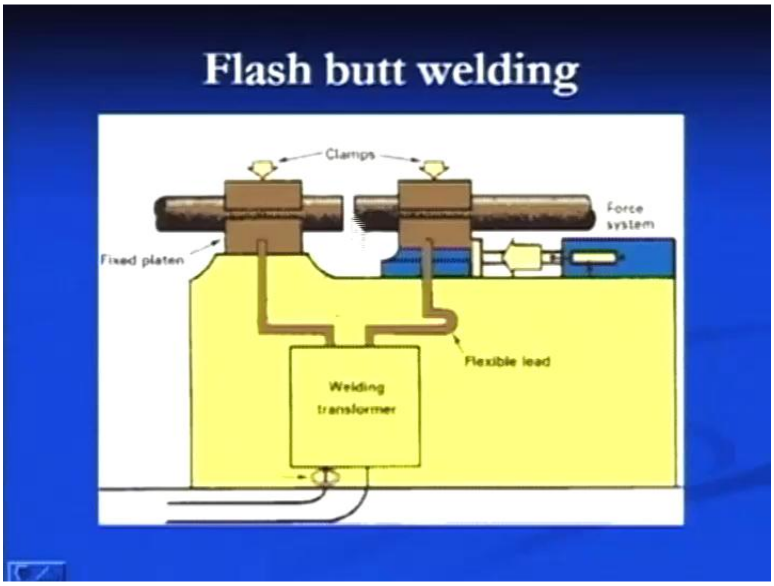

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Next is the flash butt welding process. In the flash butt welding process, here one component is clamped in fixed position and another is movable. And the two are connected to the power supply. The one movable component is brought close to the another fixed component, and as soon as it comes closer to the fixed component, the short circuiting takes place, that leads to the heavy arcing or flashing action.

This flashing action generates a lot of heat, and which helps to increase the temperature of the faying surfaces to the forging temperature; and as soon as that condition is attained, the movable component is forged with the fixed component, and joint is produced. Here combination of the initial arcing is responsible for producing the joint.

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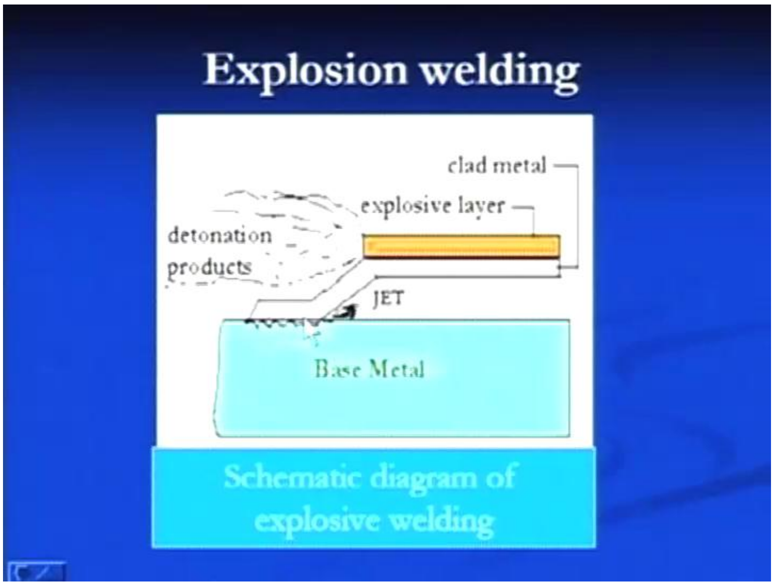

The explosion welding is another welding process in which explosive material is placed in one of the component at the top surface, and then, that explosive material is detonated. And that helps to produce very high velocity to one of the component, and that leads to the striking or collusion with the another component. And when the one component collides with the another component at very high velocity, the localized deformation at the interface takes place, and that localized deformation produces the composite kind of material at the interface and the joint is produced.

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Explosive for explosion welding

Explosive	Detonation velocity (m/s)
RDX ($C_3H_6N_6O_6$)	8100
PETN ($C_5H_8N_{12}O_4$)	8190
TNT ($C_7H_5N_3O_6$)	6600
Tetryl ($C_7H_5O_8N_5$)	7800
Lead azide (N_6Pb)	5010
Detasheet	7020
Ammonium nitrate (NH_4NO_3)	2655

Here we will see the different explosive materials, which are used for explosion welding process - like the RDX, PETN, TNT, lead azide, detasheet, and ammonium nitrate. And the different velocities - detonation velocities - are generated by these explosive materials for explosion welding.

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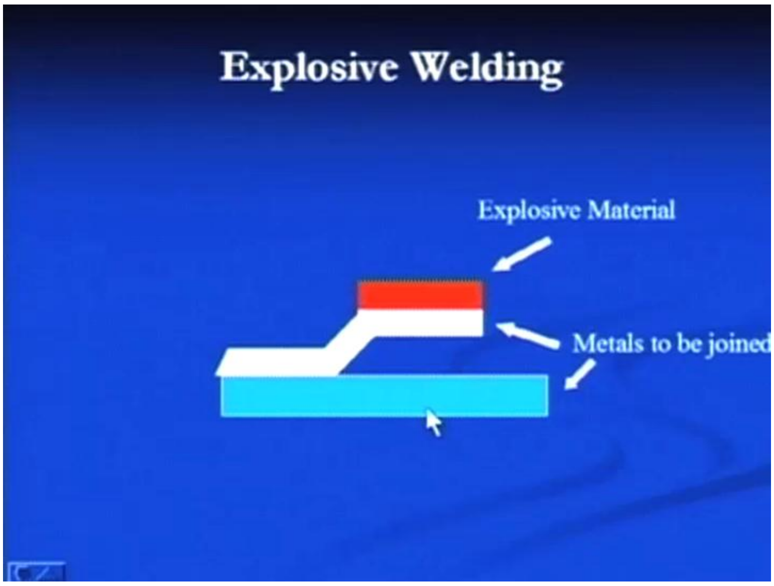

The schematic diagram or animated diagram will show that how this explosive welding works here. This is the explosive material, which is placed, and when it is detonated, the things go like this. This is know the joint at the interface is formed between the one component and the another component; and here at the interface very localized plastic deformation takes place, and that leads to the mechanical kind of bond between the two components.

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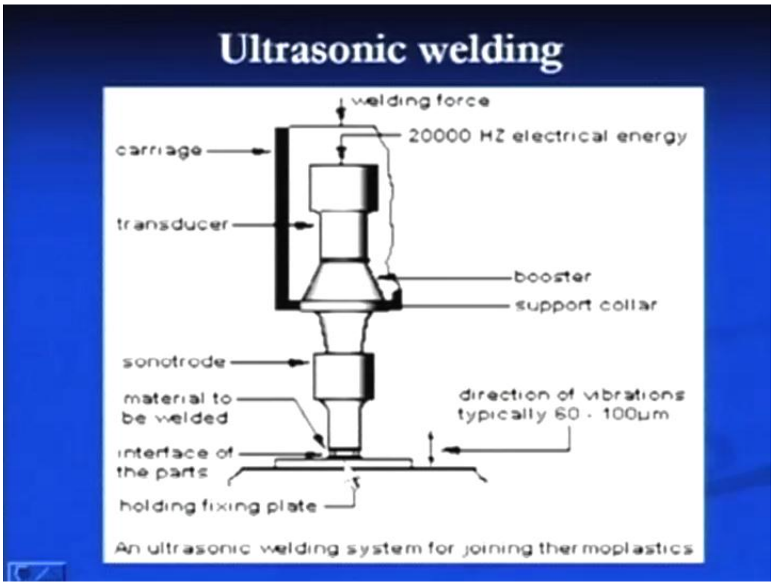

Ultrasonic welding is another process where high frequency vibrations are used to develop the bond between the two components to be joined. Here under pressure the two components are placed, and then the high frequency vibrations are provided, and that helps to generate the bond, because of the localized deformation at the interface.

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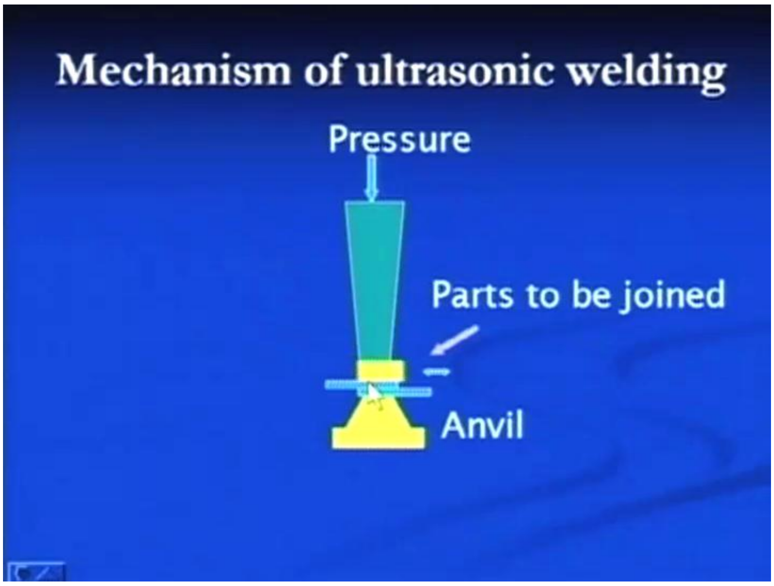

Here we will see the mechanism of the ultrasonic bonding. Here is an anvil and this is the sonotrode tip. And this is how the jointing of the two parts in ultrasonic welding takes place. Both shear stresses and the compressive stresses are held responsible for producing the joint at the interface.

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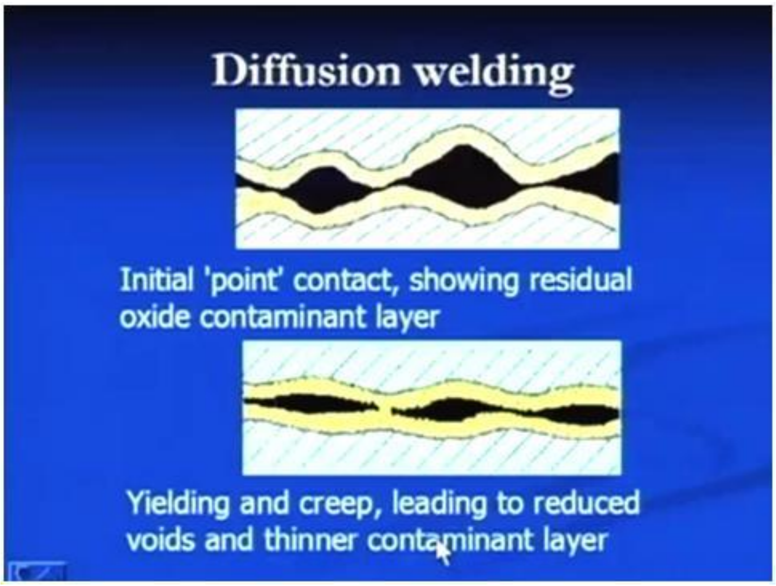

Diffusion welding is another welding process in which the components to be jointed are caped under pressure at high temperature. Initially, there is a point contact here at these locations. And gradually, when pressure is high and temperature is also high, yielding and creep at the interface takes place, which in turn increases the actual contact area, and which leads to the reduced voids and thinner contaminated layer.

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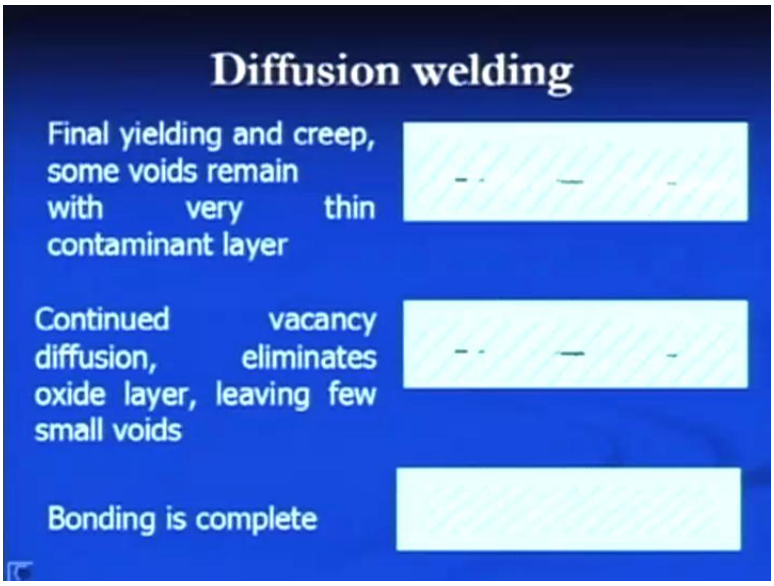

If this process continues for long, then the number of voids at the interface goes on reducing, and finally, with the continued vacancy diffusion and the removal of the oxide layer, results in very few voids at the interface. And if the diffusion welding process at high temperature and high pressure is continued for very long time, then the complete bond between the two plates can be obtained free from the voids and porosities.

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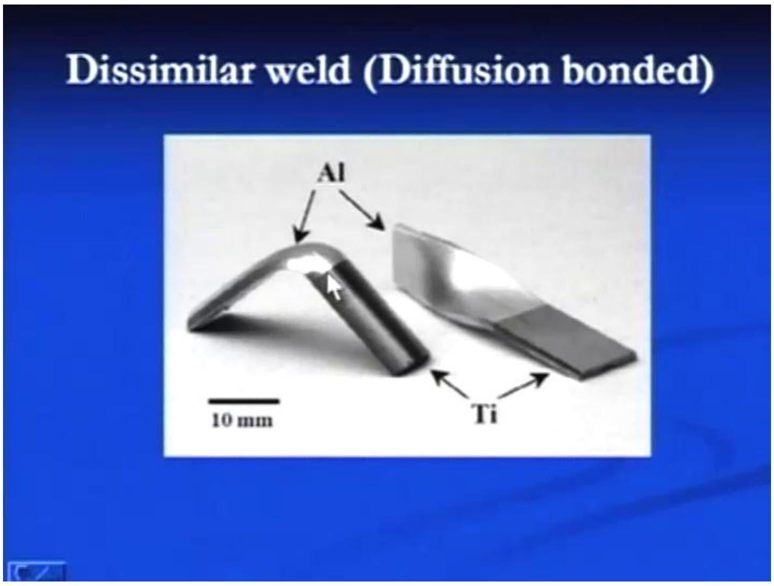

The dissimilar welds, which are produces by the diffusion bounding, can be seen here. The titanium and the aluminum joint has been produced by the diffusion bonding. And so, the dissimilar metals are which impose the problems related to the metrological compatibility, can be effectively welded by the diffusion welding process. Now we will look into the various… by having all these understanding about the common welding processes, we will try to see that how the welding processes can be classified based on the various factors, which we discussed in the beginning of this lecture.

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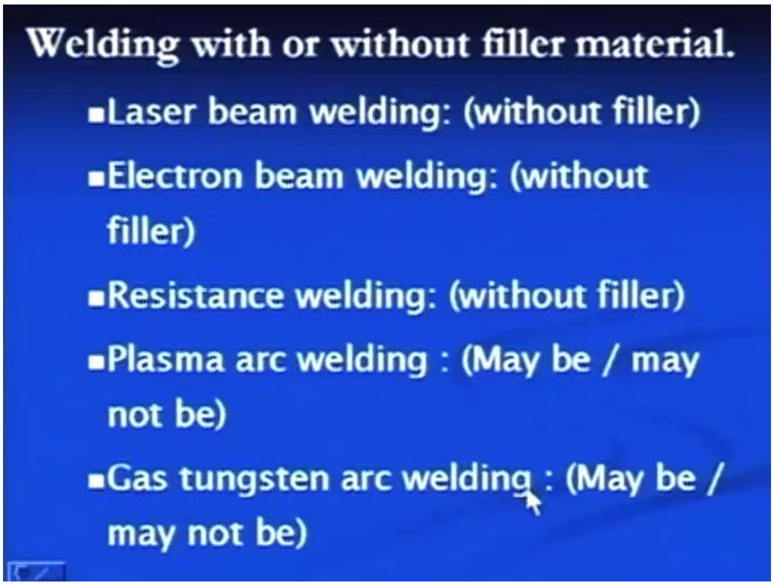

Like welding with and without filler metals can be classified like this: the laser beam welding - normally carried out without filler metal; electron beam welding - without filler metal; resistance welding - without filler metal; plasma arc welding - filler metal may be used, may not be used; tungsten arc welding - filler metal may be used, may not be used.

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Then, we have gas welding process, gas welding process - filler metal may be may not be used; and metal inert gas welding process - filler metal is used; and submerged arc welding process carried without the filler metal, where consumable electrode acts has a filler metal; then flux cord arc welding, also with the filler metal; electro gas and electro slag welding process are performed with a filler metal.

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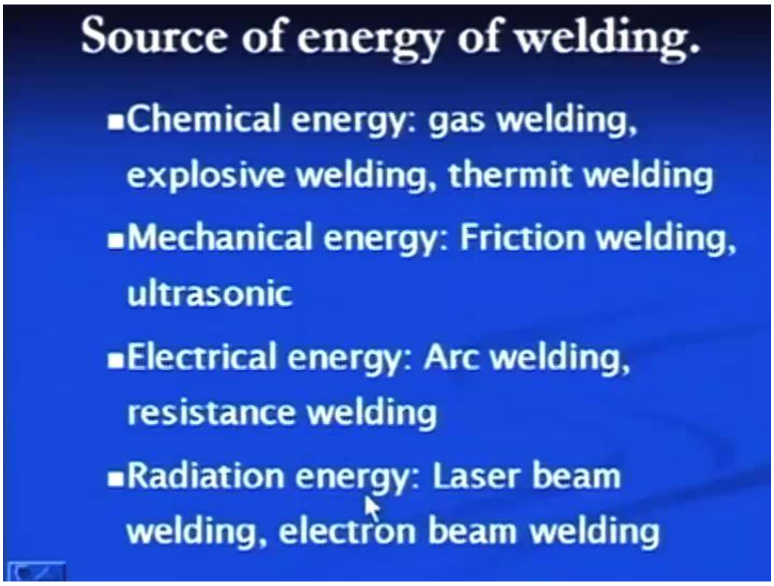

And if we see that the Welding Process Classification based on the type of energy being used for producing the weld joint, then you will see here the chemical energy is used in gas welding, explosive welding, and thermit welding. Mechanical energy is used in the friction welding and ultrasonic welding. Electrical energy is used in arc welding and the resistance welding processes. And the radiation energy in form of the laser beam or the electron beam welding processes is used, but if we see, except chemical energy most of other energies are generated from the electrical energy for producing the joint.

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The Welding Process Classification based on arc or non-arc welding process. If you see a non-arc based welding processes are like this: resistance welding processes, gas welding, thermit welding, ultrasonic welding, diffusion welding, explosive welding.

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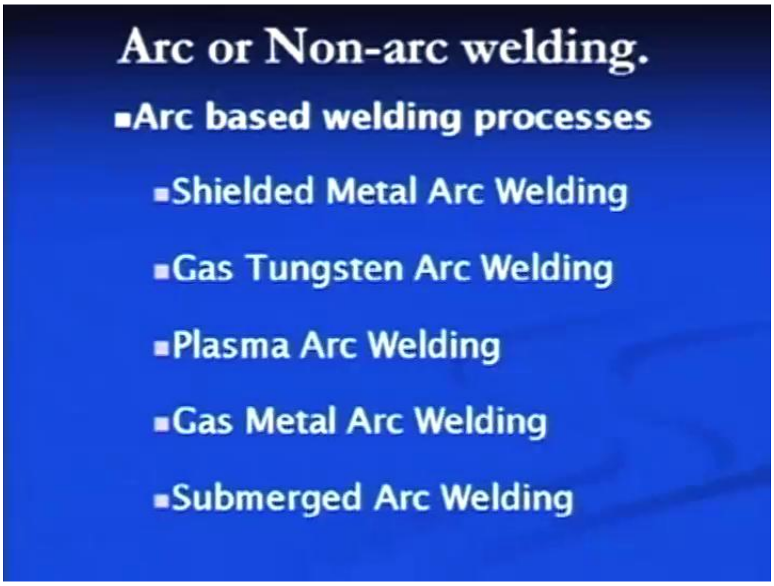

An arc welding processes are those in which electric arc is used to generate the heat desired for producing the weld joint, by melting the faying surfaces of the filler metal. These welding processes are like shielded metal arc welding, gas tungsten arc welding, plasma arc welding, gas metal arc welding, submerged arc welding.

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And in the pressure or fusion welding processes, the pressure welding processes are those processes in which the molten metal of the weld pool or the semi-solid metal, solidifies in very confined space under the pressure. Based on this concept, if we see the pressure welding processes, then we can put following welding processes under the pressure welding: resistance welding processes like spot welding, seam welding, projection welding, flash butt, arc stud welding; ultrasonic welding; diffusion welding; explosive welding; friction welding and many other welding processes under which such kind of conditions are formed when weld joint is produced.

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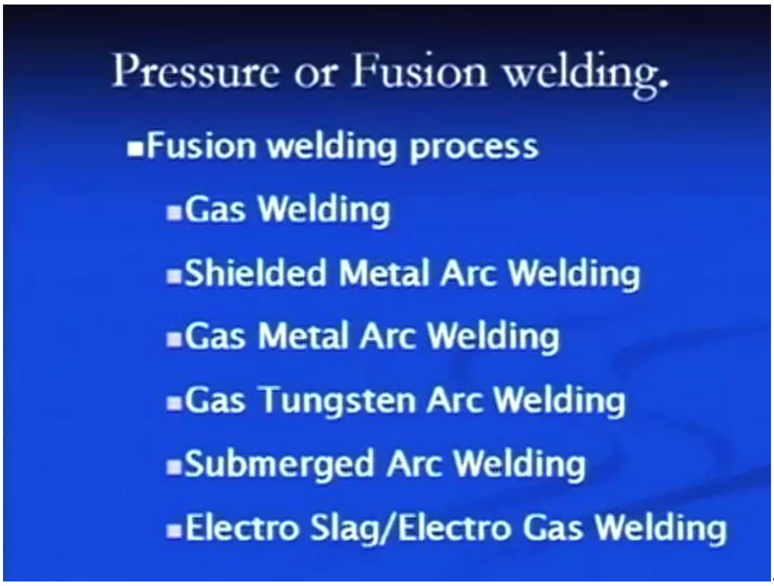

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Then we will see the fusion welding processes where molten metal is produced and it is allowed to solidify freely. Then the welding processes under which such kind of conditions is produced can be like this: gas welding process, shielded metal arc welding, gas metal arc welding, gas tungsten arc welding, submerged arc welding, electro slag and electro gas welding.

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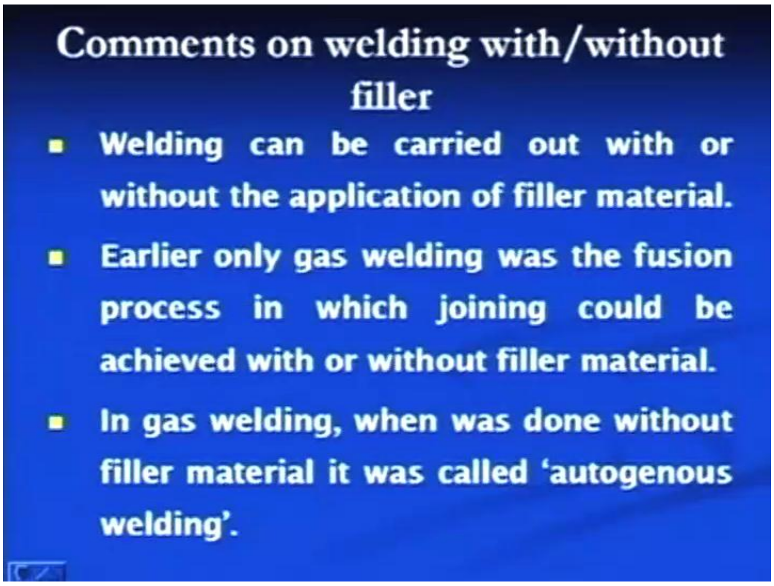

You have seen that the classification based on these four factors is not very clear. That is why some comments are there related to the classification of the welding processes based on these factors, and these comments are like this: for the first factor, like comments on the welding with and without filler metal. Welding can be carried out with or without the application of the filler metal. Initially when welding technology was developed, earlier we were having only the oxy acetylene gas welding or gas welding only was the commercially useful process, and because of this, earlier only gas welding process was the fusion process welding in which joining could be achieved with or without filler metal.

In gas welding process, when filler metal is not used, then the joint produced so is called the autogenous weld or that such process is called autogenous welding.

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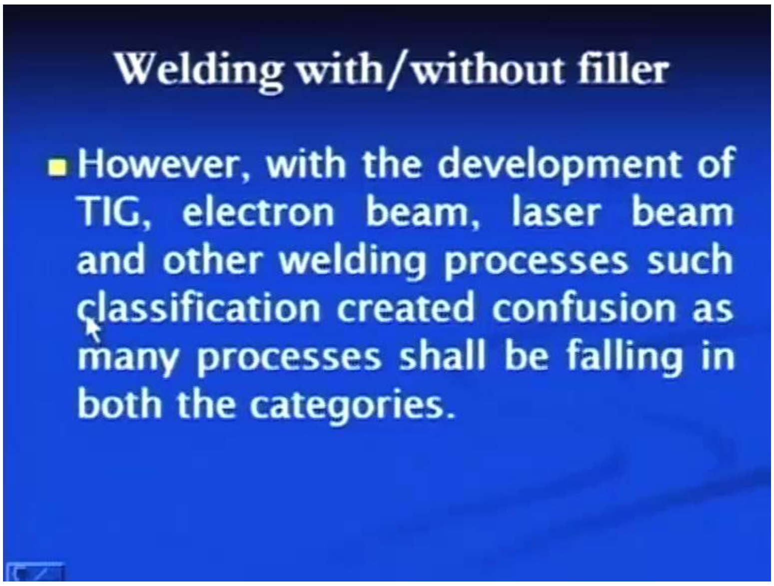

However, with the development of the processes like tungsten inert gas, electron beam welding, laser beam welding, and other welding processes, classification created confusion, as many processes shall be falling in both the categories. Like we have seen earlier, many processes are such that where filler metal may be used or may not be used - like in gas tungsten arc welding, plasma arc welding, electron beam welding. So depending upon the thickness of the material or the conditions, which may allow or may not allow to use the filler metal; that is why this factor for classifying the welding process was not found very good.

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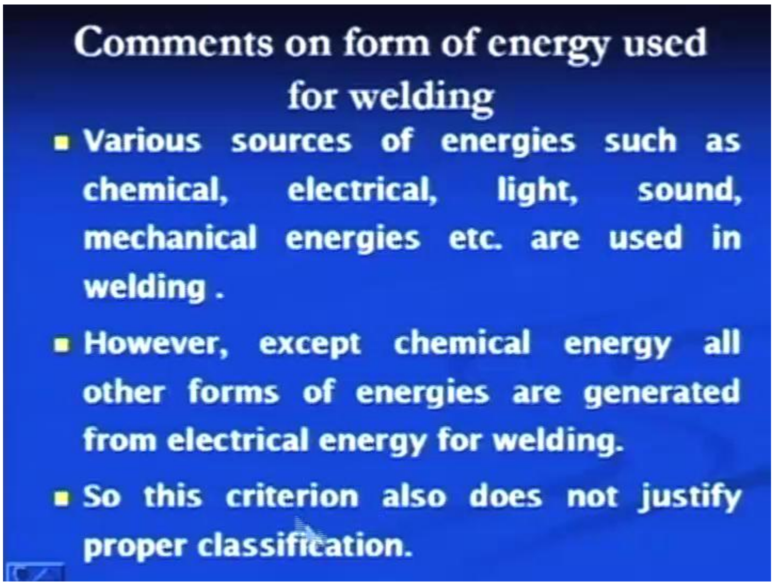

Next, we will see the comments on the form of energy used for the welding process for classifying the welding processes. We have seen that the various forms of the energies are used for producing the weld joints such as chemical energy, electrical energy, light, sound, mechanical energies etcetera. However, except the chemical energy, all other forms of the energies are generated from the electrical energy for the welding purpose. That is why this criteria is also not justified for proper classification of the welding processes, because energy required for most of the welding processes are generated from electrical energy, except in the welding processes like gas welding or thermit welding where exothermic reaction takes place to generate the sufficient amount of heat for melting of the faying surfaces of the base materials, and for producing the sound joint.

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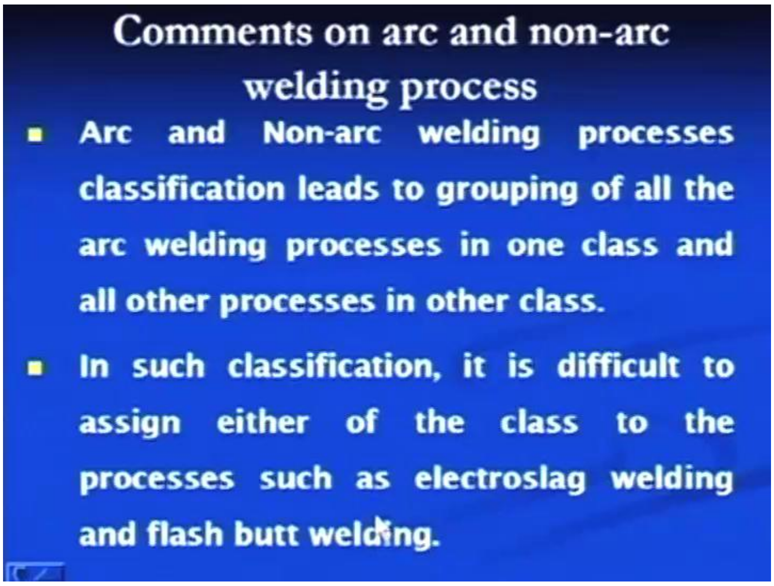

Now, we will see the comments on the arc and non-arc welding process classification. Arc and non-arc process classification leads to the grouping of all welding processes in one class and all other processes in other class; means, this if we try to classify the welding process on the basis of arc and non-arc welding processes, then all arc welding processes will come in one category, and rest of the processes will come in another category.

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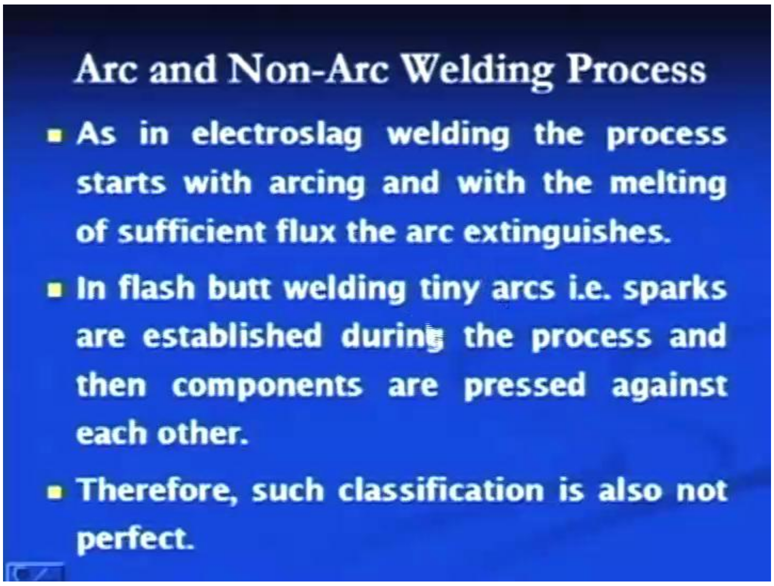

In such classification, it is difficult to assign either of the class to the processes such as electro slag welding and flash butt welding; the reason of this you will see. In arc as in the slag welding process the processes starts with arcing and with the melting of the sufficient flux leads to extinguish the arc.

And further heat for melting of the faying surfaces and filler metal in electro slag welding process, takes place by the heat generated due to the flow of current through the molten slag. The heat generated by the flow of current through the molten slag, generates high temperature in the molten slag, and that heat is gracefully transferred to the faying surfaces and the base material, which leads to the melting of the faying surfaces and the electrode.

So here, heat is initially generated by arcing between the electrode and the blanking plate to produce the molten slag. And then arc is extinguished by the molten slag, and heat is generated by the electrical resistance heating due to the flow of current through the molten slag to produce the joint. And that is why the classification of this welding process or this electro slag welding process is difficult to put in either of the categories, either arc welding process or non arc welding process.

In flash butt welding process, on the other hand, tiny arcs are generated; these tiny arcs are also termed as sparks or flashing. These tiny arcs lead to the heating of the faying surfaces to the forging temperature, and as and when that forging temperature is attained, the moveable component is pressed against the fixed component to produce the joint. Initially, the heat is generated by the saw circuiting between the faying surfaces, when the two components are brought in contact.

So, it is the combination of the electrical resistance heating at the interface and that the tiny arc development; both lead to the development of the heat to produce the joint. Thus here such classification is also not perfect, because it becomes difficult to put the electro slag welding or the flash welding - flash butt welding- process in any of the categories.

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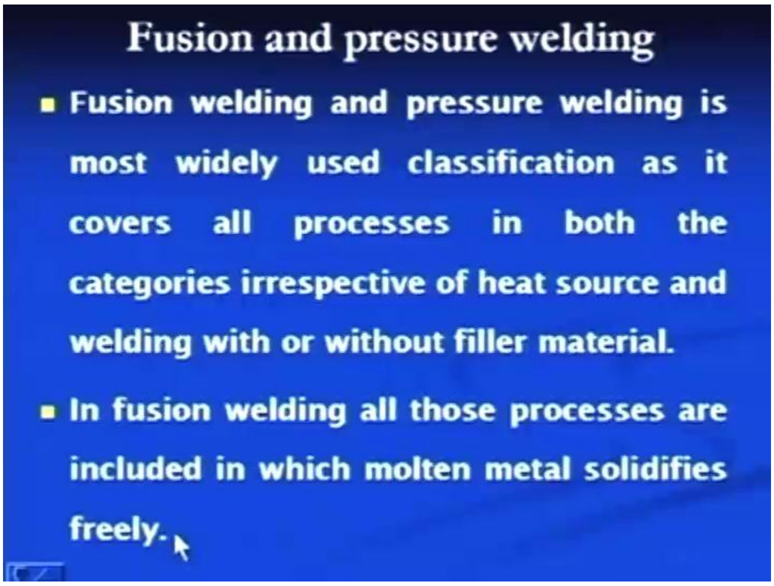

The fusion and the welding pressure welding process classification. Comments are like this: fusion and pressure welding is most widely used classification as it covers all the processes in both the categories, irrespective of heat source, and welding with or without filler material.

In fusion welding, all those processes are included in which molten metal solidifies freely; means, molten metal is not subjected to pressure of any sort during the solidification - like in gas welding process, submerged arc welding process, shielded metal arc welding process - where molten metal is generated by the arc or the gas flame, is allowed to solidify freely.

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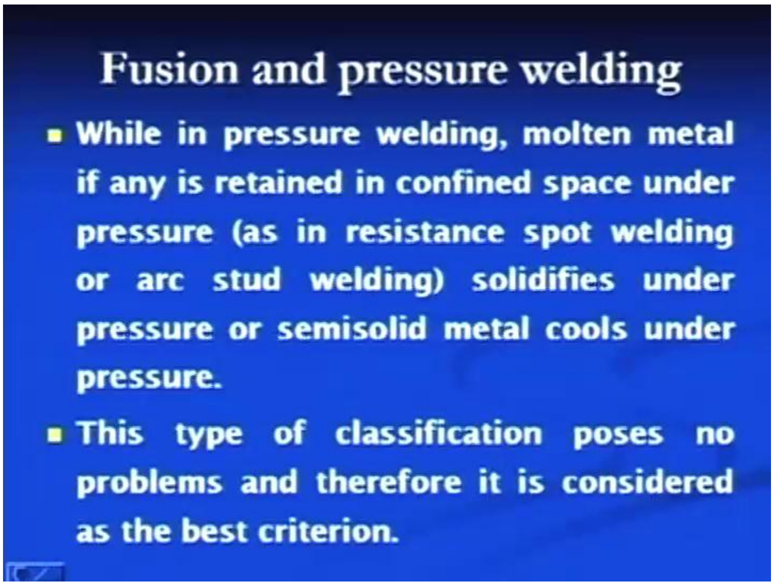

A few more points: while in pressure welding, the molten metal, if any, is generated at the interface, is restrained in confined space under pressure, and solidifies under pressure or semi solid metal cools under pressure; means, whatever molten metal or semi solid metal is produced in the welding processes, that is kept under pressure during the solidification - like in resistance welding process, nugget is formed or in arc a stud welding process joint is formed at the interface. This type of the classification poses no problems, and therefore, it is considered as the best criteria for classifying the welding processes. All types of the welding processes can be easily and effectively classified using the fusion and pressure welding process.

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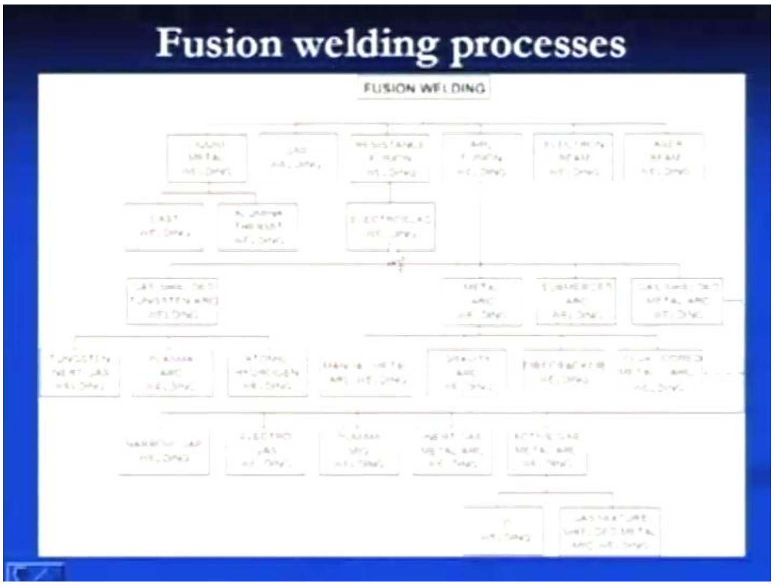

Based on the fusion welding process criteria we will see that in all these welding processes the molten metal is allowed to solidify freely.

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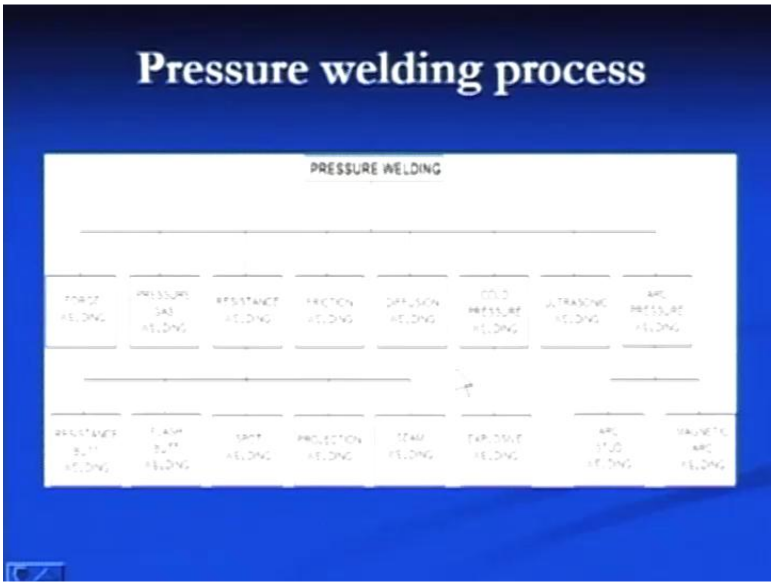

And in pressure based welding processes, where molten metal solidifies under pressure in confined space - like the pressure gas welding or resistance welding, friction welding - so in all these processes, either semi-molten metal or a molten metal is allowed to solidify under pressure to produce the sound joint.

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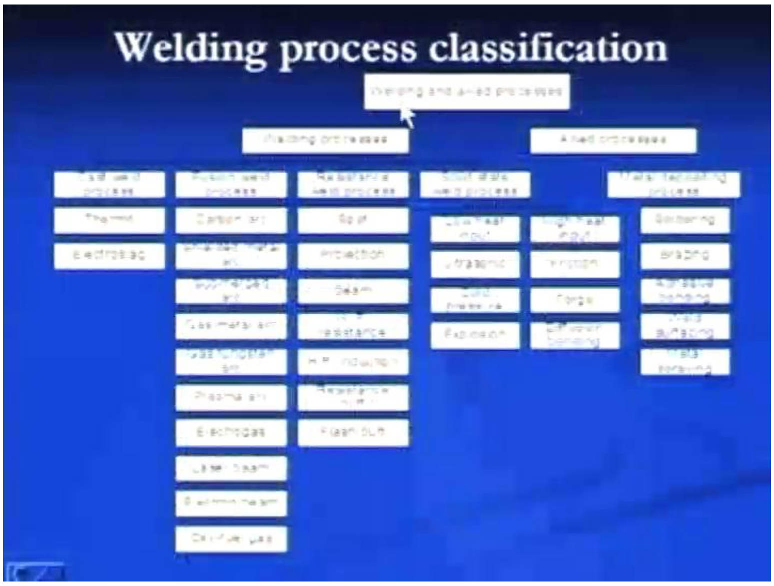

Welding process classification can also be based on the factors like the welding and allied processes. The welding processes are those in which joint is produced, and allied processes are those in which either joint is produced or some sort of layer at the surface of the component is produced. So, based on this welding and allied processes criteria we will see that how processes can be classified.

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The welding and the allied processes. The welding processes are like this. The cast weld processes in which molten metal, which is generated by either flash butt welding or by any at external heat source is poured in between the faying surfaces to produce the joint. Fusion welding processes, resistance welding processes, solid state welding processes in which a metal remains in solid state and no significant heating of the metal takes place to produce the joint.

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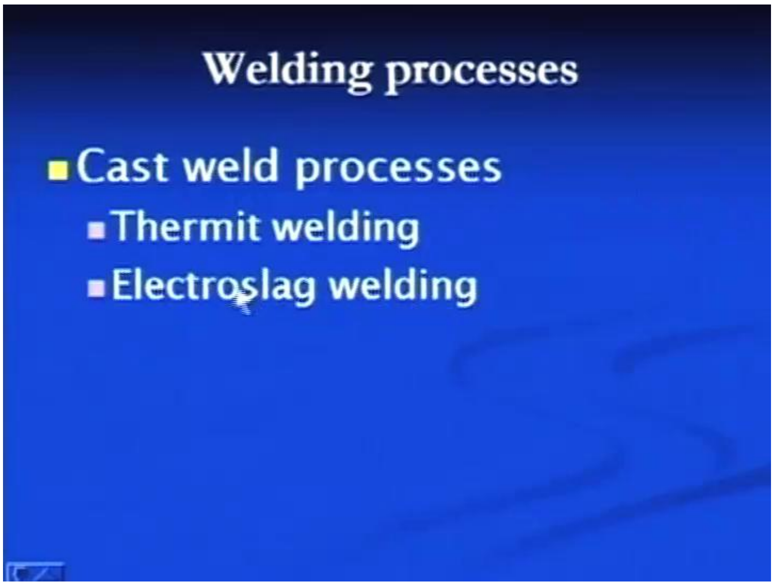

In allied processes, you will see here now, the cast weld processes are like this - thermit welding and electro slag welding. In thermit welding, molten metal is generated by exothermic reaction, and the molten metal is poured in between the plates to be joined and after the solidification we get a sound joint.

And the electro slag welding, as I have explained earlier, the cast structure is produced in the joint, because of very low cooling rate, which is generated, and the molten metal is developed because of electrical resistance heating due to the flow of current through the molten flux. So the molten metal is filled in between in the faying surfaces and the joint is produced in electro slag welding.

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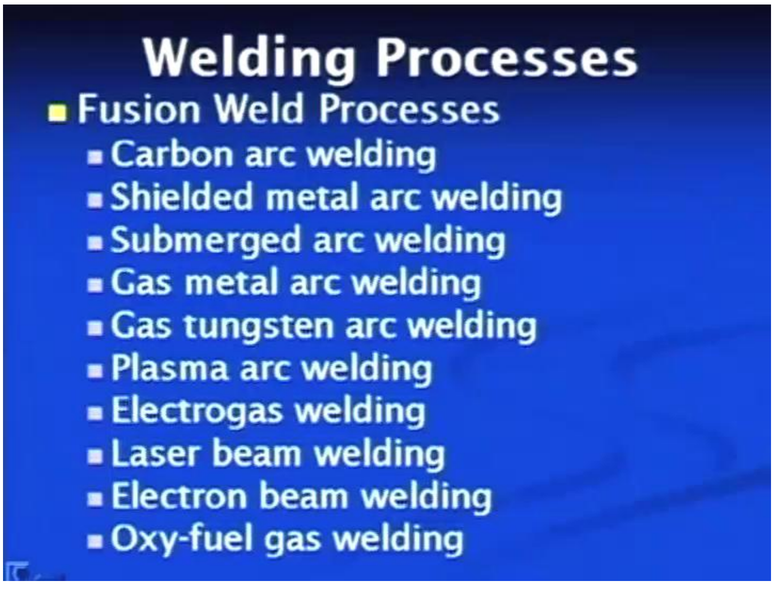

The fusion welding processes are those in which the faying surfaces are brought to the molten state, and then, they are allowed to solidify - like carbon arc welding process, shielded metal arc welding process, submerged arc welding process, gas metal arc welding process, gas tungsten arc welding process, plasma arc welding, electro gas welding, laser beam welding, electron beam welding, oxy fuel gas welding. In all these fusion welding processes, the melting of the faying surfaces takes place, and then that molten metal is allowed to solidify to produce the joint.

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In resistances welding processes, joint is produced by a the heat which is generated due to the flow of current, in the welding processes like a spot welding, projection welding, seam welding, high frequency resistance welding, high frequency induction welding, resistance butt welding, flash butt welding, stud welding. In high frequency resistance welding, and high frequency induction welding, the principle of the high frequency - the principle, which is used in both these welding processes is the use of a high frequency current - that when high frequency current is applied, the localized heat is generated at the interface by the resistance in the resistance welding process, and by the induction of the current in the induction welding process.

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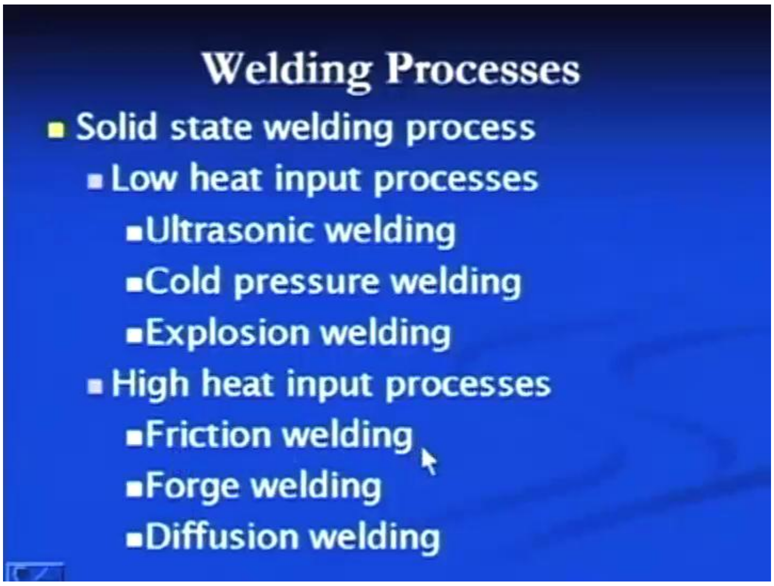

In the solid state welding process, no significant heating of the metals to be joined take place. Like low heat welding processes are those in which not much heat is applied or developed at the interface for producing the joint, like a ultrasonic welding, cold pressure welding, and explosion welding; mainly the localized plastic deformation of the metal at the interface in these welding processes takes place, and which is held responsible for producing the joint. High heat input welding processes in which melting does not take place, but a significant heating occurs, like in friction welding, forge welding, and diffusion welding.

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Allied welding processes are those in which either joint is produced or some sort of layer is developed at the surface to protect it from the environment or the wear and tear, like metal depositing processes, soldering, brazing, adhesive bonding, weld surfacing, metal spraying. In first three processes - like soldering, brazing, and adhesive bonding - joint is produced; while in weld surfacing and metal spraying some sort of layer is developed at the surface to protect the component from the external environment or for increasing their wear resistance.

In soldering process, the two parts are placed in a designed position and they are heated. And after that, solder or the filler metal is placed near the area where joint is to be produced; that solider melts, and then, it is sucked in between the faying surfaces by capitulary action, which after solidification produces a sound joint. But a strength of the joint produced by a solder becomes low, and becomes unsuitable for the high temperature applications.

In the brazing is the another method which is used to produce the joints. Like soldering, in brazing a filler metal is used, which is mainly of the copper based alloy, and that filler metal is applied near the heated base metal surfaces which are to be joined, and in the same way like soldering that molten filler metal is sucked inside by the capillary action to produce the joint on the solidification. The strength of the brazed joints becomes somewhat better than the soldered joints.

In adhesive bonding the joint is produced by putting the adhesives between the faying surfaces, and then, the joint is kept under pressure, and sometimes the curing is also carried out to increase the strength of the joint. The typical example of the adhesive bonding is use of M-Seal or the Fevicol.

In the weld surfacing process, the weld bead deposited at the surface is mainly used to cover the external surface to protect it from the wear and tear, like the adhesive kerosene on Arosen. The welding based processes like a shielded metal arc welding, submerged arc welding, or flux code arc welding processes are normally used for developing whey resistance layers at the surface; such processes are called weld surfacing processes.

And then, in metal spraying, the metal in form of whey resistance material in form of either powder or the filler wire or in form of wire is used to develop a whey resistance layer at the surface. Here molten metal - whey resistance material - is brought to a molten is state by using the various types of the heat sources. And that molten material is then accelerated towards the surface on which the whey resistance layer is to be deposited, which after the solidification leads to develop a protective coating on the component.

So, these are the allied welding processes, which are used for producing the joints or for developing the whey resistant layers on the substrate or on the surface of the component. So now, we can summarize this lecture. We have seen that there are many ways to classify the welding processes; however, fusion welding and pressure welding criteria is best suited and most accepted way to classify all the welding processes.

Thank you, students.