Fundamentals of Manufacturing Processes

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Lecture – 49
Joining of Metals: Welding Processes I

Hello, I welcome you all in this presentation related with the subject fundamentals of the manufacturing processes and we are talking about the joining of the metal; so, joining of metals.

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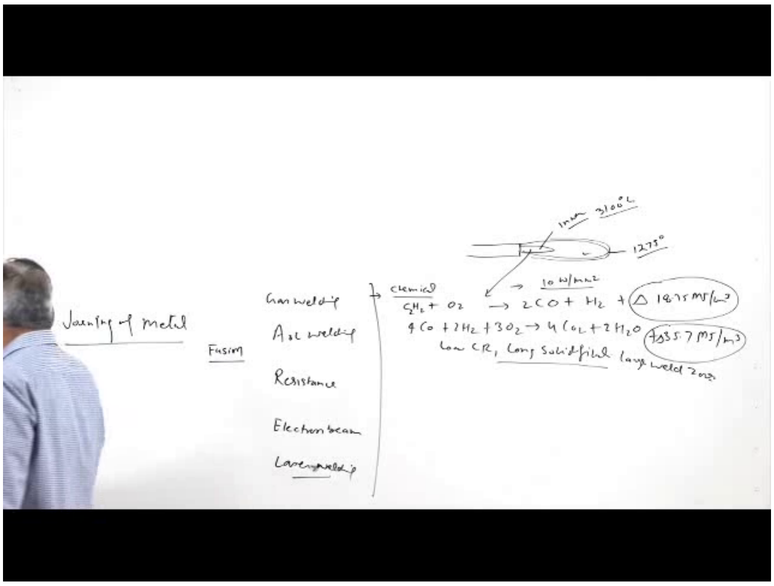

We have talked about some fundamentals related with the metal joining like the fusion welding, solid state welding and related with the and related effect of the heat and the pressure.

So, among the fusion welding processes, the common welding processes are like the gas welding, arc welding, then we have resistance welding, then electron beam welding and laser welding, laser welding. So, what we need to see is the way by which heat is generated in these fusion welding processes, for that if we see and the kind of quality that we get in.

So, here this involves the chemical reactions where most common fuel gas like Acetylene is burned with the oxygen so that it produces, it produces the carbon monoxide CO plus H 2 plus some amount of the heat is generated which is about 18.75 mega joule per meter cube of the Acetylene on the. So, this is what happens in case of the combustion of the Oxy-Acetylene flame.

So, when Oxy-Acetylene flame is produced we get the 2 cones primarily, one is inner cone where the temperature is much higher than the outer cone, inner cone offers the temperature of around 3100 degree centigrade while outer cone offers temperature around 1275 degree centigrade. So, in the inner cone somewhat lesser heat is generated, that is this area, but the area exposed inner cone despite of having the lower amount of the heat being generated its surface area is less. So, it results in the much higher temperature and further it enclosed by the other outer hotter envelope which is this one at 1275 degree centigrade.

Ah. So, this kind of the reaction takes place in case of the inner cone while the outer cone offers the another reaction wherein more amount of the heat is generated and the reaction occurs of this kind wherein 4 CO 2 plus twice H 2 O plus lot of heat is generated like 35.7 mega joule per meter cube of the Acetylene.

So, lot of, so this is a big exothermic reaction which takes place and lot of heat is generated, but since the area exposed to the room temperature conditions or ambient conditions is much larger. So, therefore, despite of having the more amount of heat generation it results in the lower temperature of the flame in the outer side. And if we measure, since the flame is much larger in size it will be covering the very larger area of the base metal and that is why the energy density which is associated with this process is quite low which is like say 10 watt per mm square.

So, it takes lot of time to reach to the fusion temperature and in mean time lot of heat is dissipated to the base metal and that’s why it results in very low cooling rate as well as long solidification time of the weld metal and the large weld fusion zone is produced as a result of the gas welding. And if the plate is really very thick then it may not be possible to, it may not be possible to fuse also because whatever heat is fed or supplied that will keep on dissipating and to the base metal.

So, the melting may also be difficult in this case, but you know as the amount of the heat being supplied increases it reduces the cooling rate of the weld. So, which in turn increases solidification time increases the grain size and. So, those are the other effects related with the heat input. Apart from the heat aspect the gas welded joints you will see.

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So, let us talk little bit in in detail where in how the heat input affects the joint. So, we know that the weld size increases with the increase in the heat input. The amount of the heat delivered to the base metal also increases. So, heat to the base metal also increases which in turn reduces the cooling rate. There is in general H net is inversely proportional to the cooling rate which is experienced by the weld metal as well as so, because of the greater amount of the heat being supplied to the base metal below the fusion boundary. So, this will be increasing the size of the heat affected zone. Reducing cooling rate with the increase of the heat input results in the weld metal taking longer time to solidify and because of this all the impurities if they are present in the weld metal they will have enough time to flow toward the surface.

So, the tendency for the porosity and inclusions is reduced, means interrupt meant tendency for pores and inclusions is reduced due to the lower cooling rates. At the same time, segregation tendency, segregation tendency especially in case of the alloying element increases of the increase of a solidification time and reduction in the cooling rate.

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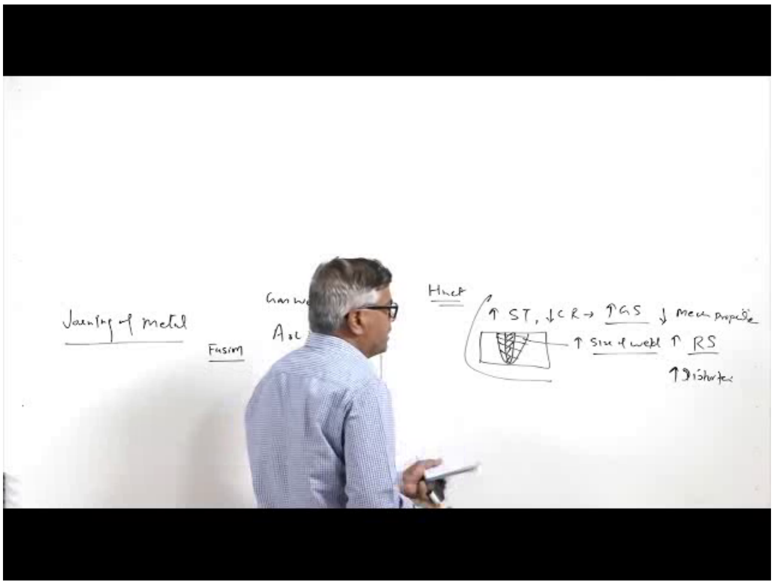

So, these are some of the effects which are related with the heat input. Another there few more effects like the increase in the solidification time and reduction in the cooling rate in general increases the grain size of the weld metal and increase in grain size in general reduces the mechanical properties. So, this is what is generally observed.

A, with the increase in the heat input and with the increase in size of the weld pool also with the low heat input will be resulting in a smaller weld size while the increase in, means reduction in heat input will be resulting in the smaller weld size for the high energy density processes while when the low energy density processes are used we need to supply lot of heat and that will be increasing the size of the weld pool.

Increasing size of the weld increases the residual stresses being developed around the weld pool and which also increases the distortion tendency in the weld. So, in order to deal these, with these issues it is always preferred that heat input being supplied during the welding is as less as possible while the metallic continuity and metallurgical continuity is realized during the welding.

Apart from the, apart from the this heat input aspect all the fusion welding processes for all the welding processes another aspect which affect the quality of the weld is the weld metal protection.

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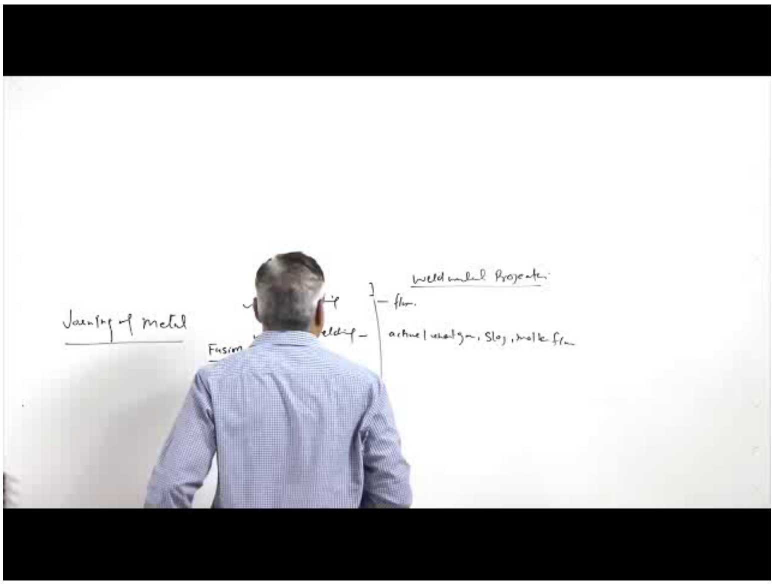

It is always desired that the, since the different welding processes work on the different principle of the weld metal protection for example, electron beam welding uses the vacuum, resistance welding normally done in the environmental conditions, arc welding uses the different approaches like the active gas or inert gas environment or the slag or the molten flux, molten flux.

So, because of the different and in the gas welding normally no protection approach is used except in some cases flux may be used in order to deal with the issues deal with the problems of the oxidation. So, since the different processes offer the different kind of protection or different approaches used that’s why the cleanliness of the weld with regard to the presence of oxygen and nitrogen in the weld is different in the welds produced by the different welding processes.

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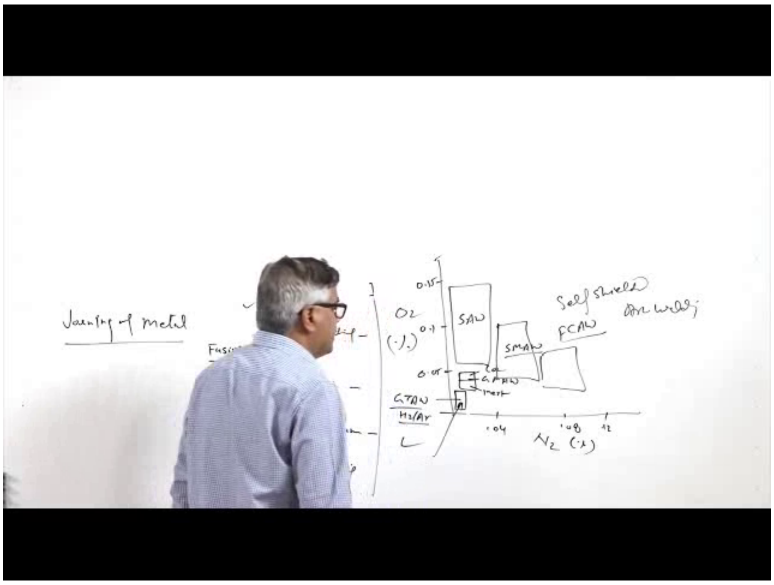

So, if we see just for an example if we see here 0.04, 0.08 and 0.12 percent of the nitrogen the X axis and in the Y axis say if we have 0.05, 0.1, 0.15 for the oxygen percentage in the weld metal. So, with regard to this the cleanest weld is produced by the TIG welding process GTAW.

When we are using helium kind of the process Helium or Argon, what somewhat more amount of the oxygen and somewhat more amount of the nitrogen is also produced when GMAW using inert gas it will be resulting in somewhat lower amount of oxygen and with the CO 2, more amount of the oxygen in the weld is produced.

Then we have the processes like submerged arc welding will be resulting in larger amount of the heat in the weld metal while the shielded metal arc welding process will be resulting in this is the stick electrode or shielded metal arc welding process which will be resulting in the more amount of oxygen as well as nitrogen. And large amount of oxygen and nitrogen is produced in the process like FCAW flux cored arc welding or self-shielded arc welding process.

So, since the different welding processes work on the different; so, all these other different arc welding process which use the different approaches for protecting the weld metal, that's why the cleanliness of the weld metal is different. The cleanest weld is produced among all these welding processes by the GTAW, thereafter it is the GMAW and SMAW, SAW and FCAW. Since the oxygen and nitrogen content in the weld metal will be reacting with the metal and which in turn will be leading to the formation of the oxides and nitrites.

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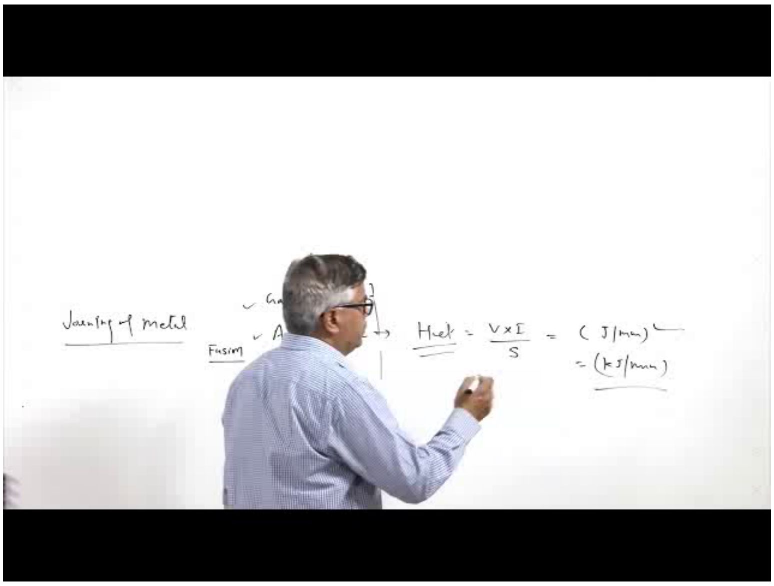

In the presence of these oxides and nitrides in the weld metal as inclusions will be adversely affecting to the mechanical properties of the weld joint, a heat in the arc welding is produced using the simple concept like power of arc is identified through the voltage arc voltage and welding current which is being used. Since the arc is continuously moving so we need to divide the welding speed and when this combination is used it results in the joule per mm or kilo joule per mm is the kind of unit which is used to express the heat input.

So, power of arc is basically VI, but if you have to calculate the net heat input H net then VI by S is used and that in turn will be expressed in terms of the joule per mm. Depending upon the kind of process, the different kind of the heat inputs are used like the GTAW offers, gas tungsten arc welding offers very low heat input maybe like say less than 1 kilo joule per mm while it is for SAW it may be like 2 to 5 kilo joule per mm.

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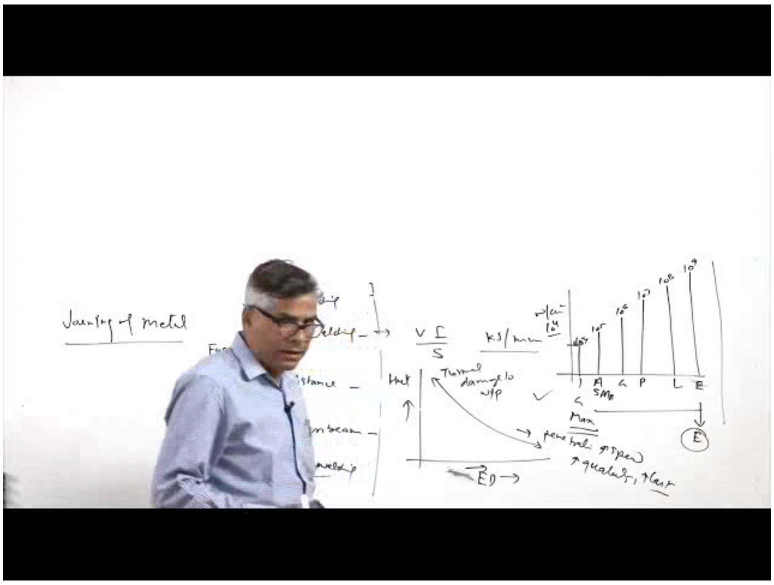

So, depending upon the process for the GMAW it is maybe it may be in between for PAW it is like 1 to 1.5 kilo joule per mm, like this. So, depending upon the net heat input which is being delivered the weld pool size and cooling rate, all that are affected.

So, in case of the arc welding processes depending upon the welding process which is being used is generally the power of arc VI and depending upon the speed we determine the heat input kilo joule per mm. So, increasing the heat input they will be leading to the like say in this plot the gas welding like the arc welding, gas metal arc welding, plasma arc welding, the laser welding and electron beam welding.

So, laser welding, laser welding, electron beam welding, plasma welding, gas metal arc welding and arc welding or SMAW, SMAW and gas welding. So, if we see the power density in terms of, like this is in 10 to the power 4 watt per centimeter square.

So, here 10 to the power 4 watt per centimeter square, 10 to the power 5 watt per centimeter square, 10 to the power 6 watt per centimeter square, 10 to the power 7 watt per centimeter square, 10 to the power 8 watt per centimeter square or even 10 to the power greater than 10 to the power 9 watt per centimeter square. So, energy density keeps on increasing, this is in increasing order in case of the fusion welding processes.

So, maximum heat input is there in case of gas welding and the minimum heat input is there with the electron beam welding. So, so if we try to see the; how does it affect like this, this is in the X axis, if we have energy density and in Y axis we have thermal damage to the work piece.

Then this will be, basically it is h net and this will be increasing H net heat, net heat input which is being supplied and increasing thermal damage to the; to work piece. And here increasing penetration, increasing speed of welding, increasing quality of the weld, at the same time increasing cost of the system also.

So, with low energy density processes will be resulting lesser penetration, lesser welding speed, lower quality and lower cost while high energy density processes will be resulting in the greater penetration, greater speed, better quality and higher costs. So, this is what we can understand that’s why efforts are always made to use the high energy density processes.

So, that the quality of the weld joint can be, good quality weld joints can be produced while economics is also kept in mind while taking decision about the process to be used. On the other hand the resistance welding processes they work on the simple principle of the electrical resistance heating, electrical resistance heating.

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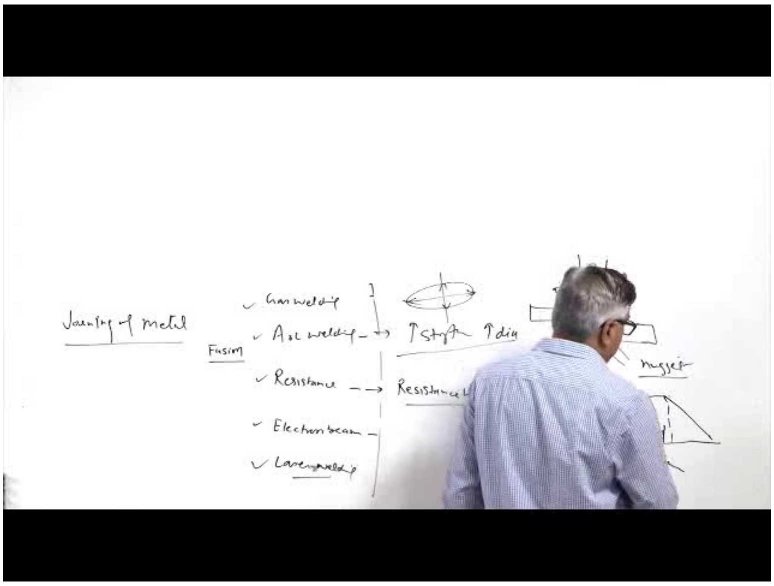

In case of electrical resistance heating I square RT principle is used where in the surfaces to be joined the components to be joined are brought in contact under pressure. With the help of electrode we feed the power which is to be delivered like this the copper electrodes which are normally used.

So, the flow of current through this end results in the maximum contact pressure is observed at the interface and the somewhat contact pressure is also experienced, contact resistance is experienced at the contact between the work piece and the electrode. So, according to this for the flow of current I and for a period of the time at t, the maximum heat is generated at the interface.

So, this heat generation results in the fusion at the interface. So, once the fusion takes place at the interface it results in the in the weld nugget. So, weld nugget determines the size of the weld diameter of the weld nugget. There are 2 accesses like because the weld nugget is like this. So, average diameter of the 2 is used to determine the size of the nugget which determines the strength of the weld. Normally greater is the nugget diameter, greater is the strength of the just the spot joint, joint which will be made by this.

The typical cycle which is used in terms of like safe pressure is increased. So, that increased gradually. So, that the plates coming from contact their pressure is held constant and thereafter the pressure is relieved gradually after the welding. And once the pressure means the once the pressure the plates are firm in contact with the electrode the flow of current is started.

So, that there is heat is generated and then once the heat is generated to the fusion will take place and under the pressure confined, under the pressure in confined conditions the solidification will be taking place. So, this is the welding time and this is the time for which pressure remains constant and thereafter it is released.

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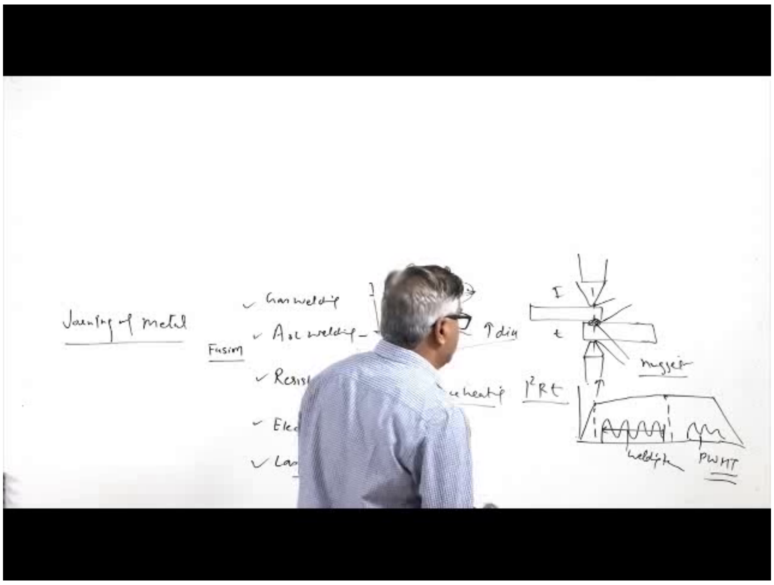

Sometimes the sometimes the pressure is maintained for much longer period and then once the solidification is over again the flow of current is started for one more round for a while so that the post weld heat treatment can be facilitated. But normally the pressure is held constant whenever there is a flow of current.

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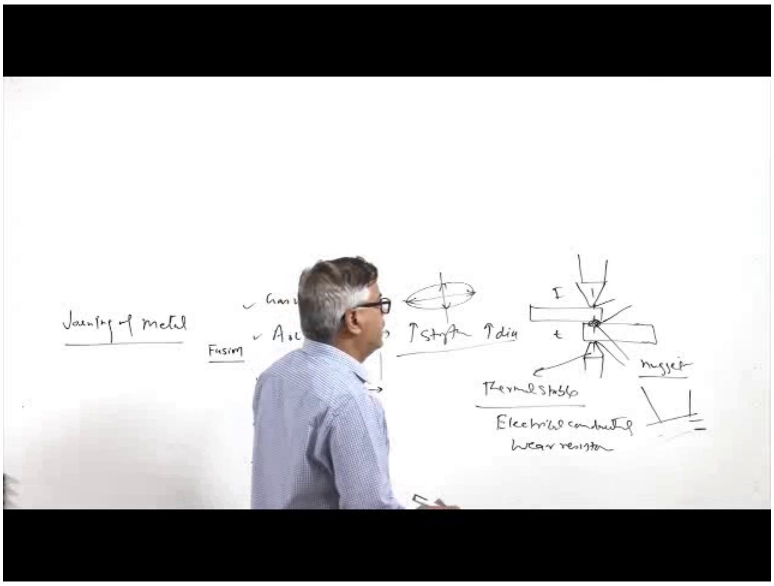

Since the flow of current will be taking place through these copper, through these electrodes so it is important that whatever electrodes are being used they are thermally stable and they are good conductive, they are a good electrical conductivity and they do not wear out. So, there wear resistance is good.

It is important that the diameter of the electrode remains constant because gradual wear will be leading to the increase in diameter which will be leading to the reduction in current density and the reduction in current density will be reducing the nugget diameter. So, gradually the electrodes if wear out they will be adversely affecting the nugget size which in turn will be affecting the joint strength.

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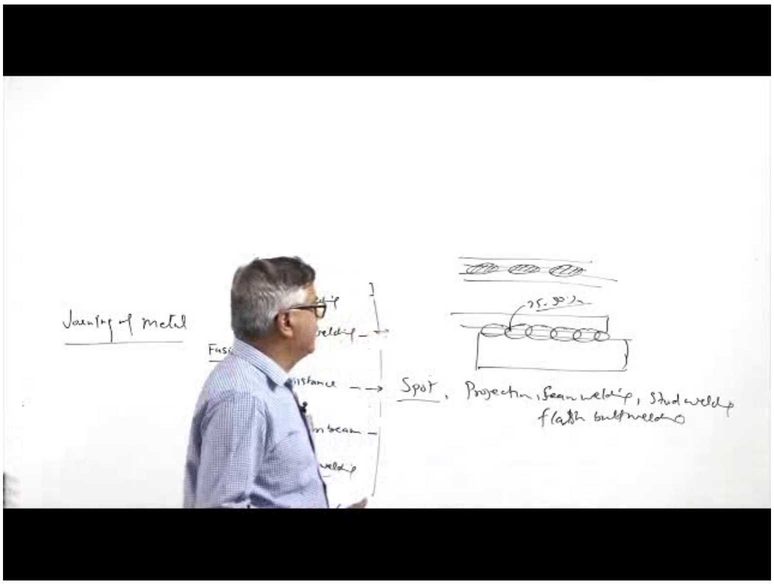

There various types of the resistance welding processes, the commonly these are like; the spot welding is one of them, projection welding, seam welding, stud welding. These are some of the resistance and flash butt, flash butt welding; these are some of the resistance welding processes. In case of the seam welding what we do like these are the plates to be welded together so continuous welds, continuously spots are made like this is 1 plate and this is another plate and so in that case the spots are made can overlapping each other, so this is what is there.

Continuous seam or interrupted seam is also, interrupted spots are also made in the case when somewhat better strength, but not air tightness is needed.

So, in that cases spots are made at some distance or overlap otherwise overlap of 25 to 50 percent can be done if the air tight and the leak tight joints are to be made. If we compare the seam welding and the spot welding what we will see here in case of this spot just 1 spot is made. So, in this case, the current requirement is somewhat lesser as compared to the case when the number of spots is to be made.

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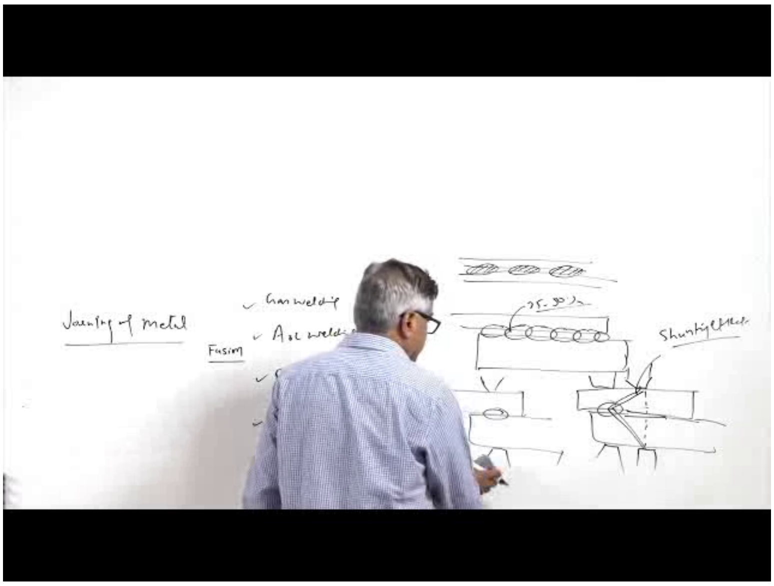

Like say in this case when the number of spots are to be made, 1 spot has been made by having the electrodes positions here thereafter if another spot is to be made, then the shunting of the current will be occurring which means that although electrode positions are these and here at this location there is no metallurgical continuity initially.

So, the flow of current through take place through, flow of current will take place through the already developed nugget to complete the circuit. So, this will be leading to the reduced flow of current through the, through the location where actually the nugget is to be made.

So, this kind of effect is called a shunting effect, shunting effect because of which much higher current requirements will be there when the number of spots is to be made. And that is why when the seam weld is made we will see that the welding requirement, requirement of the welding current increases too high because of increased shunting effect due to the continuous overlapping spots spot development during the welding.

A electron beam welding is the process wherein its much high energy density process, it is much high energy density process where like say greater than 10 to the power 8 watt per centimeter square energy density is observed.

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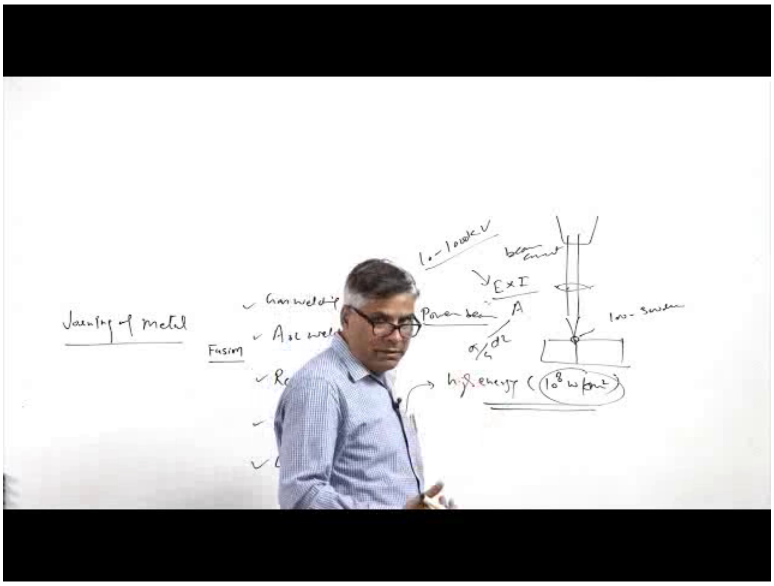

And under these conditions you know in this case there is a source of the beam a; which is directed through the lenses it is converged on to the location where the joint is to be made.

So, say this is the location of the work piece, a high energy density process the beam focused over a very small area like say 100 to 300 micrometer in diameter and in order to obtain the power of the beam, power of the beam in case of the electron beam welding, power of the beam E into I where E is the accelerating voltage which is in range of 10 to like say 1000 volts.

And the I is the beam current, I is the beam current and if the beam is focused over a particular spot area then area is obtained from the pi by 4 d square d is the diameter of the spot where beam is being focused and this results in a much higher energy density so there are various.

Since the beam is of the electrons, electrons when traveling through the air there they collide with the atmospheric molecules and there is speed is very adversely affected they lose their energy in course of the traveling in the atmospheric conditions. So, it is always preferred that the electron beam is performed under the vacuum condition.

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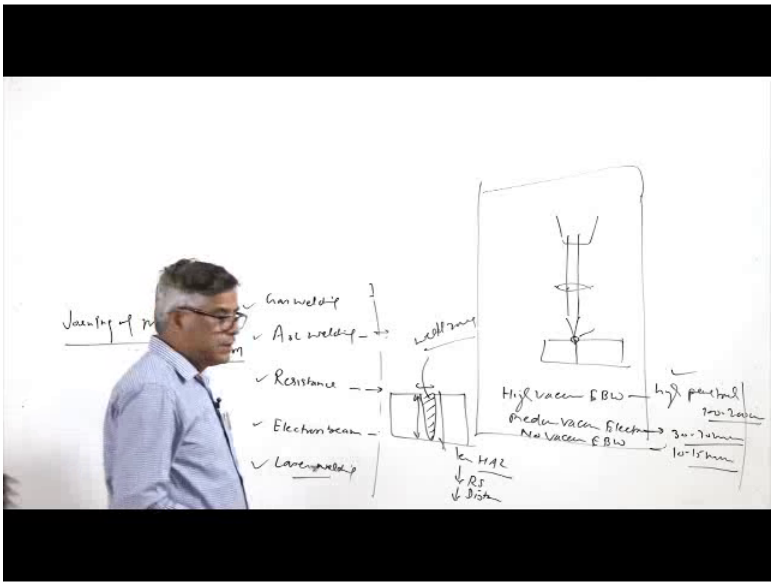

So, entire system of the beam and the work piece travel system is enclosed in the vacuum. So, basically a high vacuum electron beams welding, medium vacuum electron beam welding or the no vacuum electron beam welding. So, it results in the high penetration like 100 to 200 mm in thickness, these results in somewhat lower like 30 to 70 mm depth of the penetration and like 10 to 15 mm thickness of the penetration.

So, when the, when the electron beam welding is carried out in the vacuum; so, absence of the air results in the high-quality weld joints using the low heat input and that in in results in the very good quality weld joints without contamination from the air and limited size of the weld zone, limited size of the heat affected zone and very high depth to width ratio.

So, depth to width ratio is very high width if the weld is very less and depth is very high and these conditions are very favorable for the welding of thick plates. This results in the very less heat input heat affected zone size, very less residual stresses and very limited tendency for the distortion as well as the weld zone size is very very small, weld zone is very small under vacuum results in a very clean and good quality weld.

A, but since the electron beam welding is carried out under the vacuum conditions that's why the job size is limited. The limited job size can be handled using the electron beam welding process. Now I will summarize this presentation. In this presentation, I have talked about the effect of the heat input on the different characteristics of the weld metal at the same time a; I have also talked about the principles which are used for generating the heat input in the different fusion welding processes like gas welding, arc welding, resistance welding and electron beam welding.

Thank you for your attention.