Fundamentals of Manufacturing Processes
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Lecture – 48
Joining of Metals: Fundamentals II

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

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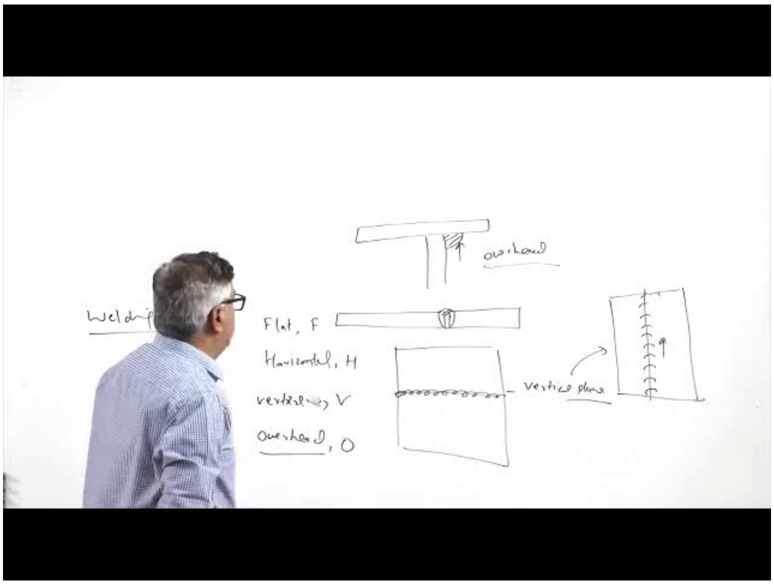

So, basically we will focus on the fundamental aspects related with the metal joining. So, as I said last time the we need to talk about the welding positions, the these are the positions in which the welding is performed. So, the one is called flat represented by letter F and it is the horizontal position the plates are kept horizontally.

And then the joint is made like this. Then there is a horizontal welding represented by letter H, and here the plates are to be joined in vertical plane, and the joint is made horizontally in a vertical plane. So, the plates in vertical plane, but the joint is made horizontally. While in case of the vertical welding, vertical welding represented by letter V, the plates are also in vertical position like the horizontal welding, but the direction of the welding is also in a vertical plane.

So, it is in vertical direction vertically up or down movement both any of the 2 can be used, but the plates in vertical plane and the welding direction is also vertical, so that is vertical welding. And then overhead which is very commonly used which is very difficult position for the welding purpose. So, in this case basically like this is the top plate and another joint is to be made in this way by depositing this filet.

So, this is the kind of overhead position of the welding. This is most difficult and requires very close control over the heat input and manipulation of the molten metal so that it can it can be it can be placed properly at the place where I desired. So, similarly the control of the heat input as well as proper control of the molten weld pool is also needed in case of the horizontal, and the vertical welding because the orient the molten metal will be placed in the vertical planes. So, which will have tendency to fall down.

So, maximum tendency to fall down is observed in case of the overhead welding thereafter in vertical welding and horizontal welding. So, very close control over the heat input molten metal and skill of the operator these factors play an important role in successful welding in vertical as well as horizontal and overhead positions.

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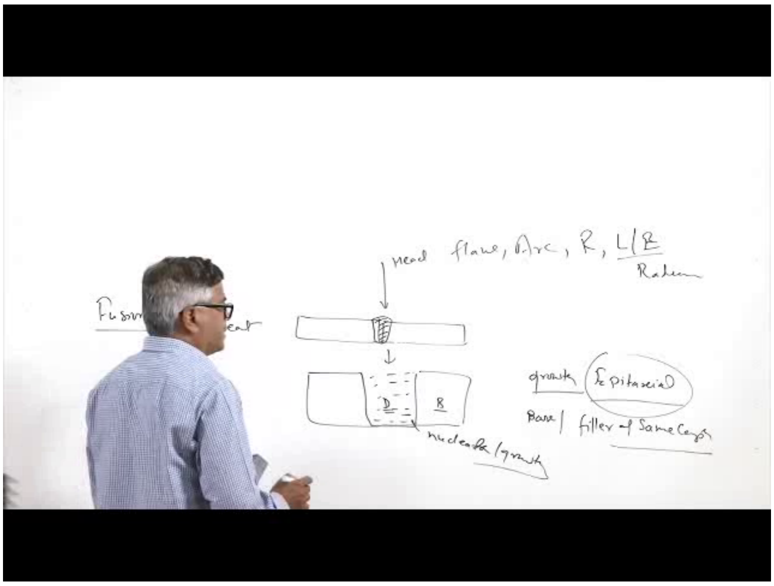

So, if we see like in case of the fusion welding processes, we need to for fusing these surfaces we need to supply heat for heat at the faying surfaces. So, this heat can be used this heat can be fed through the different sources of heat, which may be in form of flame like in gas welding, it may be in form of the arc like in arc welding processes or it may be like resistance in case of electrical resistance heating or resistance welding processes, and then it may be in terms of the laser beam or electron beam in case of the radiation being processes.

The heat is delivered to the faying surfaces of the plates to be welded, and the different melting of the faying surfaces results in the metallic continuity and after the solidification of the weld metal. So, in this situation where just the faying surfaces are brought to the molten state and there after solidification results in metallic continuity, without addition of any filler metal this is this kind of the weld is called auto genius weld.

Normally like the gas welding of the thin plates tig welding plasma welding of the thin section laser and electron beam welding. All these are the processes wherein no filler metal is added. So, in this situation whenever the solidification of the weld metal takes place. The solidification occurs say this is an in this situation where the faying surfaces have been brought to the molten state.

So, it will have basically the number of unmelted grains. And molten metal is also off the molten metal is also of the same composition. So, these partially melted grains act as a nucleorant, and the molten metal due to the due to the loss of heat ha from the weld pool the atoms starts getting deposited over these partially melted grains directly. And so, the growth of the grains is starts, and in this case no nucleation is needed because partially melted grains of the same compositions are already present.

So, in cases where the base metal is just brought to the molten state for is just brought to the molten state, and then solidification occurs just directly by growth approach. So, this is called epitaxial solidification, epitaxial solidification. And gracefully the entire amount of the molten metal is consumed by the growth of these grains during the solidification. So, it does not involve the typical steps of the nucleation and growth.

So, the in all those cases where just the base metal is melted or the even if the filler metal is a filler of the same composition is added, then also the epitaxial solidification is observed. While in other cases where the composition of the filler metal is significantly different there the conventional solidification is observed wherein like say this is the base metal and the weld metal produced by adding the filler metal from outside.

So, this is completely different from the base metal and if it is. So, like the crystal structure is different metal is different so that will be leading to the first nucleation and then nucleation and then growth steps for completing the solidification.

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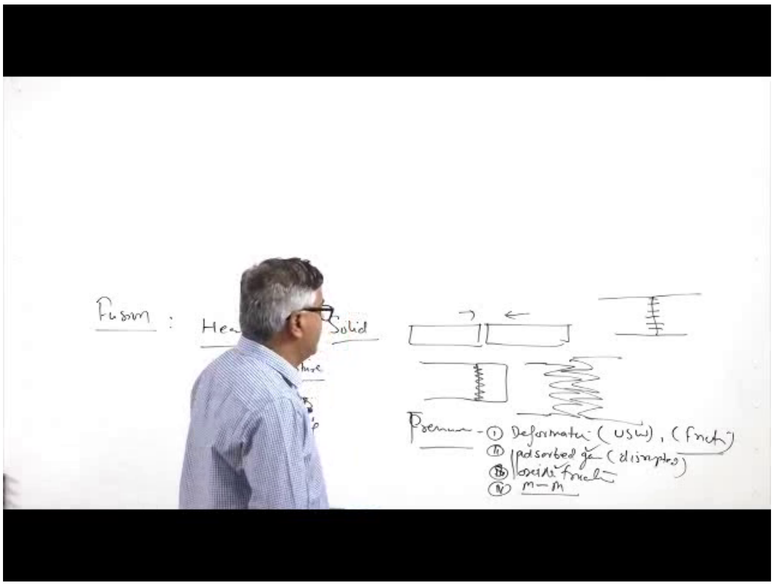

So, this is called the solidification where in the nucleation and grain growth both are involved is in case of the; so, this is what is the role of the heat in the fusion welding in addition to the in addition to the fusing faying surfaces heat also evaporates the moisture if it is present at the surface. So, the moisture is taken off as well as the if oxides are present then these can be broken down and decomposed in course off the heat application of the heat. And then the melting of the faying surface is also facilitated with the application of the heat.

If we consider like the solid state joining processes where in the metal pieces to be joined in the solid state. So, under pressure the 2 are brought very close to each other so that the faying surfaces touch each other very firmly and the metal to metal contact is established through the deformation of the peaks and valleys at the surface.

So, like the peaks and valleys are present on the surface like this. So, peaks and valleys from both the sides will be getting deformed at the inter face and will be leading to the complete metallic intimacy. So, the role of the presser here basically it involves the use of the force or pressure, so that the required deformation whether it is micro level or the macro level deformation can be achieved micro level formation is used in case of the ultrasonic welding processes. While a macro level deformation is used in the case of the friction welding processes.

In addition to that adsorb the gases all gases all the surfaces will have some of the adsorbed gases presented the surfaces. So, adsorbed gases are disrupted basically with the application of the pressure at the surface oxides, now oxides are fractured with the application oxides are fracture due to the micro level deformation which will be occurring at the surface.

So, all these things will be increasing the metal to metal contact between the components to be joined and once if it is there then will have the metallic metallurgical continuity. If the 2 components are kept under pressure for a certain time then the metallurgical bond is established. So, the breaking of the adsorbed disruption of the absorbed of gases and the fracture of the oxide layers present at the surface is mandatory for having the direct metal to metal contact between the components being joined in the solid state.

So, these are this is these were the different kind of the things which are realized with the application of the pressure in this solid state, joining processes like friction welding ultra sonic welding explosion welding and the another solid state welding process is the diffusion one.

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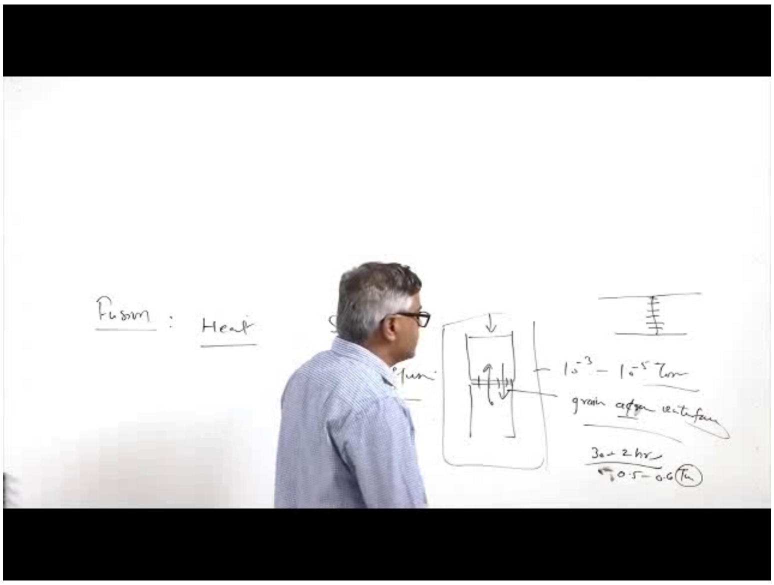

Here the diffusion the 2 surfaces to be joined are kept in some contact metal to metal contact with each other. Under pressure in the vacuum environment normally the vacuum is of 10 to the power minus 3 to 10 to the minus 5 tor and under these conditions direct metal to metal contact existence.

So, the diffusion starts from one side to another due to the concentration gradient of the elements across the interface. And this even forms the grains across the interface grains across the interface so that in turn leads to the mythological continuity. So that heating is important to facilitate the diffusion since the diffusion is a slow process it takes time. So, we need to provide enough time. And so, that diffusion can occur across the interface normally 30 minute to the 2 hours time. It takes to have the kind of the metallurgical continuity across the interface and the temperature can vary to the range of like say 0.5 to 0.6 times of the melting point of the metal in kelvin.

Another important thing is here pressure is normally plays a big role pressure should not be too high, otherwise the macro level deformation at high temperature can occur so that the pressure is normally like say 2 to 10 mpa pressure is normally used in order to have the diffusion bonds. Various approaches have been tried in order to increase the effectiveness of the diffusion bonding process through the pressure pulsation or by putting in the soft material inter layer So, that the diffusion. And then the metallurgical connectivity means the metal to metal contact can be enhanced through the use of the presser pulsation increasing the pressure as well as the use of the a soft metals inter layer. Like the copper nickel or the silvers are silver are the common the metal systems which are used for this purpose.

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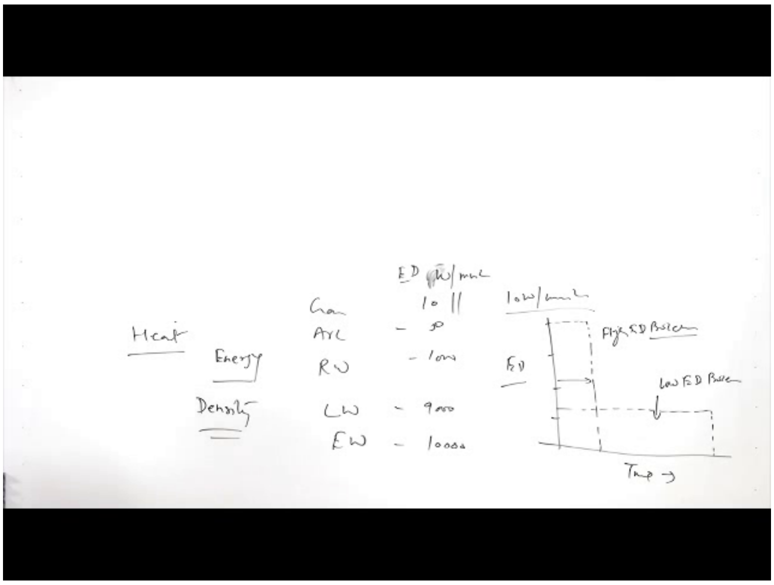

Now, as I said for the fusion welding what we need we need to supply heat. So, there are various heat sources each differ in terms of the energy density which is available with them. And it plays a big role like energy density which is delivered by the different processes like gas welding, arc welding, resistance welding, then laser beam welding and electron beam welding. These processes differ with respect to the significantly in terms of the energy density that they provide.

So, energy density if we measure in terms of the like joules sorry watt per mm square. Then for the gas welding it comes out to be the 10 for arc welding it is 50 for resistance welding it is thousand for laser welding it is 10000 and a 9000 and for electron beam welding it is 10000.

So, for facilitating the fusion minimum 10 watt per mm square energy density is needed. So, what is the role of the energy density in facilitating the fusion and the amount of the heat which is required to melt. For that we need to see if we have here the time on the axis scale and energy density on the y scale.

Then what we will see here is that like say when the energy density is low it is required to supply the energy or the heat for a longer time as compared to the case when the energy density is high related with the process. So, so for short time we need to supply the energy. So, this is for high energy density process like laser beam or electron beam and this is like say the low energy density process, like arc welding or the gas welding.

From the fundamentals of the heat transfer we know that if the heat is delivered for longer period then lot of heat will be transferred to the underlying base metal and in that case it will require larger amount of the heat as compared to the case when the heat is delivered for shorter period in order to ensure the melting.

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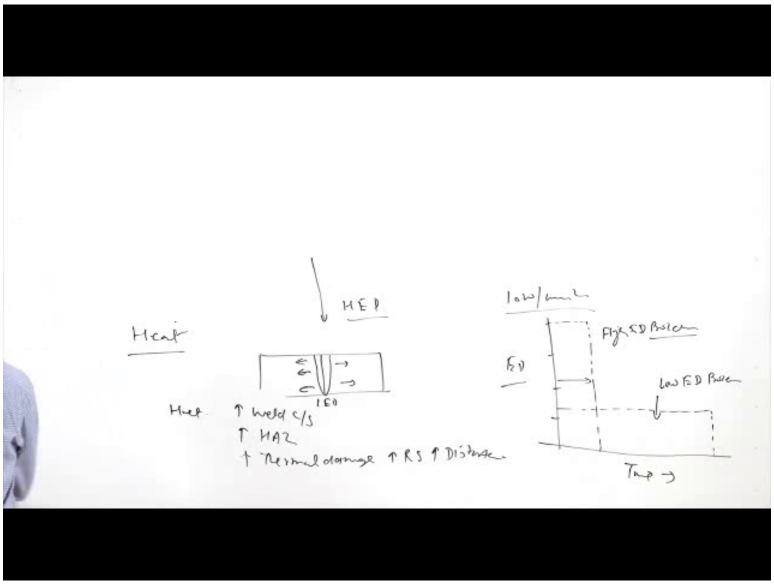

So, now if we see here like the these are the plates to be welded. If the energy density is high then to ensure the melting very shorted to ensure the melting energy is to be delivered or heat is to be delivered for a shorter period of time.

So, in that case the dissipation of the heat to the base metal will be less as compared to the case when the same kind of a combination subjected to the lower subjected to the delivery of heat using the low energy density process. Say this is a high energy density process and the low energy density process. So, well it requires a lot of heat to be delivered to the base metal, because it takes longer times. So, lot of heat will be dissipated to the base metal.

So, if we compare the net heat input for the amount of heat that is required to be delivered to the base metal for low, energy density process is much more as compared to the case when the high energy density process which is used. So, H net if we see the net heat which is required for ensuring for facilitating the melting in the 2 cases, H net will be more for the low energy density process as compared to the case when the high energy density process is used.

So, the time for which energy is delivered or heat is delivered to the base metal metals a lot in terms of the amount of heat that is required to be delivered because lot of heat is dissipated to the base metal, and that will be causing the number of effects which may be in terms of. So, increasing the H net simply increases the weld cross sectional area it will increase the heat affected zone size will increase the thermal damage to the work piece in terms of the like increasing the residual stresses increasing the distortion tendencies.

So, all these problems will be will be more. So, it is always good that the joint is made using the as less heat as possible for facilitating fusion. And for this purpose high energy density processes offer the much better results in terms of the thermal damage to the work piece which will be taking place and due to the application of the heat.

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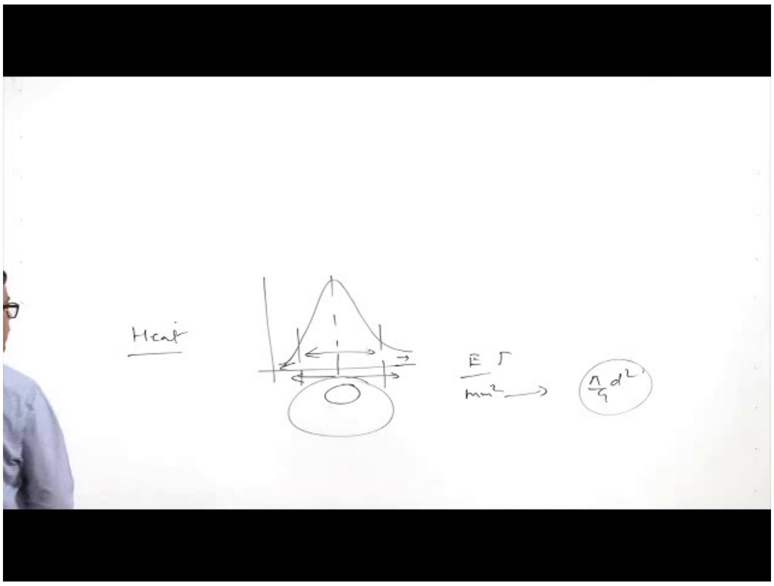

So, if we see here the energy density actually in energy density varies with the varies as we move away from the center like say this is the center of the heat source. So, the energy density increases and then it decreases as we reach away. So, on moving away from the center of the heat source energy density decreases rapidly.

So, these are the locations if we see at the center of the arc we have much higher energy density as compared the case when the outer region of the heat source. So, this is what we can directly calculate like the energy being delivered maybe in terms of the joule, and the area over which it is being delivered if we consider this area or this larger area in both the cases the energy density will be different.

So, energy density in joule divided by the area that is what we can calculate in mm square. So, we will be getting like area pi by 4 d square as for the location of the interest d we can select. So, this is what will be telling us the energy density will be maximum. At the center and it will keep on decreasing on approaching from the center to wards the surface of the heat source, like it may be a flame or it may be arc.

Then coming to some fundamental aspects like people have identified the amount of heat required for melting can be given by like relationship.

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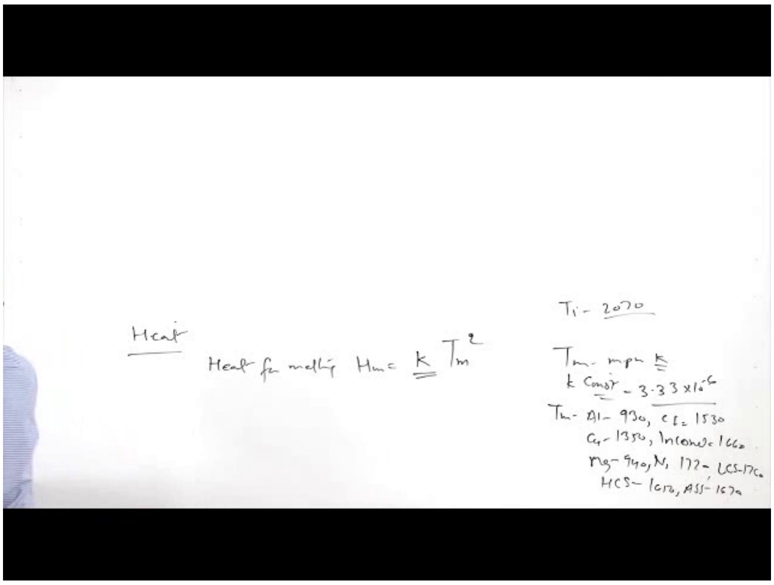

Heat for the melting purpose can be obtained through the simple relation, like k multiplied by T m square. So, T m is the melting point in kelvin, and the k is constant and whose values the value of the k is given as like 3.33; 10 to the power minus 6.

For while the value of the value of the T m the melting point for aluminum like say in the kelvin scale is considered 930. For cast iron it is 1530. For copper it is 1350. For inconel one of the very commonly used commercial metal it is 1660. For mg it is low 940, and for nickel it is 1720. For low carbon steel low carbon steel 1760. For high carbon steel it is low comparatively low. So, it is 1650. And austenitic stainless steel say 1670.

So, these are the and lastly one for the titanium which is much higher like 20 70. So, multiplication of the T m; these are the T m values the temperature multi point temperature in kelvin scale for the different metal systems. And by multiplying this we can identify the amount of heat that will be required for the melting purpose.

So, actually the amount of heat required for the melting purpose can be calculated using this, but we know that whenever we use any process like whether it is arc any other process.

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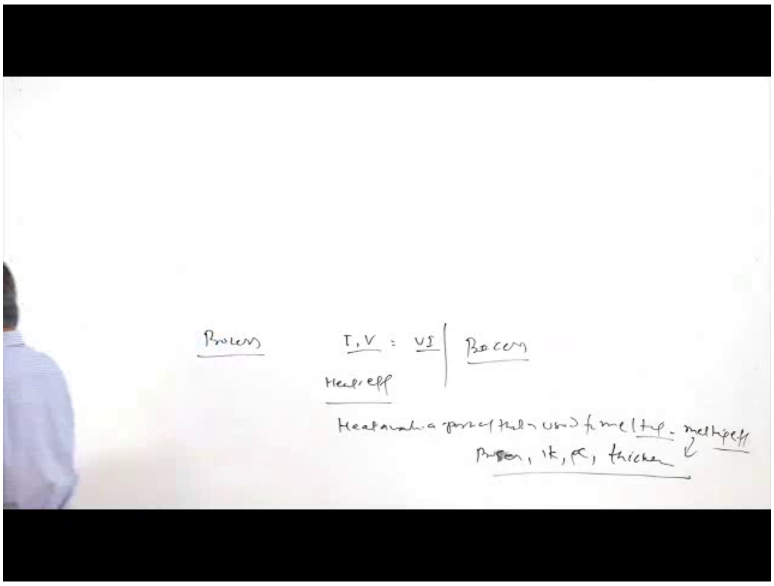

So, we deliver some amount of the energy like say some current and some voltage, but whatever energy is generated can be obtained say from VI, but the same amount of energy is not converted into the heat.

So, and the part of the heat which is converted energy the part of the energy which is converted into the heat is termed as the heat efficiency. And whatever is the amount of heat is available heat available only a part of that is part of that is used for the melting.

So, amount of heat available and what portion of heat is being used for the melting purpose that gives us the melting efficiency. So, depending upon the process the heat efficiency is influenced while the melting efficiency determines depends on the process as well as the thermal conductivity, and the volumetric specific heat rho c, and like a thickness of the metal.

So, all these factors they which will be affecting the melting efficiency, means the proportion of the heat which is actually being used for the melting purpose so that the joint can be obtained while out of the given amount of the energy, what proportion of the energy is being converted into the heat that gives us the heat efficiency or thermal efficiency of the process.

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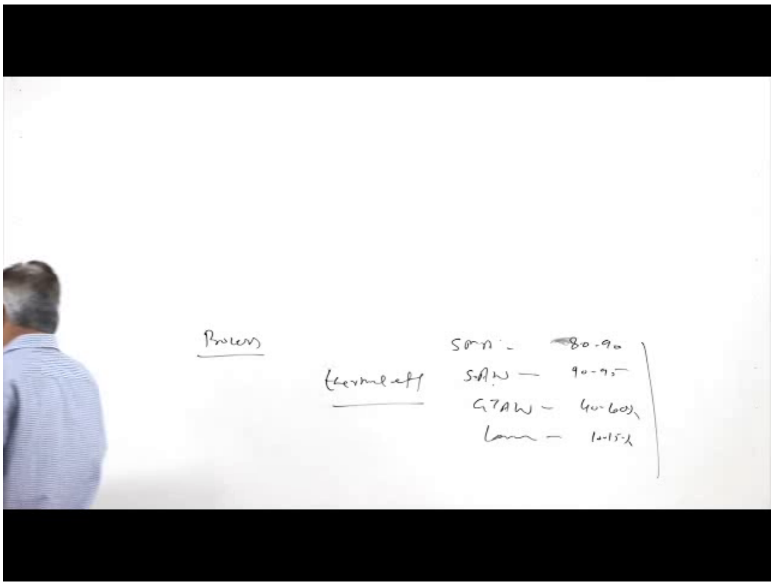

So, normally So, if both are clubbed like we call it as a thermal efficiency of the welding process, which is normally like say for the different process it is different like for the simple arc shielded metal arc welding process this may be like 80 to 90 percent.

But for submerged arc welding process this is 90 to 95 percent. For the gas tungsten arc welding process it is very low 40 to 60 percent. For the laser beam; it is further low like 10 to 15 percent. So, depending upon the processes the different thermal efficiencies are observed wherein we deliver some amount of the energy during the welding, but only part of that is used for the welding purpose melting purpose.

So, remaining portion of the energy is wasted in different ways. Like say if you have to calculate the amount of the heat and the rate at which the weld is being made heat delivered during the welding is equal to the energy used for melting, multiplied by energy used for melting of unit volume multiplied by volume of the weld which is being made.

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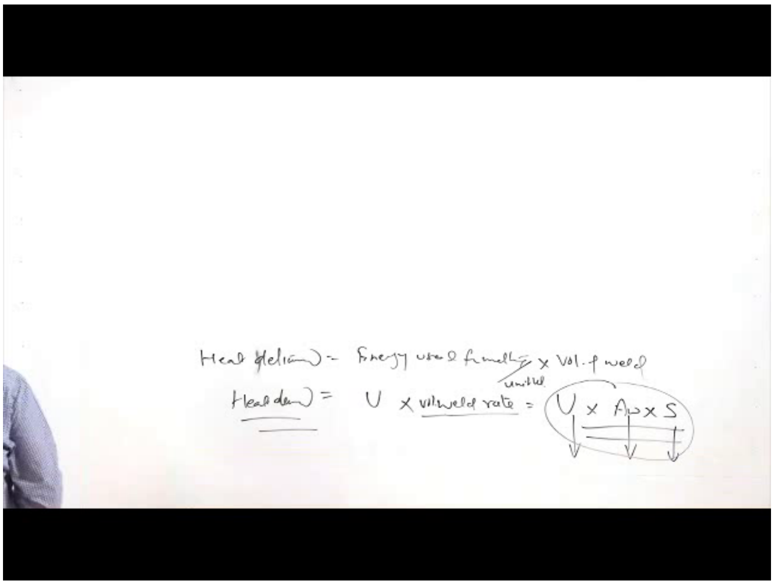

So, if we calculate this the energy is the energy u is the energy required for unit volume multiplied by the rate at which the weld is being made weld rate. The rate at which the weld being weld is being made. And so, it is volume of the weld the rate at which it is being made and for that u is the heat required for unit volume multiplied by A; Aw is the cross sectional area of the weld multiplied by the speed of the welding, like say S.

So, the speed of the welding cross sectional area of the weld and amount of the heat required for melting the unit volume of the metal. This will be giving us how the heat delivered is being utilized. So, if we are aware of the heat being delivered for the melting purpose during the welding, then the unit volume of the heat required for melting and the heat required for melting the unit volume of the metal cross sectional area of the weld and the welding speed, this can be used.

So, anyone if is not known can we determine like the heat required for melting the unit volume of the material is a kind of property which can be obtained from the welding speed will be knowing the rate speed at which the welding is being done. And so, from the setting of the welding current welding parameters we can obtain the amount of heat which is being delivered as far as from the thermal efficiency over the weld.

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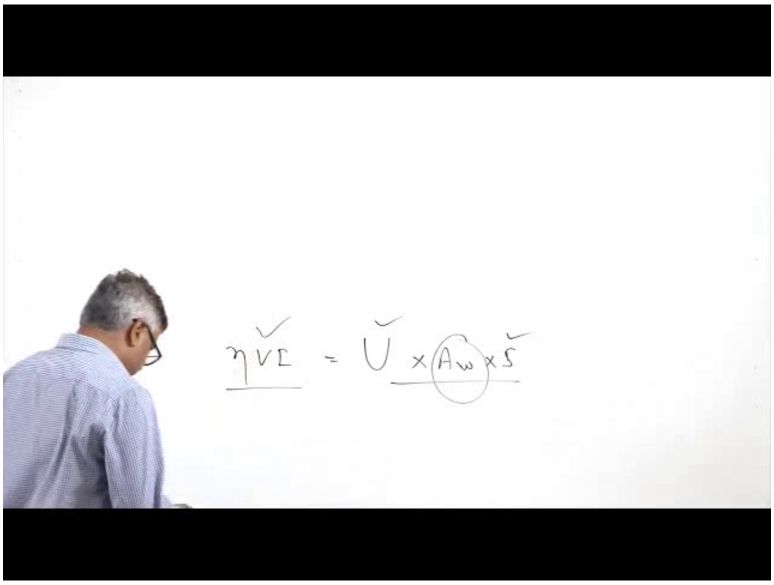

So, like say eta multiplied by say for the arc welding process this will be giving us the amount of heat which is being delivered then the unit amount of amount of heat required for melting the unit volume of metal multiplied by weld cross section area multiplied by the welding speed. So, if we know this if you know this if you know welding speed we can determine the weld cross sectional area.

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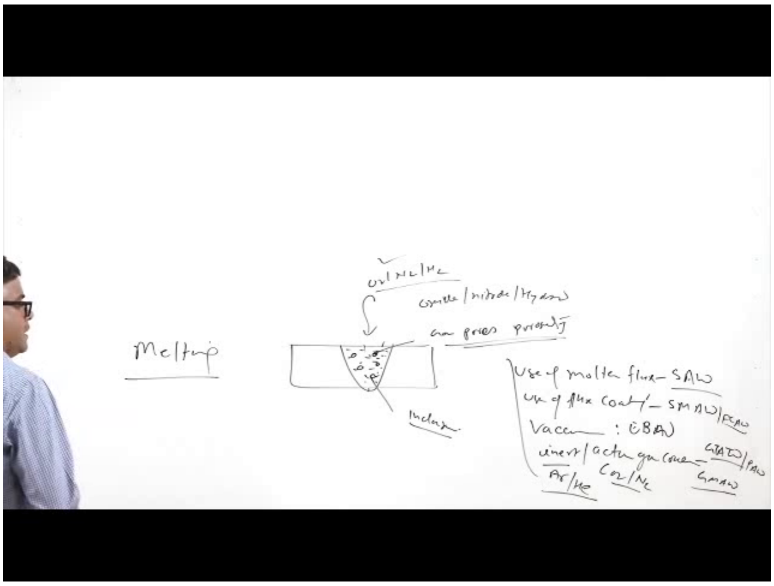

Now we know that whenever the metal is melted during the welding melting of the metal increases the temperature as well as brings the part of the metal in the molten state. So, this molten metal when it comes in contact with the atmospheric gases when it comes in contact with the atmospheric gases like oxygen nitrogen hydrogen etcetera. So, this interacts and forms their oxides, nitrides and hydrides.

So, if these are having the density same as that of molten metal then they will get uniformly distributed. And after the solidification these will represent as inclusions. And if this is the case when the these guesses have interacted or reacted with the molten metal. In the case when these do not interact then these will represent as a gas pores which is called a porosity.

So, if they interact they will be leading to the inclusions and if they do not interact then they will be present as inclusions. So, it is important that we take care of the atmospheric gases properly during the fusion welding. And for that purpose the various approaches are used these approaches are like use of the use of the molten flux, use of flux coatings, use of vacuum and use of the inert or active gas cover or blanket around the arc.

So, these are the approaches which are used. Use of the molten flux is used in the submerged arc welding process. Flux coating is used in case of shielded metal arc welding process, as well as in the flux (Refer Time: 30:09) will flux cored arc welding process, and then vacuum is used in electron beam welding process, electron beam welding process and the use of cover of the inert or inactive gas is used in case of the gas tungsten arc welding. Like inert gases and gas metal arc welding paw plasma arc welding also uses the inert gases.

Then gas metal arc welding uses both inert gases or active gases. Like maybe Co2 or nitrogen can be used or here inert gases like argon and helium are normally used. For high quality weld helium is preferred well for commercial quality weld joints at the nor argon is normally used because organ is cheaper, and cost effective as compare to the helium also the availability of the helium. Becomes an issue because it is not that easily available and the cost difference is huge like maybe 4 to 5 times cost difference in the cost of the argon and helium.

So, for most of the commercial purposes like the welding of the pressure vessels and where is newly good quality welds are required helium is used as in shielding gas. Oh sorry; argon is used as a shielding gas while helium is preferred for the for very high quality weld joints because it is very costly and very high flow rates are needed when the helium is used.

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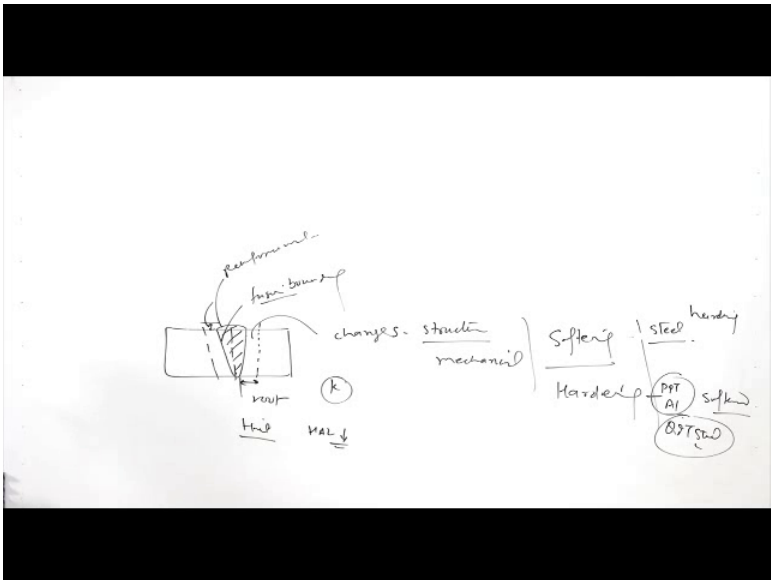

Now, apart from this application of heat for the melting purpose are results in the first is the fusion of the faying surfaces. So, this melt molten metal is created. Then adjoined near the base fusion boundary like say this is the fusion boundary. This is the route. This is the reinforcement. This is the reinforcement.

And So, fusion boundary and the region near the fusion boundary is heated to the high temperature it does not remain at room temperature and this happens, because of the thermal conductivity ability of the metal to transfer the heat away from the fusion boundary. So that this rise in temperature actually changes the this.

So, then the region near the fusion boundary experiences the changes in terms of the microstructure of the metal and the mechanical properties. There is no particular pattern in which the structure and the mechanical properties will be affected sometimes, it causes the softening of the metal another or it may also leads to the hardening.

So, depending upon the kind of metal systems which are being welded they may get hardened or they may get softened. For example, most of the steels in normal condition like annealed normalized conditions they get hardened, while the precipitation hardened aluminum alloys as well as quenched and tempered steels, quenched and tempered steels both get softened.

So, depending upon the kind of process and metal system the hardening and the softening can occur in the heat affected zone. So, it is irrespective of the weld metal quality the there is always the heat affected zone formation. And this the size of the heat affected zone may vary depending upon the kind of the heat input which is being delivered, and the conductivity of the metal thickness of the C2 etcetera.

So, it is always efforts are always made that haz size as less as possible so that these changes being experienced by the base metal near the fusion boundary are as less as possible. Now coming to the arc welding processes that this is one of the major category in the welding processes and which are extensively used like among the all metal weld metal deposited, and the shielded metal arc welding accounts for about 70 to 80 percent of the weld metal volume.

So, that is of the great commercial importance. Apart from that submerged have arc welding shielding metal arc submerged arc welding and the electro slag welding is also used for the welding purpose. So, coming to the some technical aspects related to the welding.

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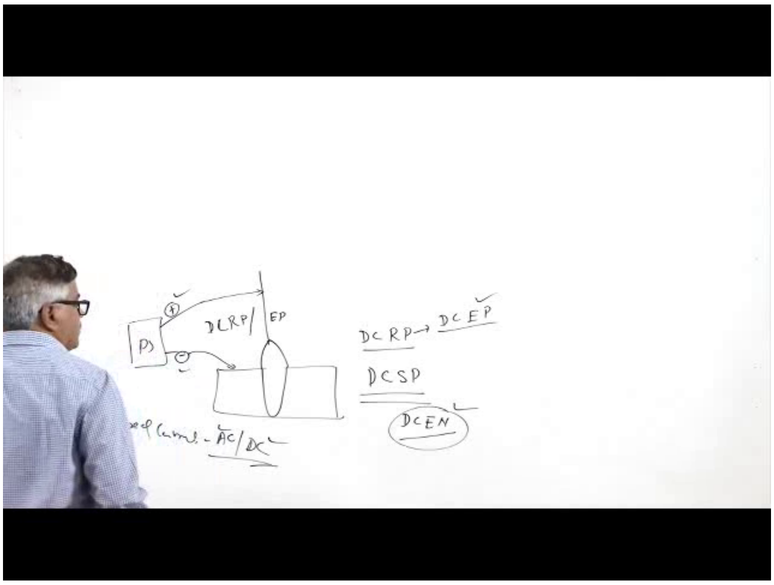

The welding processes like there is one electrode, there is one work piece like this. And there is one power source which may be connected to the electrode.

So, power source will have positive terminal and a negative terminal. So, depending upon the kind of polarity or the kind of type current type of current it may use AC or DC. So, when AC is used the polarity will keep on changing after every half cycle. So, accordingly the polarity of the welding arc will be changing.

Well in case of the DC will have the freedom of choosing whether the electrode will be connected to the positive terminal or it will be connected to the negative terminal. When electrode is connected to the positive terminal and work piece is connected to the negative terminal it is termed as a DC reverse polarity, and otherwise when the electrode is connected to the negative terminal and work piece is connected to the positive terminal it is termed as DC is straight polarity. Or this is also called as DC EN and this is done as DC EB. DC electrode positive or electrode negative or a straight polarity or negative polarity.

So, this is the case of the DC RP reverse polarity or electrode positive. So, what is the importance of the DC E and or DC RP. We know that whenever there is welding arc the more welding arc the more heat is generated on the positive side and the less heat is generated emitted on the negative sides.

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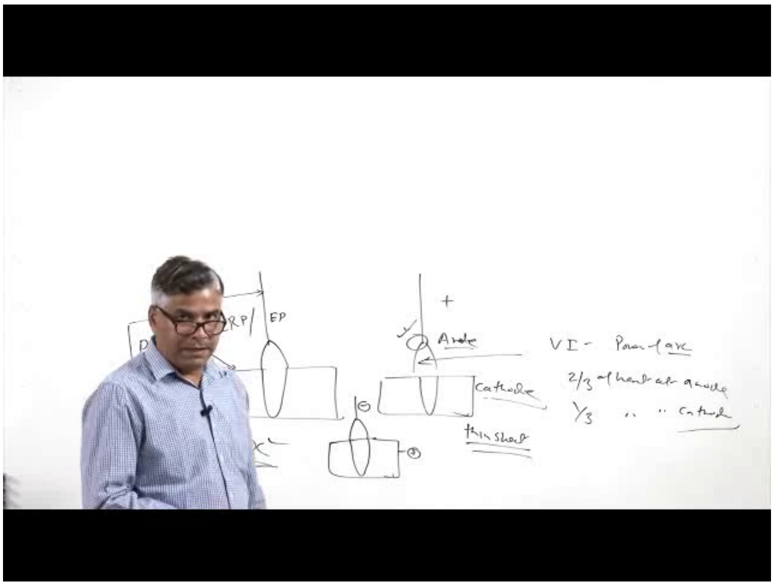

So, means the electrode if it is connected to the positive, then it will return as anode and another one work piece will be termed as cathode. So, in this configuration whenever there is welding arc the more amount of heat. Like say the heat is generated by the arc can be given by VI this is also termed as power of arc. So, whatever heat is generated by the welding arc 2 third of the heat is generated heat at the anode side while one third of the heat generated by the arc at the cathode side.

So, in this scenario more melting of the electrode will be occurring as compared to that of the base melt base metal. So, this will be leading to the well melting of the electrode at much faster rate than the base metal, but when we are. So, this may be good when the thin sheets or thin plates are being welded, but when we are working with the thicker plates.

So, for welding of the thick plates normally we prefer to go for the electrode negative and work piece positive so that more heat is generated in the work piece side in order to ensure the penetration through the thickness of the plates, so that the required weld can be obtained. So, electrode DC EN is preferred when the high conductivity of the metal greater thickness of the plates are being welded.

So, the more amount of the heat being generated in the electrode side can facilitate the melting of the base plates. So now, I will summarize this presentation. In this presentation I have talked about some of the basic aspects related with the welding positions, and the role of the heat input in development of the sound joints. And how does the power density affects the amount of heat required for the welding purpose.

At the same time I have also talked about how does the energy density varies in the heat source, which is maximum at the center and then it will keeps on decreasing away from the center with the. So, as we approach from the center through the surface of the heat source it will keep on decreasing. We have also talked about the how the heat input being delivered or heat being delivered during the welding can be used for calculation of the weld metal deposition rate or how can we calculate the cross sectional area of the weld, if we are aware of the heat being delivered and the welding speed.

Thank you for your attention.