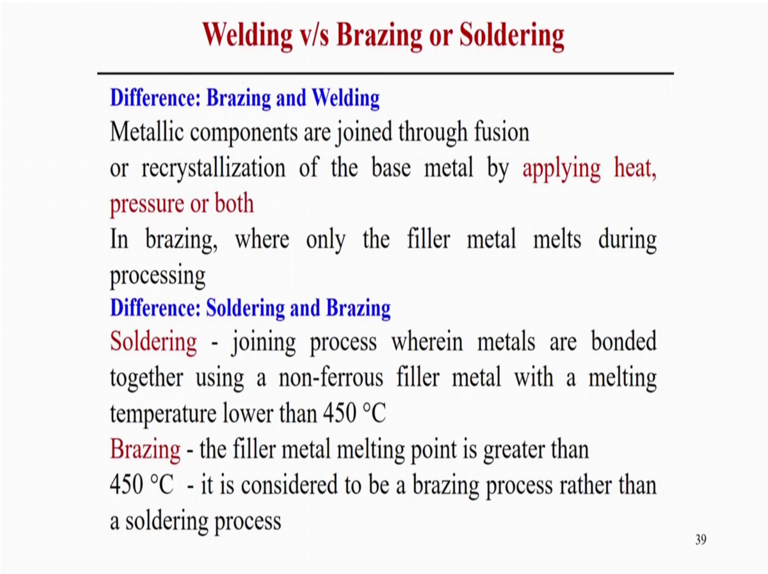
Advances in Welding and Joining Technologies
Dr. Swarup Bag
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture - 03
Fundamentals of Welding and Joining Part III

So, far we have discussed about the different fusion welding processes. And we have tried to get some idea the what are the basic mechanism in fusion welding process and how it can be characterised, but in other way that how the brazing and soldering as is also one kind of the joining process like fusion welding; but how brazing and soldering can be differentiated from the welding processes.

(Refer Slide Time: 00:49)



So, basic difference between brazing and welding process is that in the in welding process metallic components are basically necessary to made melt and then they fuse together apart the solidification, but here also in brazing or soldering here also, we generally apply the heat and melt the filler material, but not necessary to melt the base material.

So, in that sense it is different from the welding process; also apart from the fusion welding process that there is some solid state welding processing, solid state welding process the violence’s of the atoms generally happen in this case through the recrystallization of the base metal. And of course, in this case the applied heat is also necessary, but at the same type or maybe in certain case the pressure application of the pressure are also necessary or application of a both pressure, as well as the heat that actually the general physical mechanism of the welding process.

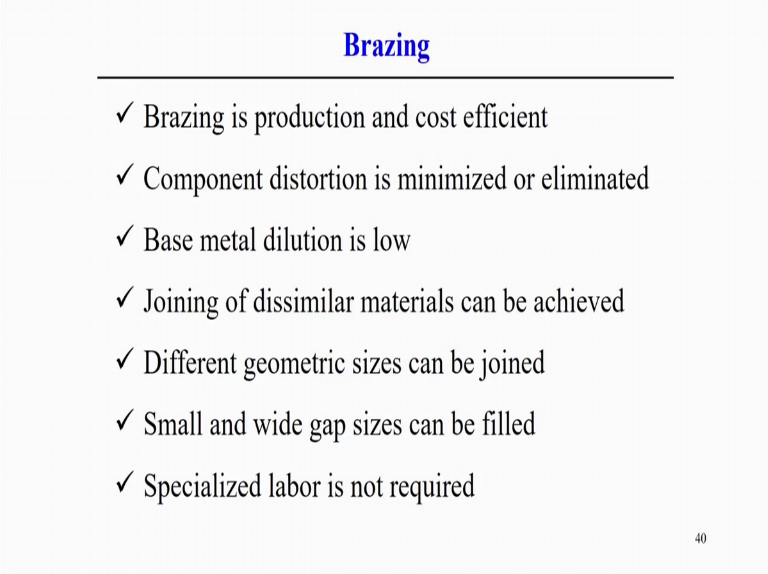
Now, in brazing and soldering of course, it is also one kind of joining processes, but how we can differentiate between the brazing and soldering process? So, soldering that is the typical joining process basically where the metals are bonded together using a typically nonferrous filler material. And we can differentiate between brazing and soldering in terms of the maximum amount of the temperature here.

So, in this case the soldering is the temperature should below than 450 degree centigrade, but at the same time the mechanism also brazing at the same; may be the filler material are different. Since the heat can be operated above the 450 degree centigrade. So, in sense that in soldering and brazing; we use the filler material having the different melting point temperature; in one case it is below 450 degree centigrade, in other case the above 450 degree centigrade.

So, that is the boundary in terms of the temperature that differentiate between the soldering brazing. Of course, when the difference; when the temperature differentiate between the soldering brazing in the sense the applied filler material should be different in this cases.

Now, we will try to get some basic idea about the soldering and brazing process; we can start with we can start with the first brazing process. So, what is the brazing process?

(Refer Slide Time: 03:43)



Brazing is production and cost effective process and in this case because in this case the two dissimilar or similar kind of materials can be joined without much affected by heat to the base material.

So, in that sense with respect to the fusion welding process; the brazing processes most more cost effective. There may not be any component distortion or component distortion is minimised or can be eliminated. Because the filler metal is only melted and after they solidify subsequently, but it does not melt the base material; so, because of that the distortion level in this process is relatively less as compared to the fusion welding process.

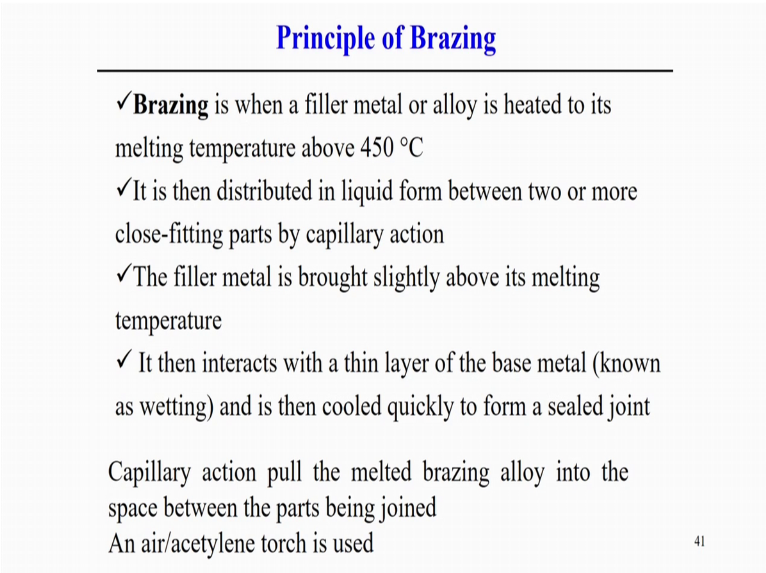
So, other significant point of the brazing has the base metal dilution is low because base metal is basically affected by the heat, but there is no change of the phase from liquid to solid. So, that is why the dilution level is low in this in this process and definitely several dissimilar combinations of materials can be achieved using the brazing process that is the one typical advantages of this process.

Of course in these cases, the joint strain may not be as efficient as fusion welding process, where two dissimilar materials can be joined by using any other fusion welding processes. Different geometric sizes can be joined; so, that join simply using the gap between the materials using the filler material or that is we can say that braze metals; braze filler metals is basically required to fill that gap between the two materials. And then after filling with the liquid metal the two solid metals can be joined that is the basic principle of the brazing process.

So, small and wide gap sizes can be filled. So, in some certain cases the gaps the gaps varies from very small to the very high gap between the two workpiece materials that can be filled by the brazing processes that; that means, using some filler materials. And of course, in this case there is no; there is no requirement of the any specialized level until because the brazing process can be done or can be converted to some kind of automated process.

So, with this typical advantage of brazing process we can look into the further of the brazing process. First we will try to discuss the what are the principle of the brazing process.

(Refer Slide Time: 06:39)



So, we already know that brazing is the process when a filler material or alloy is heated to its melting temperature and that temperature level is should be above the 450 degree centigrade

Then what happens? Then the liquid metal distributed between the two or more close fitting or if there is a any gap or there is a very well gap between these two metals, but actually the between the two close fitting materials; the liquid metal actually stick with the solid metals by simply capillary action of; filling by the capillary action.

So, this filler material is brought not too much of high too much of superheated temperature of this material; rather very low degree of temperature increment with respect to the melting point of this filler material. So, heat then interacts with the thin layer of the base metal. So, basically that total heat content of the liquid base metal when we try to interact with the solid metal, it affects up to the very small thickness of the material.

And because the difference of the melting point, the base and the base material are huge. So, in that sense it is only effective on the very thin layer of the metal and that field or acting between the base metal, it simply the principle of the waiting of the waiting of the solid material at certain temperature.

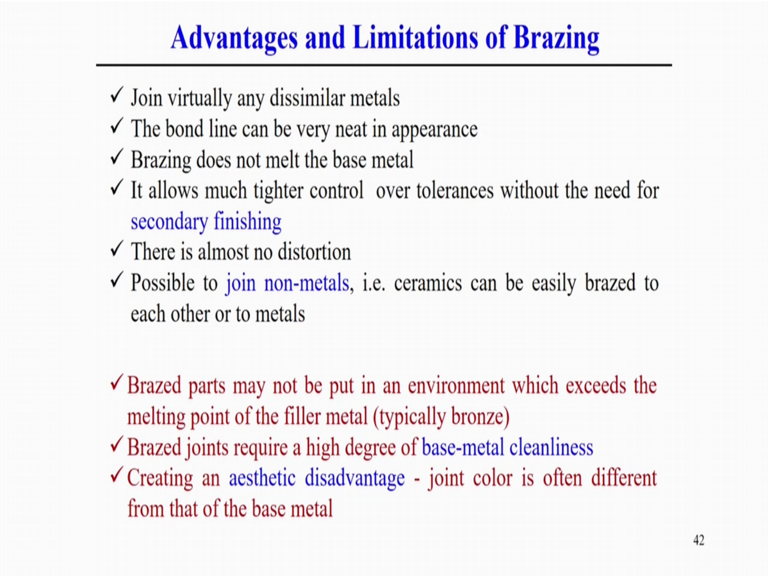
So, then after that that when it is just exactly fill the gap between the two solid metals and after sometimes, it becomes solidify or cool down to the cool down to the ambient temperature. And that finally, creates the joint between the two base metals of course, it is the intuition is that in this case specifically, the liquid metal simply waiting the solid metal so, we cannot expect the very high strength of this weld joint like any other fusion welding processes or any other solid state welding processes.

So, definitely the main principle is that capillary action of the liquid metal of the the liquid metal means basically that is the braze alloy that actually fill into the gap between the parts to be joined. So, in that principle the brazing process actually works. So, sometimes, but in this case to melt the braze alloy or filler material; its necessary to put some there may be the different kind of source of the heat, normally brazing we can in general we can use the an air or acetylene torch simply by locally heating that alloy so, that the temperature can be reached above 450 degree centigrade.

But another significant point is that; above 450 degree centigrade, but the maximum temperature may not be the much higher than that of the 460 degree centigrade. So, little bit higher the melting point temperature that is followed in case of the brazing process. So, because in that actually makes the waiting action are between these two base metal at the same time not much affected by the amount of the heat to the base metal. So, to avoid much much affected by this amount of the heat to the base metal that is why the melting point that is why the increment of the temperature is just below above melting point temperature of the brazed alloy.

So, in general if we try to look into the; what are the typical advantages and the disadvantage of the brazing process? So, first we look into the; what are the advantages of this process.

(Refer Slide Time: 10:55)



So, first thing is that basically it join; the any kind of dissimilar materials or dissimilar metals in that sense the bond line between these two dissimilar metals is very very neat in appearance. The main thing is that the brazing process in brazing process, it does not melt the base metal. So, therefore, it allows to much tighter control over the tolerance limit without the need of the secondary finishing; that is the one advantage. So, in case of brazing process may not be require any secondary finishing operation and that sometimes is needed in other welding processes.

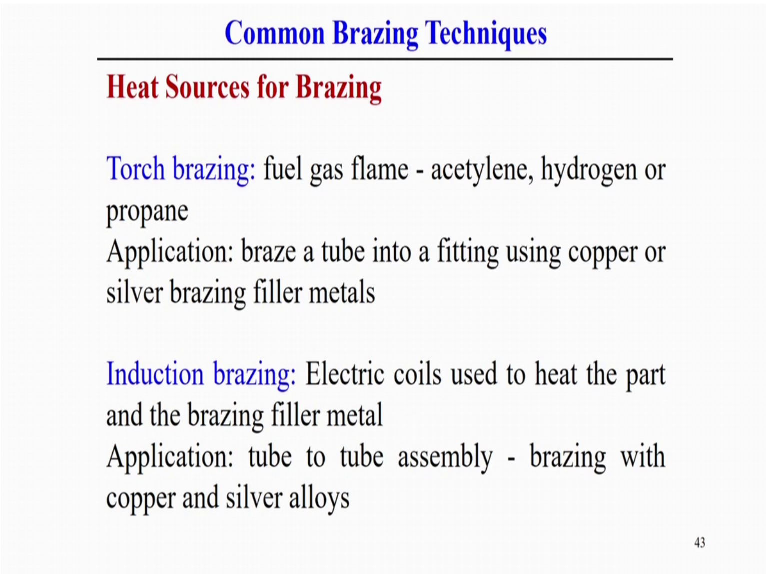
So, of course, there is no distortion almost no distortion in this process and of in the brazing process is also applicable to join the non non-metals also. So, ceramics for example, ceramics can be easily join by the brazing process to each other to each other or ceramics can be joined with the other metals simply the brazing process. So, this is the positive side or advantages of the typical advantages of the brazing process brazing process, but if you look into that; there are also some limitation of this process.

So, definitely the bridge joint cannot be used in a in a certain temperature environment, where it exceeds the melting point of the filler material. Then it will lose the strength of the joint so; that means, the limitation of the this process is that it should be applicable or the join can be used below the melting point temperature of the filler material. Of course, the base joint requires a high degree of base metal cleanliness; because if the surface are very clean then the waiting action will be good. So, in that sense that surface should be very clean to get the successful braze welded or braze joint components.

Now, sometimes another disadvantage or difficulty submitters of this process that aesthetic appearance of the weld joints. Sometimes the joint caller is basically different from the base metal and that brings the some aesthetic disadvantage of this kind of joints. So, apart from that still brazing is one of the root solution of the joining of the dissimilar materials and of course, if we try to compromise or if we do not compare the strength of this joint with respect to the fusion welding process.

Now, of when we try to melt the filler material or braze alloy in there is a requirement of the heat source. So, what are the typical heat sources practically use for the brazing purposes?

(Refer Slide Time: 14:05)



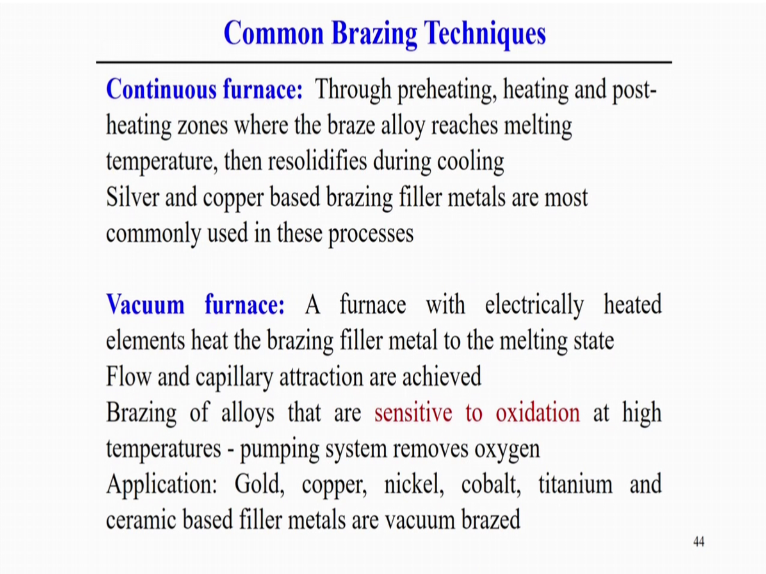
So based on that, we can define the different brazing techniques one is one is that torch brazing. So, in this case the fuel gas flame is basically used like acetylene hydrogen or propane they are used to heat the alloy material; braze alloy.

So, what are the typical applications? So, when there is a tube can be try to use a fitting into the other components using the copper or silver brazing filler metals, we can find out this we can generally use the user torch as a oxy-fuel torch basically; the fuel torch in this case as a source of the heat. And that you can easily control locally control the to a specified zone simply the focusing the torch in that specific position.

Induction brazing is another kind of techniques induction brazing where the induction means we generally use the electric coils to heat the part and as well as the brazing the filler material. So, in this case when there is a assembly between the tube to tube assembly brazing can be done with the copper and silver alloy between this these two tubes to join the tubes.

So, induction heating then here the electric coils is used; in this case probably it is more controlled way we can produce the amount of the heat or you can control the temperature of the filler material as compared to the simply torch brazing process.

(Refer Slide Time: 15:51)



So, other brazing process is the user continuous furnace. So, there is the sequence of the torch free heating sorry through preheating the sequence of the sample to get, to assemble the different components through the brazing techniques in this case sometimes continuous furnace are used.

So, here the terms basically used in the preheating of the material; then heating and after that post heating zones. So, that can be controlled using the continuous furnace and the with the sequential way. And of course, definitely the braze alloy in this case also reach the melting point temperature and then solidified during the welding process.

So, in this case silver and copper based brazing filler metals. So, silver and copper based alloy basically used for most of this assembly by this brazing techniques. Other type of brazing technique is basically vacuum furnace; we use the vacuum furnace also for the brazing process. So, in this case a furnace with the electrically heated elements which is basically part of the furnace and it generally occurs under the vacuum.

So, what happens in this case also of course, in this case the flow and the flow ability of the liquid braze alloy and capillary attraction are also achieved in even in if it when you try to do even the vacuum furnaces. The brazing alloy; so, why sometimes the vacuum furnace definitely the this process is the costly as compared to the other brazing techniques, but if there is a requirement of the or there is a application of the certain materials which is having very much sensitive to the oxidation.

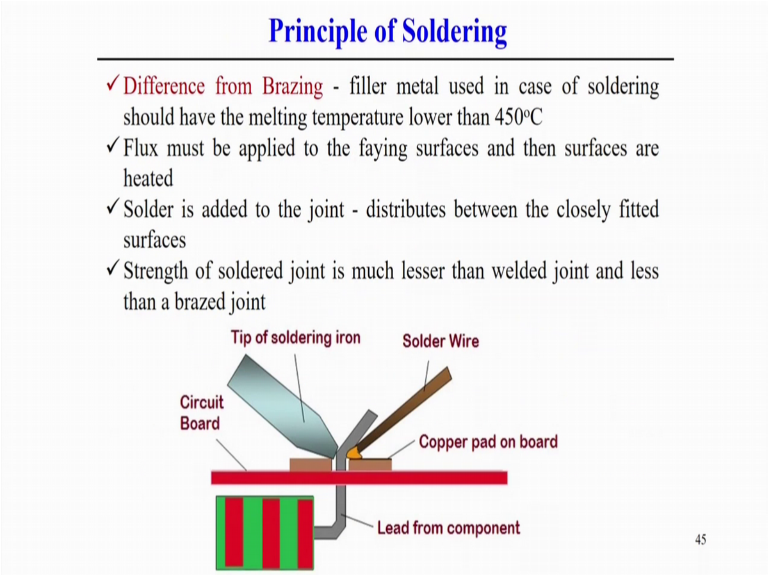
So, in that case oxidation and that oxidation normally increases with respect to the temperature. So, in that type of material or to avoid this kind of this to avoid the oxidation of the metal, probably there is a need for the vacuum furnace techniques to get the successfully assembly for the different components using this type of brazing techniques.

So, what happens? The pumping system actually removes the oxygen from the workpiece, from the focused zone where the workpiece is generally kept. And of course, in this case also we find out the application of the gold, copper, nickel, cobalt, cobalt titanium and ceramic based filler materials are basically the vacuum braze.

So, if we consider with respect to all this different brazing techniques; the most simply most simply application of the brazing techniques is the torch brazing. Rather induction brazing is the more controlled approach where we can control the temperature. Then continuous furnace and vacuum furnace are also other brazing techniques. So, in this case the continuous furnace its open to here; so, but in this case typically follow the sequence the preheating heating and the post heating zones can are this three zones are basically control using the continuous furnace.

Or vacuum furnace is vacuum furnace is a simple way to taking the advantage of the contamination of the during the process; to avoid this contamination with surrounding atmosphere, in this case generally the vacuum furnace are required.

(Refer Slide Time: 19:40)



So, apart from this various brazing techniques now we come back to that different soldering process. So, first we start with the principle of the soldering process. So, principal of the soldering process more or less similar to the brazing process, but there is some minor difference with respect to the brazing process; that in this case the filler metal used in case of the soldering process must have the melting point temperature below 450 degree centigrade. So; that means, that filler materials may be different as compared to the brazing techniques.

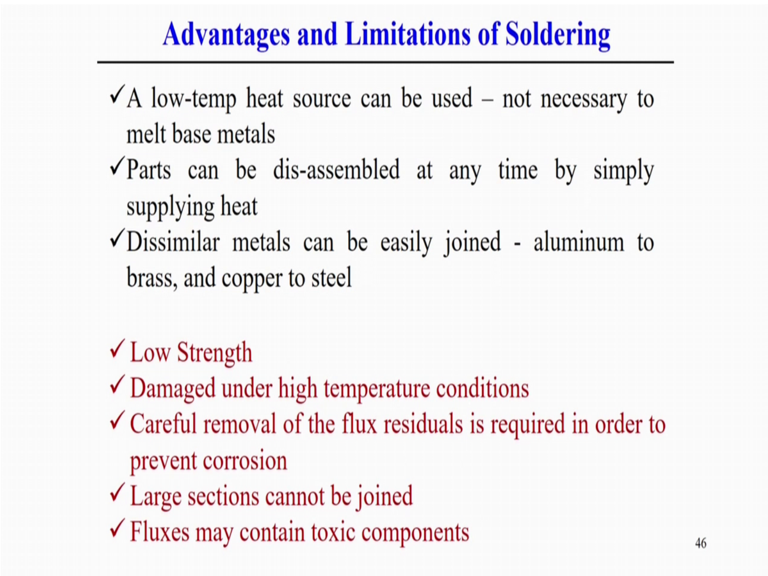
Flux normally applied to the faying surface and then surface are basically heated. So, soldered is added to the joint and then distributes between the closely fitted surfaces. So, in the similar principle; the solder material is basically distributed through the surface. And when the application of the application of the heat to the filler material in this case also and that basically melts and it is waited the surface to the solid surfaces. So, in that principle the soldering process basically works.

But main significant difference with respect to the brazing process is the strength of the solder joint is basically lesser than the weld joint and even also less than that of the brazed joint. So, in that case, but of course, the application are the applicability of the soldering process are different as compared to the brazing process.

So, from the figure if you see that it is better explained the soldering process. So, lead from the component that there is a solder where is used and copper pad on the board and circuit board the basically to electrical heating and the tip of the soldering iron and in this case purposes was to melt the solder wire and that becomes the part of the workpiece material that is supposed to join with respect to other processes.

So, and in practically see the electrical circuit board; there is a huge application of the soldering process. So, where the electrical connectivity may be the main important components, but may not the mechanical strain may not be the significant in this case. So, applicability of the soldering process is developed based on the connectivity of easy connectivity of the different component of the materials; may be either similar combination or the dissimilar combination, but where the electrical connectivity is the main significant main significant, but mechanical strength may not be significant in this case.

(Refer Slide Time: 22:40)



Based on the applicability of the soldering process; in general view we can find out also some advantages and limitation of the soldering process. If you see that soldering process is basically low temperature, heat source is required in this case; not that heat source not required to melting the base material.

Or; that means, heat source can be applied low intensity heat source can be applied exactly on the on the soldering wire where it is supposed to melt the soldering wire, not supposed to melt. The base material parts can be disassembled after joining the parts can be disassembled at any time by simply applying the heat. So that heat actually not affect much to the base material, so disassembled is also possible in this case easily. And dissimilar materials can be joined easily for example, aluminium to brass and copper to steel.

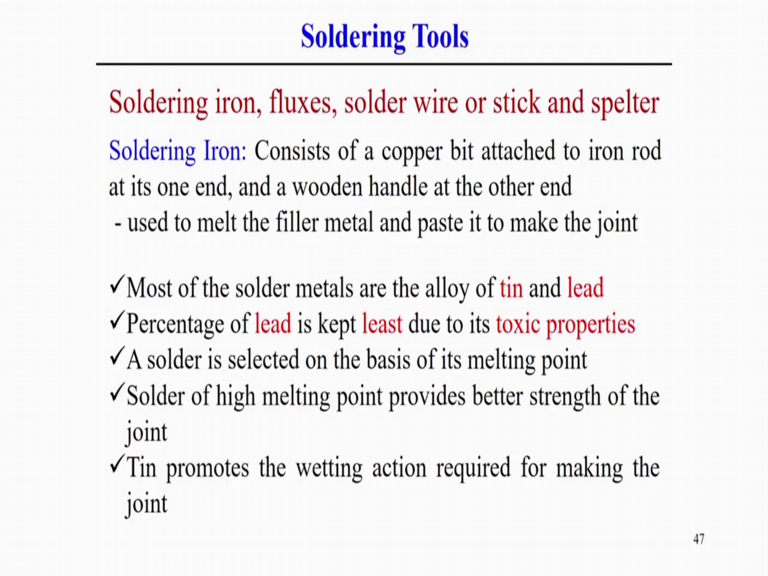
So; that means, the this dissimilar combination metals can be joined using the soldering process, but we cannot expect the much strength of this joint when we try to compare with respect to the normal fusion welding process or solid state welding process or this joints is even less than that of the brazing processes as well.

So, typical limitation of soldering process is the strength is very low and it may damage on the high temperature conditions. So, we try to localise the amount of the heat of the application and of course, the heat intensity of the heat should be low enough so, that temperature should be control below the 450 degree centigrade. Careful removal of the flux residual sometimes; because it is required sometimes in order to prevent the corrosion of the solder surface.

Large scale cannot be joined; so, basically the mainly the soldering purpose in the sometimes we use the repairing purpose. So, large sections probably cannot be joined and very small components can be joined and mostly for the required purpose. And of course, the main if we look into the environmental aspects though fluxes sometimes may contain the toxic components, sometimes the flux contains the lead which is not in which is the toxic components and may not favours for the as a green manufacturing technology.

So, in that sense we try to avoid using that such kind of fluxes.

(Refer Slide Time: 25:31)



So, apart from this several advantage and limitation of soldering process, but still there is some development of the soldering process also happens. So, now, if we try to look into this process; we can try to first look into what are the soldering tools. So, typical soldering tools in this process are soldering iron, fluxes, solder wire or stick and spelter are also used in this process.

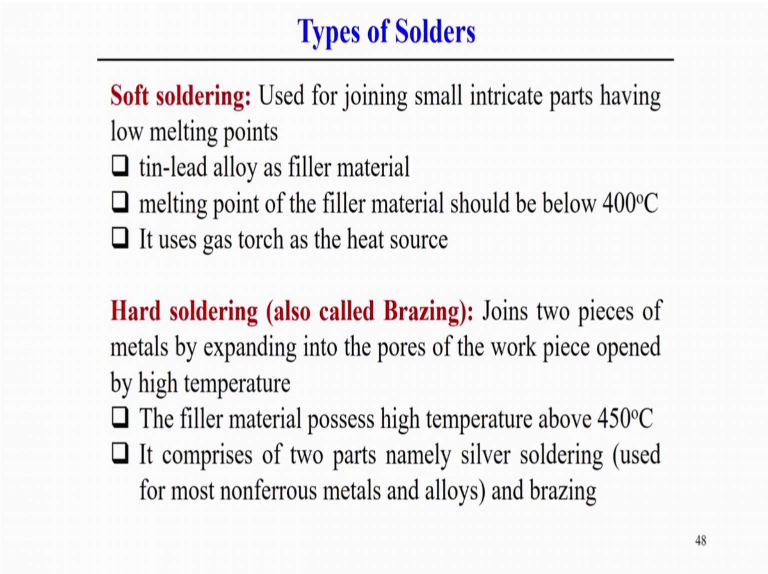
So, soldering iron is basically consist of the copper bit attached to a iron rod and acts one end and other case the; it is attached to the wooden handle so, that it can be hold on. Then use it to melt the use this can be used to melt the filler material and basically at the same time it can be used to test that filler material to make the joint. So, that is the basic principle and we have seen the soldering process in practically is applicable; practically we can see this soldering process very frequently in the when in the connectivity of the electrical circuit board.

So, most of the soldering metals are of the alloy of tin and lead. So, basically percentage of lead is kept constant because it is toxic properties and nowadays some other soldering metals has been developed also to avoid or using the component like lead in this case.

A solder is selected on the basis of its melting point definitely and the melting point is relatively in the lower side typically less than the 40 degree centigrade, but solder of the high melting point provides; if compared the melt high melting point use the high melting point, but limitation is up to 450 degree centigrade. So, in that case it can provide the better strength of the weld joint.

Team promotes waiting action required for making the joint basically the purpose of using the team the melting point temperature is low and its basically create bit nicely that waiting action, when you try to join the two components of the materials. So, types of solders.

(Refer Slide Time: 27:52)



Here basically two types of shoulders we generally observe one is the soft soldering another is the hard soldering.

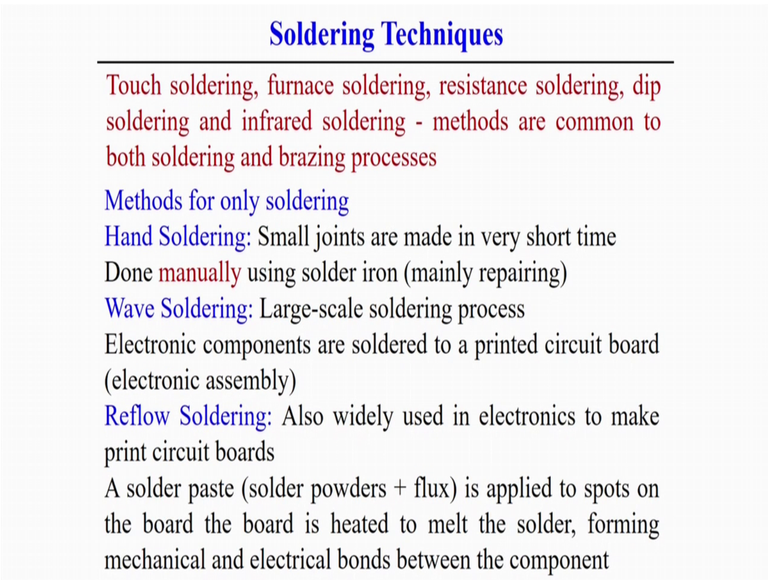
Soft soldering means used for joining the small intricate parts having low melting point that is called soft soldering. So, melting point is low; tin lead alloy as filler material can be used and of course, melting point of this filler material is below the 400 degree centigrade; around 400 degree centigrade and then in this case to locally melt that filler material, we generally use the gas torch as a source of the heat.

So, typical characteristic of the; so, soft soldering in general we can say that operation is done basically the temperature in the lower side; temperature below the 400 degree centigrade. And accordingly we can use the different filler material we can choose the different filler material and to melt the filler material; we can use the heat source so, that it can be locally applied even and should not affect much to the base metal; that means, temperature maximum temperature of the system can be below the 400 degree centigrade

But in other side that is the hard soldering and sometimes it also called the brazing process as well. So, definitely in this case hard soldering or we can say the brazing process. So, in this case joints of the two metals can be used and relatively at higher temperature. So, filler material used in such a way that their melting point; should be the above 450 degree centigrade.

So, it consists of the two components one is the silver soldering. So, silver alloy can be used for the soldering purposes and used for the no for silver soldering used for the most nonferrous metals and alloy joining most nonferrous metals and alloy. And other component is the simply step forward the brazing; so, in this case brazing is defined in such a sense the in terms of temperature as well as the what are the filler materials is used for the brazing purposes. So, normally sub soldering is basically what we can call the in general that is the soldering and heart soldering we can say in general that is the part of the brazing process.

(Refer Slide Time: 30:16)



So, now we will look into the; what are the different soldering techniques. So, definitely there are several techniques exists depending upon the type of the heat source and the depending upon the use of the different kind the filler materials and or based on the different methods. So, if you look into the different soldering techniques, we can find out the torch soldering sorry torch soldering, furnace soldering, resistance soldering, dip soldering, infrared soldering; all these are methods are common to the basically both soldering and brazing processes. But typically if we try to look into that what are the different soldering processes? What are the different methods of the soldering?

First is the hand soldering. So, hand soldering basically small joints are small joints can be done in a very short time period and typically and soldering is done manually. And using the soldering iron and these methods is mainly used for the repairing purpose; since it is done only manually.

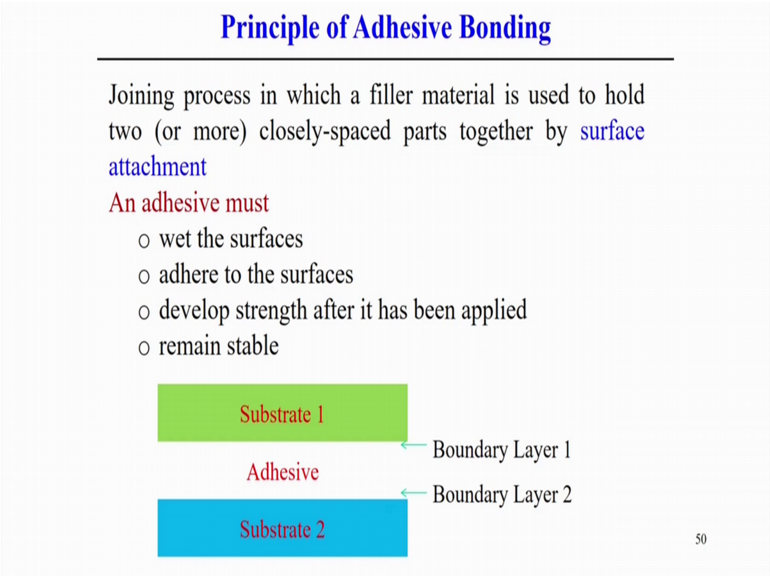
Wave soldering is also when there is a requirement of the large scale soldering process. So, in that case the wave soldering is the another soldering techniques where electronic components in the printed circuits circuit board are joint, but in this case using this techniques, we generally do the only electrically assembly of the different components; typically the metal circuit board to the metallic components are done using this kind of soldering process.

So; that means, the large scale soldering process and the small scale soldering process; the difference is that small scale done manually and repairing purpose, but large scale soldering done when there is a when we try to automated this process and there is a this automation this is a heat of the large scale welding large scale soldering process.

So, there is another large scale soldering process that is also reflow soldering; it is also widely used in the electronics industry to make the printed circuit boards. But difference from the wave soldering and the reflow soldering is that in this case; the reflow soldering actually use the solid paste solder power and flux used and they are applied to the spots on smoother different parts on the board. And then board is heated to melt the solder and finally, it makes the forming the bond; the electrical bond as well as the mechanical bond between the two components.

So, reflow soldering in this process the importance is not only the electrical connectivity, the mechanical strength and electrical connectivity both are achieved in a very organised way that is in that sense the reflow soldering is basically different from the wave soldering process.

(Refer Slide Time: 33:26)



Now, after the welding first we have discussed the different welding processes and principal of the fusion welding process, then we discussed the brazing and soldering that is the another joining process.

And now we will try to discuss the adhesive bonding this is also one kind of the joining process. We will try to look into the basic principle of the adhesive process and what are the different methodology techniques can be used in case of the adhesive bonding process. So, what are the principal of the adhesive bonding?

So, in adhesive bonding the joining process in which the filler material is used to hold two hold two or more than of the components and they are closely spaced parts together by simply the surface attachment. So, in principle this is different from the fusion welding process or soldering of brazing process.

So, here the joining of the between to two components is done using some; we can say that some other type of the filler metals or it filler metals means here the adhesives with or without the application of the heat may or may not be the necessary of the application of the heat.

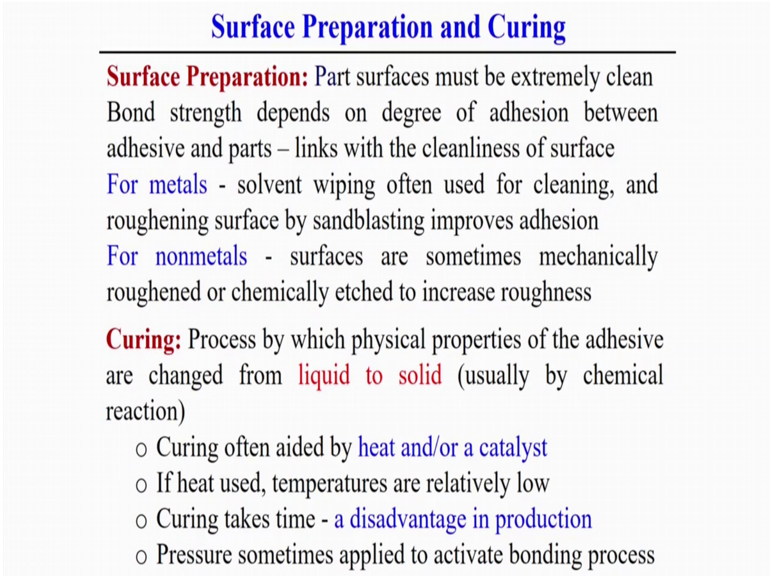
So, the in that way this is different from the any kind of fusion welding processes or brazing and soldering process. So, when we use the adhesive to join between the two substrates; if you look into the figure in this case the substrate 1 and substrate 2 we will try to join using some adhesive. So, the most important factor using the adhesive the type of the adhesive. Second important point is that when we join substrate one and substrate two; what may be the gap? That means, what may be the thickness of the adhesive? The joint strength of the joint can vary depending upon the nature of the adhesives and depending upon the thickness of the adhesives.

And maybe other secondary requirements are also there to get a successful weld joint simply by adhesive bonding. So, in principle that it follow the surface attachment between the two components. So, therefore, when you adhesive should have some quality such that it will try to wait the surfaces; both the surfaces when which surface we are supposed to join. And it exactly adhere to the surfaces and develop the strength after heat has been applied; that means, when sometimes the simply putting the adhesives and there is a necessary to keep in keep hold on for a long time and; that means, that is call the curing process.

So, in that after curing they the join between these two surfaces and simply waiting the surface and, but this joints should be riven stable after a certain period of time. So, this adhesive bonding happens, but to do get the successful joint using the adhesive bonding there may be some that this process can be explained in the two terms. One is the surface preparation and the curing; these are the two significant terms based on that adhesive bonding can be explain in better way.

First is that surface preparation. So, definitely the workpiece surface like fusion welding process also to get the successful weld joint it is necessary to clean the surfaces of the workpiece of substrate material before welding.

(Refer Slide Time: 37:21)



Similarly here also some surface preparations are necessary to get a successful weld joint with a application of the adhesives. So, part surfaces must be extremely clean such that because the bond strength actually depends on the degree of addition between the two surfaces or two adhesives between the addition between the surface and the adhesives. And adhesives and the parts that actually very much links to the cleanliness of the surface.

So, therefore, extremely clean surface is required in this case. Second, but other points for the surface preparation this I mean how we how the surface preparation can be done in case of the metals and in case of the non-metals. So, in case of metals; the actually we using the solvent wiping after use after use for the cleaning often use for the cleaning purposes and then roughening of the surfaces also required.

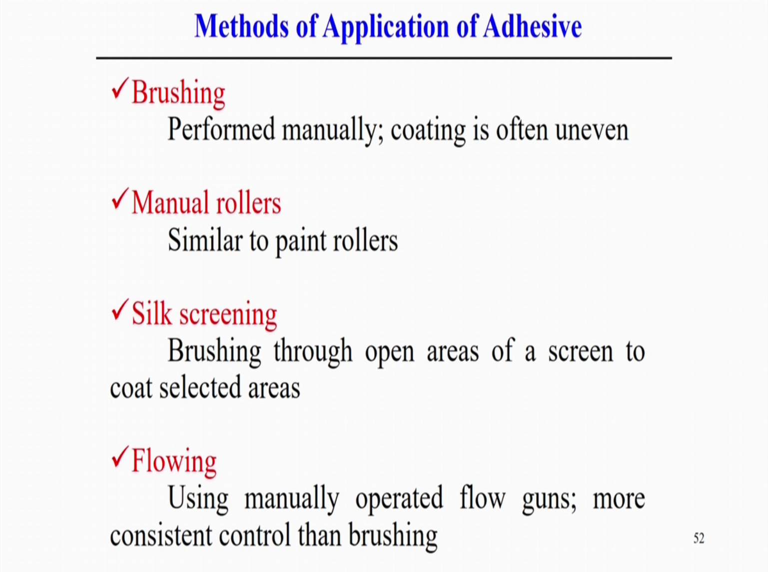
Sometimes the sandblasting techniques is required to improve the surface roughness of this material, but surface may not be too rough then there may be the other difficulties, but certain roughness is require so, that waiting action can be good by the adhesive to the surface.

But for non-metals the roughness is improved sometimes; the mechanically or sometimes you can use the chemical enchant also to increase the roughness. So, the in general the surface preparation for the adhesive bonding is the first one; the cleanliness second secondary thing is that some sort of roughness should present in the in the surface.

And next curing another component of the adhesive bonding is that curing action. So, this is the process by which the physical properties of the liquid adhesive changed; when it is changed to the solid comes to the solid phase. So, that comes easily some by some chemical reaction. So, in this case the curing can be done carefully in the adhesive bonding process. So, it is open use by the by curing can be done with the aid of the heat sometimes or sometimes we can use the some catalyst for the curing purpose of the adhesives. So, if there is a need of need of the application of the temperature during curing purpose, but that temperature may not be too high it should be very low relatively low.

But the main disadvantage of this process is that curing times is relatively takes a very long time. So, that is why production rate is relatively slow in this case; so, that is the disadvantage of this process. So, sometimes it requires to applying the pressure also; so, that applied pressure activates the bonding between the two substrate materials.

(Refer Slide Time: 40:46)



So, but now we come to that point that what are the typical methods of application of the adhesive? In what way we can put the adhesive between the substrate material? So, it simply manually we can do the simply brushing and, but when you do the manually this thing there is a possibility of the uneven coating; may not be the coating may not be the very even.

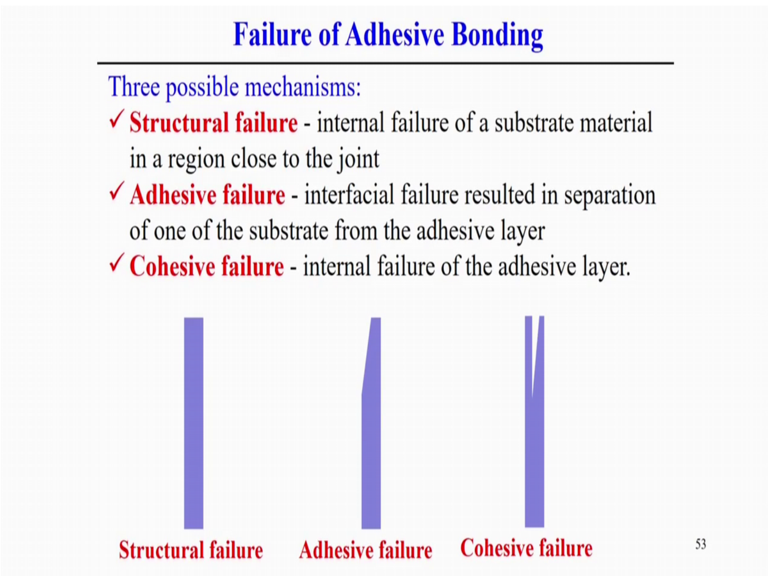
And; that means, there is a variation of the thickness about the surface. So, that is the one thing the simply brushing. Sometimes we can use the manual roller similar to the paint roller, but in this case definitely can maintain the smoothness of the surface and, but since it is doing the manually; so, there may be the possibility of the variation of the thickness also.

Silk screening also sometimes this is another methodology to application of the adhesive. So, simply brushing through the open area open area of a screen and screen that actually used to coat the selected ; if you use the screen it is possible to use the putting the coat of the selective part, selective area or selective area of the components. So, this method is sometimes applicable to application of the adhesives.

And flowing; so, usually sometimes use the manually operated gun; for flow gun basically that is required and when there is a consistent control of the consistent control is required and advantages as compared to the simple manual brushing process. So, this typically typical methods for the application of the adhesives to the substrate material.

So, after application of the substrate material then there is a need may or may not need of the pressure aid of temperature or sometimes we can use the; this adhesives along with the some catalytic element so, that it can accelerate the chemical reaction during the process. So, that it can the curing can be done; that means, the change of phase from liquid to the solid phase can be done quickly also.

(Refer Slide Time: 43:08)

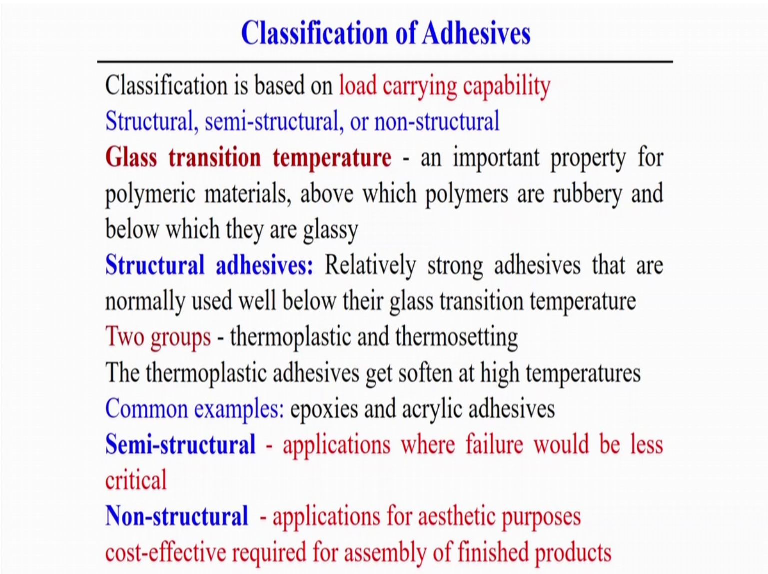


Now, if you look in to the typical failure modes on the adhesive bonding when you after the making the bonding ah; what are the typical failure mode of the adhesive bonding. The three possible mechanisms one is the structural failure, here we can see the internal failure of a substrate material in the region close to the joints. So, failure is more to the substrate material with structural more to the substrate material not actually the not failure exactly happens inside the components of the adhesive part.

Then adhesive failure mean interfacial failure resulted in a specimen of one of the substrate from the adhesive layer. So, near about the adhesive layer there is a failure; if you see the figure adhesive failure figure here you can see there is a small component of the adhesive is disappear. So, actually failure happens near about the substrate material and layer is absent in this case. So, that is the typically called the typical mode is the adhesive failure.

Cohesive failure; if the internal failure occurs in the in the adhesive layer if you see look in to that see it is a completely ah; the failure is completely on the layer of the adhesive within the adhesive volume itself that is called the cohesive figure. So, these are the three different types of adhesive failure modes we observe in case of the adhesive bonding.

(Refer Slide Time: 44:41)



Now, classification of the adhesive what are the different different types of the adhesives can be used that are different way or different types of the adhesive materials can be used for the adhesive bonding, but here we try to do the classification based on the load carrying capability.

So, depending upon the load carrying capability the adhesives can be defined is the structural, semi-structural and non-structural. These three different types of the classification can be done, based on the load carrying capability of the weld joined using the adhesives. But to do that one is the important point is that glass transition temperature which is very much related to the polymeric material and that the temperature decides in such way that above which the polymer are rubbery like polymer becomes like chewing gum; large deformation can be done. And below which it is like the glassy type of structure we can observe.

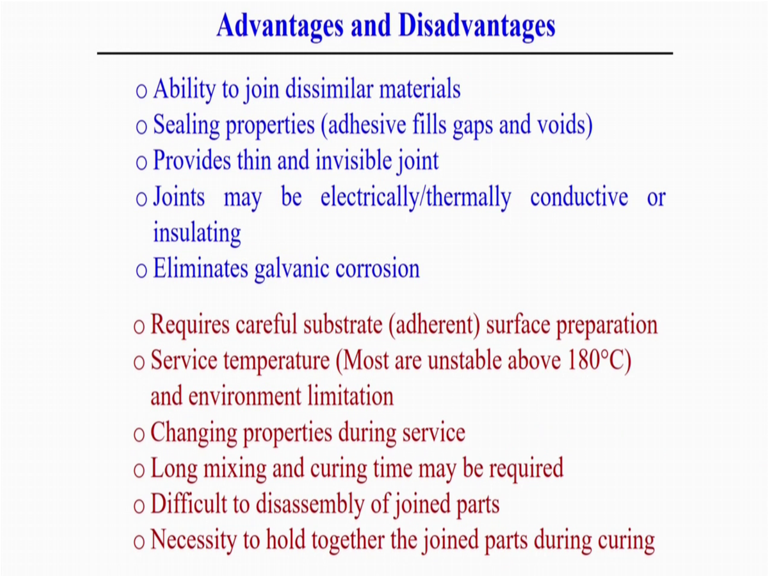
So, that sometimes we use the pen polymeric material or maybe we can that the important temperature with the glass transition temperature, which is maybe equivalent to the melting point temperature in case of any kind of metals any kind of metals. So, structural adhesives are basically the relatively strong adhesive that normally used basically while below the they are glass transition temperature. So, below while below the glass transition temperature; that means, the adhesive looks like here the it is written the structure like the glassy structure glassy structure.

So, two groups thermoplastic and thermosetting thermoplastic groups; they actually form they can be examples for the structural adhesives. But we know that thermoplastic and the thermosetting plastics; thermoplastic they actually becomes open soften at the basically high temperature, but thermosetting they becomes harder with respect to the temperature.

So, common examples of the structural adhesives are basically epoxies and this acrylic these are the typical adhesives we use for the joining of the components. So, if you look in the semi structural; in this case the application where the failure would be the less critical. So, in this case the failure with the less critical; we can use the semi-structural adhesives or semi-structural joint.

And non-structural the strength is not important here the non-structural here the application is done based on the aesthetic purposes. So, these are the if you look into that three different types of the adhesive; the structural semi-structural and non-structural adhesives and based on the load carrying capability; structural adhesive is the having the good load carrying capability semi structural it will less than that and non-structural even it is not the here the importance are given to the aesthetic purpose of this adhesives.

(Refer Slide Time: 48:09)



So, this adhesives are joined for the adhesives are used for the joining of the components, but in general and if you look into the over overall what are the advantages and limitations of the adhesive joint, you can summarise like that. The ability to join dissimilar materials that is the one advantage for the adhesive bonding; definitely which is the similar typical to the other welding processes or like brazing and soldering also.

So, sealing properties adhesives it is having the good sealing properties using the adhesive. Because it generally try to fill the gaps and the voids and definitely adhesive sometimes most of the cases use the very thin layer and invisible joint, but good joints can be achieved and the adhesives using some additive agent the adhesives can be improved electrically or thermally conductive. Or insulting whatever requirement that kind of flexibility there also using this using the adhesive joints between the components.

And of course, the adhesive joints is actually eliminates any galvanic corrosions. So, using distinct corrosion resistance can be improved using these adhesives during the adhesive bonding or if you simply use the adhesive layer of all the any kind of components.

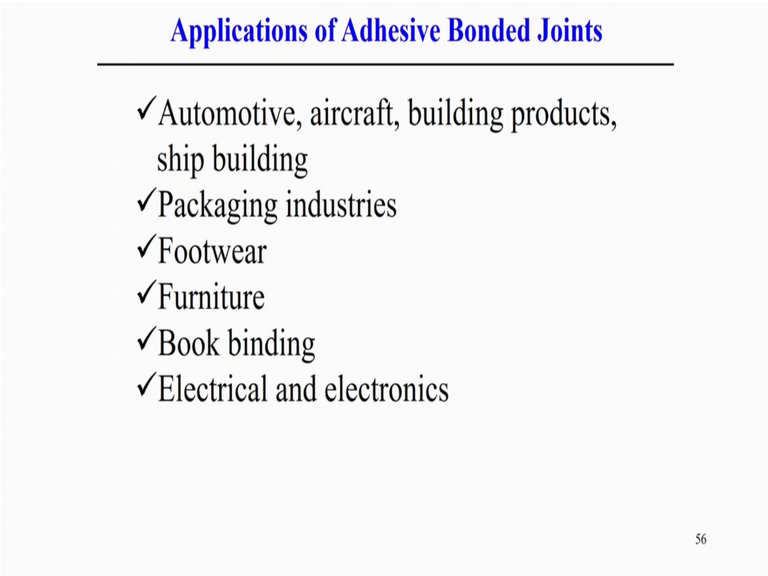
But if we see the negative side or may be disadvantage of this adhesive bonding first is that requires careful substrate surface preparation. So, surface preparation is one important factor, one is the cleanliness and the roughness these two are the important parameters for the successful weld joint using the adhesive bonding. Service temperature and having some limitation on the service temperature; most of the cases it is below 180 degree centigrade and also environment limitation. So, certain in its a in environment effect is also there and for the service life of a adhesive joint.

But main limitation is the application of the temperature. So, above 180 degree centigrade temperature the adhesive joint fails basically. So, that is the important limitation of this type of joining, it may change properties during the service. So, that is another risk that if you cannot access the changing properties during the service; then probably it cannot be very disable joint disable joint process. And the main in terms of the production of this process is the main disadvantage is that high curing time that makes the production time is very high for this adhesive point.

So, this is the another disadvantage and difficult to disassemble the joints like soldering joint its simply by applying the heat; we can easily disassemble of the joint. But once the adhesive bond has adhesive bonds has occurs between these two components then it is difficult to disassemble again ok. So, necessity to hold together to joining parts during the cure. Sometimes to since the curing time is very high, so, during the whole curing time it is necessary to hold on the two components or two substrate material until unless it finishes the curing time or for the joining of this two components.

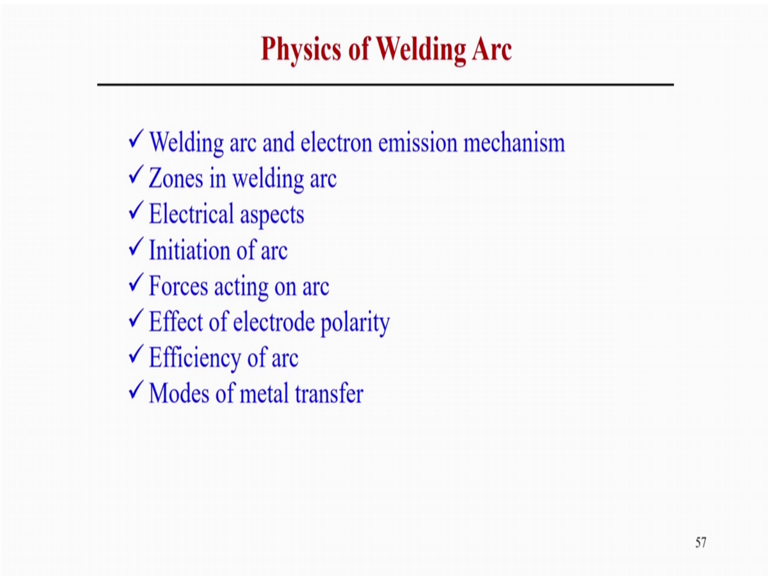
So, these are the although having the several disadvantages or even having some advantages of adhesive bonding process, but sometimes the adhesive bonding is very handy process we generally use.

(Refer Slide Time: 52:15)



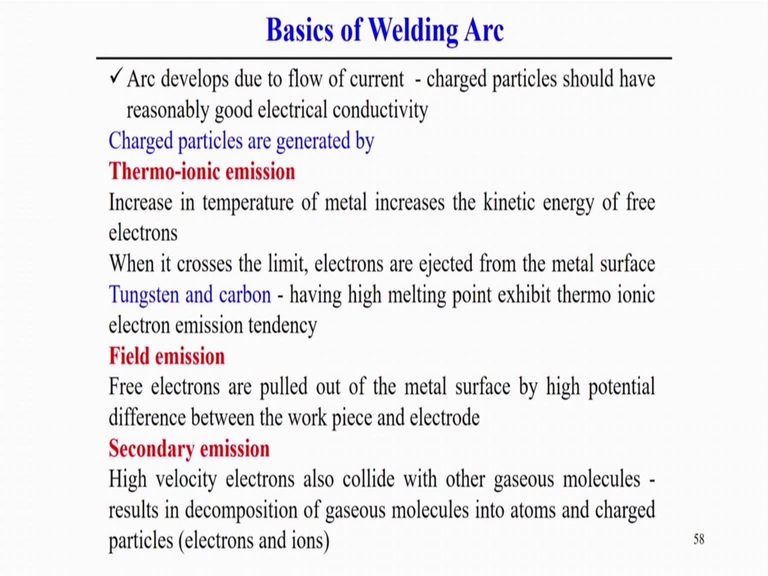
Typical application of the adhesive bonded joints we find out the practical application of the adhesive bonding joint is the automotive, aircraft, building products and ship building packaging industry, footwear, furniture, book binding, electrical and several electronics industry we can find out the application of the adhesive bond; adhesive bonding or we can find out the adhesive bonded zone in this typical industry or typical field.

(Refer Slide Time: 52:48)



Now, after the adhesive bonding we will come back to the physics of the welding arc. So, in physics of the welding arc; here we will try to focus on the basic the welding arc and the electron emission techniques or mechanism what are the different zones in the welding arc? Typical electrical aspects initiation of the arc and force acting on the arc effect of the electrical polarity, efficiency of the arc, modes of metal transfer; these are the typical topics related to the physics of the welding arc we will try to cover in this in this module.

(Refer Slide Time: 53:30)



So, here first we start with the basics of the welding arc. So, definitely in arc welding process the arc develops due to the flow of the current and charged particles should have reasonably good electrical conductivity. So, that is the main principle of the welding arc that welding arc can be representations of the charged particles and movement of the particles within the arc itself.

But discharge particles can be generated by the three different theory can be explained in this in this case. The first is the thermo-ionic emission; so, thermo-ionic emission if you try to increase the temperature of a metal and if the temperature is sufficient enough, then kinetic energy of the free electrons; basically increases and then it comes out from the metal, but and then it flow through a potential difference if there is a voltage difference it can flow through that.

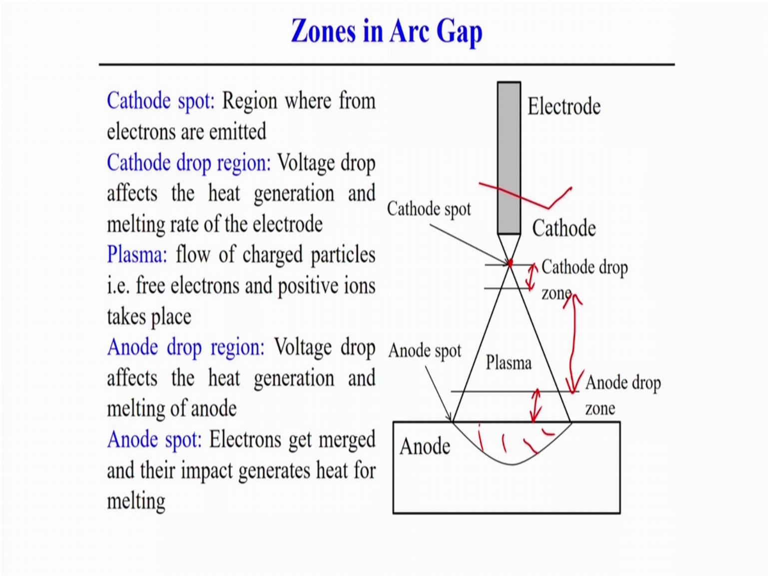
But when it crosses the limit basically there is a in some critical amount of the energy it it cross, then electrons get actually ejected from the metal surface and then it comes out in the through the specific channel in a within a potential difference. So, normally the thermo-ionic emission is in terms initially caused to the tungsten and the carbon. Because they are having the high melting point temperature and at that high temperature basically the they can exhibit the thermo-ionic emission and tendency. So, that is why this tungsten and carbon are mostly used in case of the arc welding process.

If you see then even gas tungsten arc welding here the non non-consumable electrode is considered as a as an tungsten electrode. Even also we know the carbon arc welding process also develop that is the very old oldest process. So, carbon itself use as an electrode.

So, once this is thermo-ionic emission for the different materials are different. So, so in that purposes tungsten or carbon can be used. Secondly, we can see the field emission; the free electrons are basically pulled out of the metal surface by high potential difference between the workpiece and the electrode. So, between the work piece and electrode; if there is a if we apply some voltage difference and then the free electrons actually cooled out from the tungsten and carbon electrode.

And the secondary emissions the high secondary emissions can be explained like that that high velocity electrons actually that also collide with the other gaseous molecules and results in the decomposition of the gaseous molecules into the atoms and the charged particles. Basically it is a cloud of electrons and ions is the created; do, that is call the secondary emission. So, with that these three basic mechanism that the thermo ionic emissions field emissions and the secondary emissions basically the whole arc basics of the welding arc can be better explained.

(Refer Slide Time: 57:18)



Now, if we look into the very intuitively that what are the different zone in the in a in a arc gap; we can find out that first is the cathode spot. So, that is a zone from other electrons are emitted emit electrons are emitted from the cathode. So, first the electrode is there and from electrode there is a then this component that is called the cathode. And the cathode drop zone these two certain zone from the cathode and this zone is basically called the cathode spot.

And from here to here that is called the plasma zone and this component is basically the anode drop zone and this is the workpiece or that can works as a anode here and this is the molten metal or the basically the arc is created and its try to melt the workpiece surface. So, if we look into what are the different zones and here the acting between the electrode and the workpiece when we try to create the arc. We can find out the different zone first is the cathode spot, then cathode drop zone then anode plasma zone anode drop region and then anode spot zone.

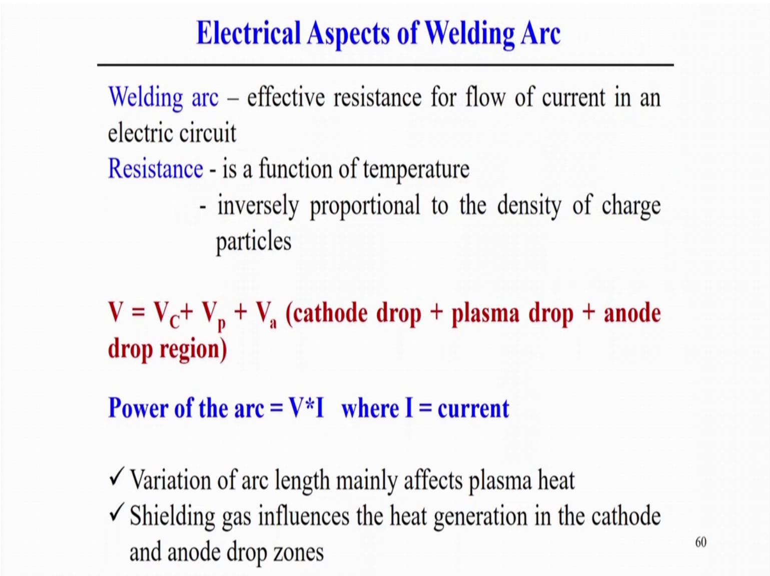
So, cathode spot the basically electrons are emitted from here at cathode drop zone; the basically voltage drop effects the generation of the heat are and melting rate of the electrode; if there is a we can we can use because in welding process we can use either consumable electrode or non- consumable electrode. For non- consumable electrode ah; the cathode drop zone actually basically decides the melting rate of the electrode. But when you use the non- consumable electrode; so, in that case definitely it creates some amount of the temperature for melting of the electrode is not important here, we do not intent to melt the electrode.

Then plasma zone is basically represented by the flow of the charged particles that is mean free electrons and the positive ions. Because plasma zone is consist of the charged particles the electrons emissions comes out from the electrode at the same times when it interact with the shielding gas and then it create some ions also. So, it is a mixing of the charged particles as well as the positive ions that is call the plasma zone. And anode drop zone that actually the voltage drop that actually decides affects the heat generation and the melting of the anode.

So, and finally, the anodes anode spot that here the electron get merged and their impact actually generates the heat spot the melting. So, basically that two voltage drop cathode drop zone and the anode drop zone in these two cases the two voltage drop actually decides the melting of the electrode or may be in other way the temperature of the electrode and the melting of the workpiece or that decided by the voltage drop in anode zone; that means, melting of the workpiece or temperature reach the maximum temperature of the workpiece that depends on the anode drop zone.

And plasma zone actually it is a charged particles as well as charged particles and then free electrons and the positive ions that exist within the plasma zone and there may be some amount of the voltage drop also happens.

(Refer Slide Time: 61:17)



So, in terms of voltage drop we can find out the represent the electrical aspects of the welding arc in other way that welding arc can be represented that the effective resistance for flow of the current in an electrical circuit. So that effective resistance of the flow of the current in an electrical circuit and that how that flow of the electron; basically creates the amount of the heat either in the workpiece or either in the electrode material.

So, here resistance, but resistance definitely is a function of temperature it is and then inversely proportional to the density of the charged particles. So, accordingly that depending upon this density of the current or it actually decides the amount of the heat generated in the anode or cathode.

So, in terms of the voltage drop we can divide the total voltage and in consist of the three different components; one is the cathode drop. In the cathode drop voltage drop, plasma drop and anode drop zones; so, in the cathode plasma and anode. So, these three different zone having the different different voltage drop and that actually decides the final voltage here.

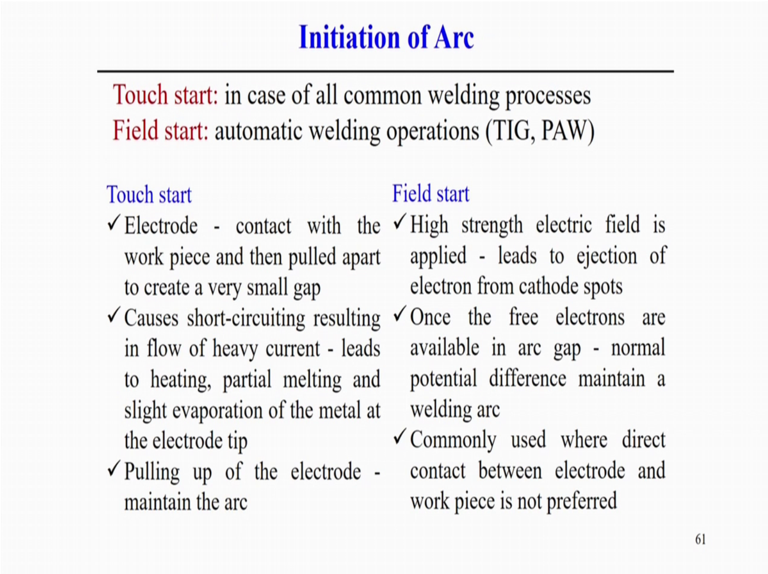
So, power of the arc is estimated that the voltage the between the electrode and the workpiece material total voltage drop and what is the flow of the current and within this electrical circuit; that means, by this electrical circuit by the creating of the arc between the electrode and the workpiece; so, V into I that actually decides the power of the arc.

Now, variation of the arc length so; that means, variation of the arc length actually affects the amount of the heat generation; because it alters the amount of the voltage drop between the cathode and anode. And of course, the nature of the shielding gas also influence in the heat generation and shielding gas of course, in the cathode and the heat generation in the because shielding gas mainly impact in the cathode and the anode drop zone.

And how the interact of the shielding gas with the charged particles of the electron here and that actually this makes a very complicated phenomena and that complicated phenomena is simple way represented by an electrical arc ah; we can say there is a plasma arc. And that to sustain this arc there is a when there is a electrical circuit is needed and that electrical circuit is characterised by the certain voltage and with the certain current. And of course, it is possible to measure the resistance also in terms of this in this electrical circuit.

So, once we can measure we can that voltage and current can be controlled by the power source and that is the measure of the arc power in this case.

(Refer Slide Time: 64:30)



Now, looking into the arc now we try to look into the initiation of the arc so; that means, how arc can be created. So, initially without the application of the means; there is a gap between the electrode and this or does not complete total electrical circuit.

So, it is possible to first simply touch the electrode to the workpiece material or substrate material, then it creates the electrical circuit; that means, the flow of the current starts in this. So, then torch start means that simply the torch simply touching of the electrode to the workpiece materials and start flowing of the current and simply take it array from the workpiece and then we maintain certain gap. So, that by creating the arc it maintains the circuit electrical circuit ah; that means, continuous flow of the electrical current here. And that gap actually mainly decide mainly decides the amount of the voltage required for this electrical circuit this is the one way.

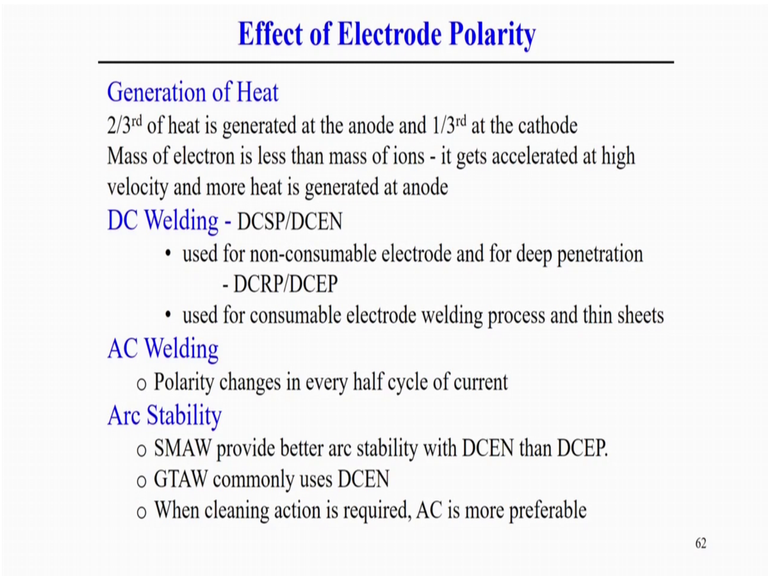
So, torch start if you look into that electrode if you separately look into the torch start the electrode that contact with the workpiece and then pull out apart to create very small gap. And basically when you touch it basically creates the short circuit result in the flow of the heavy current initially and leads to the heating and partially melting and slight evaporation of the metal at the evaporation of the electrode tip metals.

But pulling out of the electrode then it maintains the arc. So, torch start is generally done by the it is in an welding process basically its control by manually, but other type of initiation of the arc that is called the field start. So, field start is basically use in the mainly use for the automated welding process like t welding and the plasma arc welding process. So, in this case the field start high strength electric field is basically applied. So, that leads to the ejection of the electron from the cathode spot.

So, once the free electrons are available in the arc gap then normal potential difference actually maintains the arc gap between these two; the maintain the gap between the work piece and electrode. So, commonly used whether direct contact between the electrode and work piece is basically not prefer not preferred. Or when there is a need of automated process basically we use the field start by initially by initially applying the high strength of the electric field so, that even there is a constant gap between this electrode and workpiece is there.

So, initially by applying the high strength of the electric field we start the flow of the current within the circuit itself. So, that is called the field start.

(Refer Slide Time: 67:42)



Now, when we use the electrical power source in case of the arc welding process so, basically there is a possibility of use. We can use the either direct current or alternating current, but point is that in the direct current there may be the possibility of the how to select the polarity of the electrode and the work piece. So, to understand the polarity of the electrode and the workpiece, we need some basic idea about this how in which case how we can link polarity in terms of the generation of the heat.

So, if you use the direct current and if direct current and if you consider the electrode negative and the work piece as a positive. So, flow of the electrons will come from the; electrode to the positive work piece. So, that when the flow of electrons comes from the electrode to the positive work piece. So, maximum amount of the heat will be generated in the work piece. So, typically to 70 percent of the heat will be generated in the anode and remaining 30 percent heat will be generated at the cathode for the DCEN polarity; that means, direct current electrode negative polarity.

So, in this case mask of the electron is much less than that mass of the ion. So, heat basically gets accelerated of the high velocity and more heat will be generated at the anode; that means, when this electron will be attracted to the positive work piece. So, more when electrode will impact on the positive work piece; so, it is expected that the more amount of the heat will be generated in the work piece; so, that is the principle.

Now, depending upon the different application or different mode different type of welding process; how we can use different types of polarity here; for example, DC welding that already told that in DC welding we can use the direct current straight polarity or direct current electrode negative; both are the same.

Straight polarity means the electrode negative and work piece is the positive and in this case, but where is the applicability of this direct current electrode negative or straight polarity; in this case used for non-consumable electrode and for the deep penetration electrode. Because if we look into that point that when we use the DCEN; in this case the maximum amount of the heat is generated on the workpiece.

So, that is also desirable because we need to the amount of the heat generator on the workpiece and since were using the non-consumable electrode; it is not intention to melt electrode so, as minimum as possible to amount of the generation of the heat in the electrode. So, that is the reason of using the DCEB polarity for the non-consumable electrode where we are using the in welding process where we can use the non-consumable electrode. Or since the maximum amount of the heat generated in the workpiece; so, when heat also try to get the deep penetration weld.

In other way, the straight polarity sorry reverse polarity or direct current electrode positive this mode can be used when using the consumable electrode. Because in this polarity the maximum amount of the heat will be generated from the electrode; not in the work piece. So, using the consumable electrode intension is to melt the electrode material not the melt the electron material that is the one positive electron metal that is the main requirement. And of course, at the same time the less amount heat will be generated in the work piece metal that also melt the material, but more come to the control the melt of the electrode material.

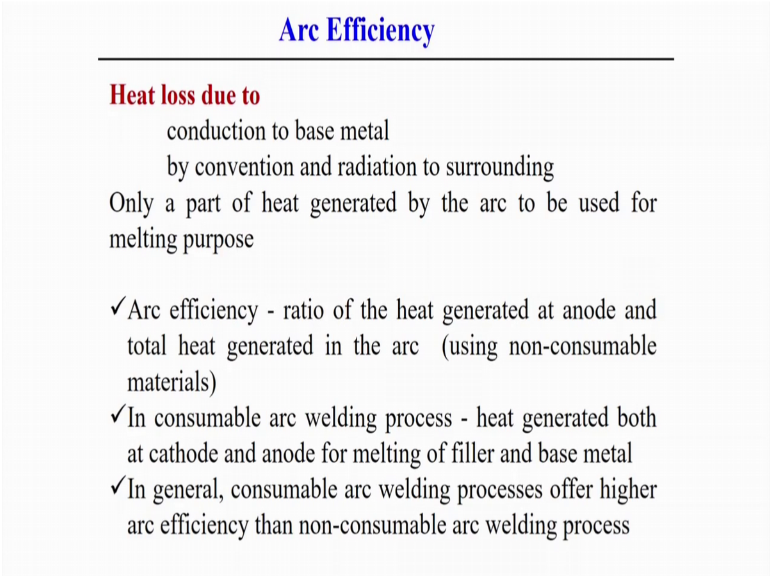
So, normally direct current electrode positive can be used when there is we can use the consumable electrode. And in this case definitely it cannot create the very thin section very deep penetration. So, thin section materials can be welded using this DCEP polarity.

Now, AC holding alternative current can also be used in the power source when there is a change of the polarity in every cycle of the current, then there is a use of the AC current. So, typical example of the aluminium; so, when you try to join the aluminium or aluminium alloy; the more preferable choice of the polarity is the AC current can be used in this case.

But arc stability in this case gas metal shielded metal arc welding actually provides the better arc stability with DCEN or then DCEP polarity. So, in this, but GTAW commonly used the DC EN polarity. And; that means, in arc stability basically arc stability is more when we use that polarity that is the DCEN polarity. So, in that in that sense the DCEN polarity can be used and in GTAW process in other welding process when we try to consider the arc stability is the criteria for the welding process.

But when cleaning action is required in this case AC is more preferable; that means, alternative current is the more preferable choice of the for welding of the different specifically nonferrous metal like aluminium. Now how to estimate the arc efficiency?

(Refer Slide Time: 73:27)



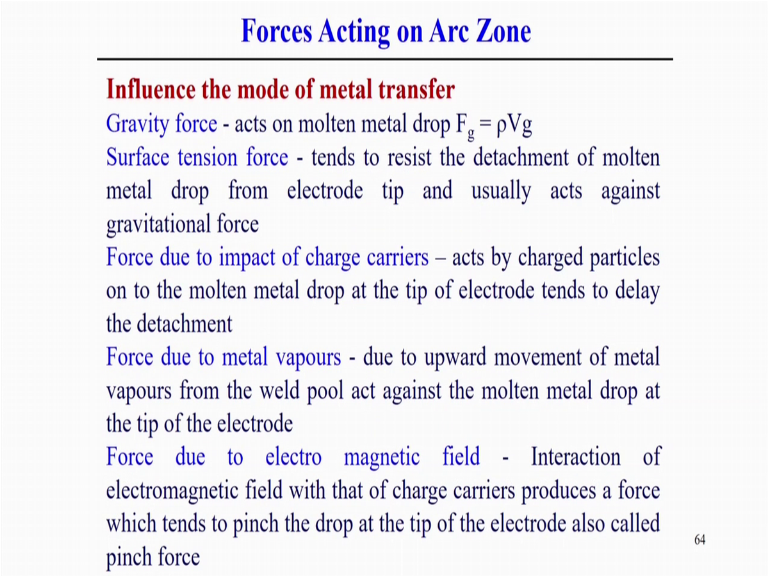
So, look into that that heat loss may be mainly due to the when application of the heat that comes from the creation of the arc; that one amount of the heat is conducted higher to the base material, but at the same time heat will heat lost due to the conviction and radiation from the work piece surface and that heat lost due to the surrounding.

So, therefore, only a component or only a part of the generated heat is by the arc is actually used to melt the substrate material. So, based on that we can find out the arc efficiency; so, arc efficiency can be defined ratio of the heat generated at anode and total heat generated in the arc. So, heat generated at anode and the total heat generated in this ratio is basically define the arc efficiency, but of course, in this case the using, the non consumable non consumable not it should be the using the non-consumable electrode material.

So, in this is the definition of the arc efficiency, but if we consider the consumable arc welding process. So, heat generated is basically both cathode as well as the anode so; that means, its melting the work piece material, melting the filler material or consumable electrode at the same time its melts the base material also. So, in this case need to count the amount of the heat generated in both the cases.

So, in that sense the efficiency of arc efficiency probably in this case; it will be more. In general the consumable arc electrode process of course, the higher arc efficiency than the non consumable non consumable welding process; non consumable non consumable arc welding processes; that means, when use the non consumable electrode.

(Refer Slide Time: 75:33)



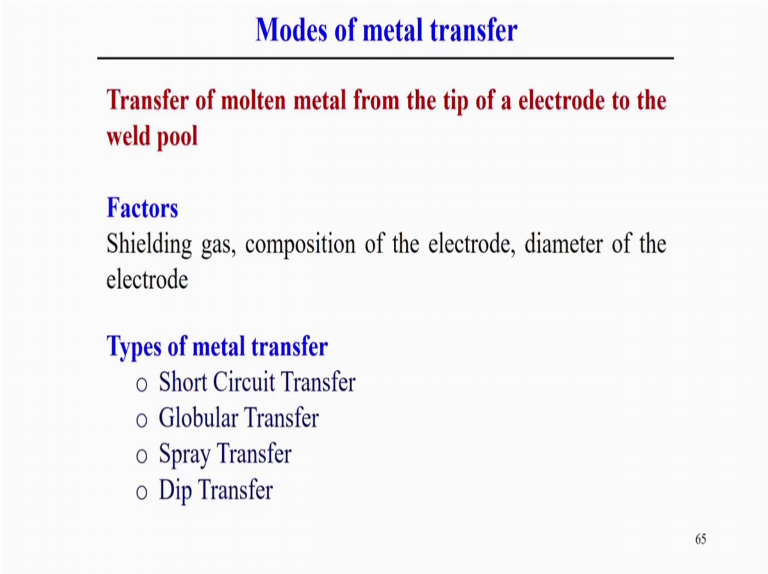
Now, what are the different forces acting on the arc zone? If we see the different forces on acting on the arc zone first is the; if you look into that when you try to analyse the mode of the metal transfer when using the consumable electrode. So, in this case it is necessary to analyse when consider what are the different forces are acting on the arc zone?

First is the gravity force. So, gravity force is actually acts on the molten metal drop and that can be estimated that that density and the volume of the drop and the the acceleration due to gravity. So, that is the gravity force is the one kind of the force that influence the metal transform. Second component is the force due to the impact of the charge carrier. So, that acts by the charge particles on the molten metal drop at the tip of the electrode and that force due to the impact of the charge carriers actually basically tends to delay the detachment of the droplet.

So, this is another force other forces are due to the metal vapour that due to the metal vapour and always it comes the upward direction. And that metal vapour acts against the molten droplet at the tip of the electrode. And finally, the other welding force that is the force due to the magnetic field; so, interaction of the electromagnetic field with that of the charge particles produces the force that actually tends to pinch of the drop at the electrode at the tip of the electrode and that is called the pinch force.

So, electromagnetic field actually creates the pinch force and pinch force is basically effect on the detachment of the drop from the molten electrode.

(Refer Slide Time: 77:44)



So, based on that different forces acting on the or maybe linked to the metal transfer in gas metal arc; welding process or in the kind the shielded metal arc welding process. So, mainly the metal transfer happens from the tip of the electrode and the factors apart from this all this different driving forces, the typical factors of the shielding gas, composition of the electrode and diameter of the electrode; these are the secondary parameters that actually influence the metal transfer.

But if we look into that different type of the metal transfer normally observed in the fusion welding process that is are the first is the short circuit transfer. Second the globular transfer the then third is the spray transfer and the final is the dip transfer. So, all these nature of the types of the metal transfer is actually governed by the different forces acting during the welding process.

So, that different forces is basically the gravity force, surface tensile force, the electromagnetic force any force due to the metal vapour. And this case a very complex impact on the different types of or different modes of the metal transfer in arc welding process.