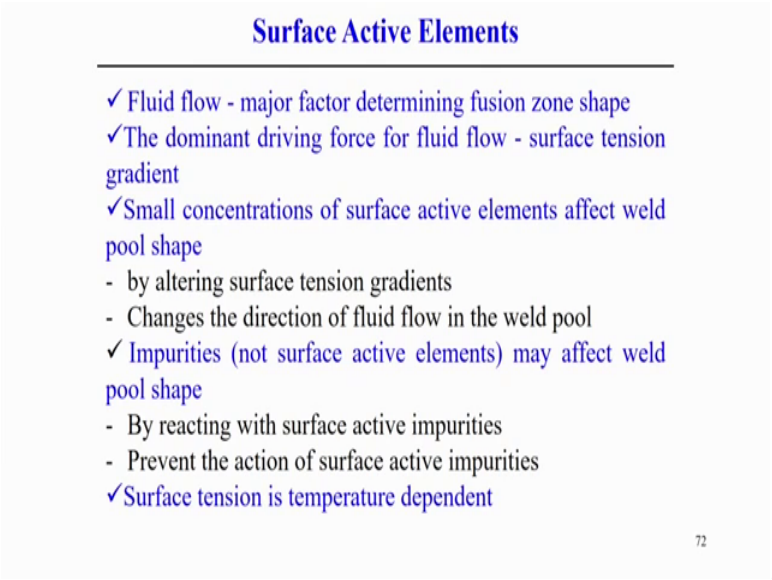
Advances in Welding and Joining Technologies

Dr. Swarup Bag
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture – 05
Fundamentals of Welding and Joining- Part V

Good morning everybody, now I will start the next component or may be last component of the module 1. So, first of all I will try to focus on the what is the effect of the surface active elements.

(Refer Slide Time: 00:45)



So, you know in welding process that apart from the conductive heat transfer that actually happens within the weld pool; there is a considerable amount of the material flow or may be fluid flow occurs within the weld pool. So, in that case that fluid flow actually takes a major role to determine the fusion zones.

Most of the cases we normally neglect these fluid flow effect and most we always try to do the heat transfer analysis by using the only heat conducts are happened during the weld pool so; that means, we generally assume the stationary molten weld pool, but very intuitively if we look in to in depth analysis of the weld pool the molten metal that actually flow one specified direction and that that flow actually driven by the different

driving forces mainly the surface tension force is the mainly responsible for the liquid metal flow within the weld pool

And of course, indirectly that flow also other way effect the shape and size of the weld pool. But there is a one question is that composition of this molten pool sometimes play an important role; in the nature of the material flow within this small weld pool. So, one of the such interesting elements of analysis in the material flow that is called surface active elements. So, in simplified way surface active elements actually influence the surface tension force; the surface tension force means between the liquid molten pool and shielding gas the surface tension force act.

So, now will try to look into the what is the nature and the direction of the surface tension force and how this surface tension force actually influence by the surface active elements. And of course, this indirectly the surface active elements influences changes the magnitude of the surface tension and that surface tension force actually influence the nature of the material flow.

So, of course, the main factor or main driving force for the fluid flow is the surface tension force apart from the buoyancy force or if in arc welding process if there is a there may be the effect of the electromagnetic force or there may be effect of the plasma force that comes from the creation of the arc that actually influence. But influence of plasma force, buoyancy force and electromagnetic force may be less impact on the material flow, but surface tension force is the most important driving force or most significant force that impact more on the material flow.

So, definitely not only the surface tension force rather it is better to say the surface tension gradient. Because the surface tension gradient also depends on composition of the metal; not only that also the it depends also the temperature so, it is a function of the composition as well as temperature. Now; sometimes the small concentration of the surface active elements actually that effect the weld pool shape.

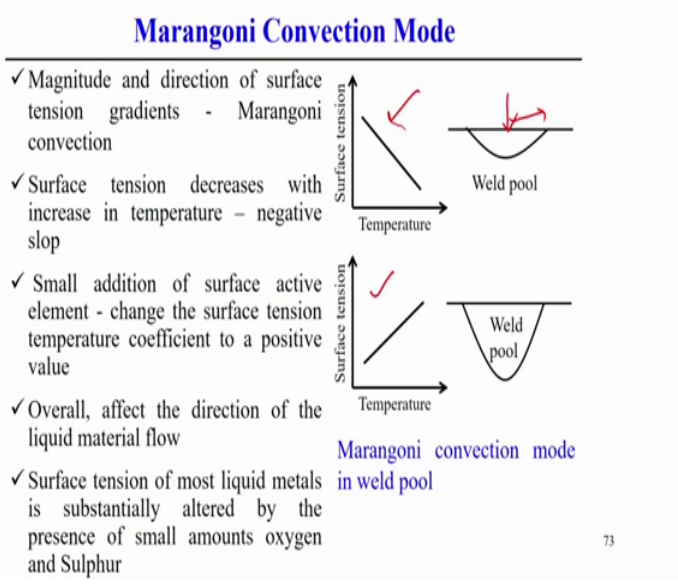
For example, if we consider the pure iron and for example, if we consider the steel if we assume the steel is having the binary system iron plus 1 surface active elements. So, between the pure iron and this binary alloy of iron that actually in these two cases the nature of the material flow can be differed depending upon the presence of the surface active elements in the second case.

So, small concentration of this surface active elements actually effects the shape of the weld pool the in the way by simply changing the or altering the surface tension gradient this is one way or then surface tension when there is the change of the surface tension gradient and there may be the changes in the direction of the fluid flow in the weld pool.

So, when there is a change of the direction of the fluid flow in the weld pool that actually influence the shape of the weld pool. But in the composition there may be some impurities which are not actually surface active elements; that may affect the weld pool shape in the way that impurities actually can react with the surface active elements and they can form the some other compound. And that compound can prevent the action of the surface active impurity impurities by simply changing their concentration gradient or simply changing their con concentration of the surface active elements. So, that way it may be a complex phenomena but.

If you try to analyze the effect of the surface active elements, we consider the it is a binary array system. So, based on that it is easy to explain the effect of the surface active elements definitely surface tension is always a function of temperature; so, that temperature dependent. So, that surface tension force will need to point of view one is concentration dependent assuming as well as the temperature dependent. So, based on this two points of view we can try to analyze the effect of the surface tension force.

(Refer Slide Time: 06:48)



So, that magnitude and the direction of the surface tension gradient that actually influence the (Refer Time: 07:00) material flow within the weld pool. So, in single term that is called the material flow within the weld pool is basically that is called the Marangoni convection. So, normally what happens the Marangoni convection mode in this case, if you see the first case or the first figure that surface tension actually decreases with increase in temperature.

So; that means, surface tension decreasing with increase in temperature in case of welding process exactly at the center point; temperature becomes maximum and away from this center point the temperature actually decreases. So; that means, there exists some temperature gradient from center to the outward periphery of the weld pool. And accordingly the surface tension also varies from that nature of the surface; direction of the surface tension force depends on the these variation of the temperature.

So, that can be represented that temperature and the surface tension in this figure that the gradient actually is the negative gradient. So, in this case the presence of this negative gradient actually creates the normal weld pool; normally having the width with its more and depth is less in this case. Now what happens? So, without any presence of surface active elements, this is the normal behavior of the material flow within the weld pool that can be represented the negative slope of the surface tension; negative slope of the surface tension with respect to temperature.

And then it creates a normal weld pool, but what happens if some small amount of the surface active elements is added? That actually changes the surface tension temperature coefficients to a positive value. So, adding of the surface active elements is basically change the slope; so, from negative to positive slope. So, when there is a change of this slope; that typical nature of the behavior of the surface tension force or surface tension gradient is basically impact on the nature of the material flow.

So, in the second case what happens? Since the surface tension; the gradient changes from negative to positive gradient then accordingly the shape of the weld pool changes. So, in this case the weld pool become narrower the width becomes narrower, but depth actually increases. So, other way you can say in the second case probably it is more advantageous if we try to achieve the high depth of penetration; so as compared to the wider width.

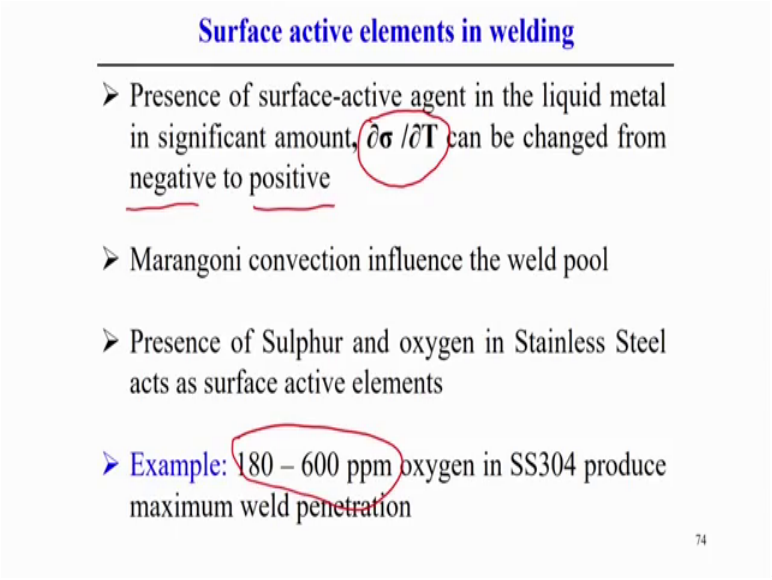
So, second case the aspects; so, also increases with respect in respect to the first case as well as the penetration also increase in the second case. So, the in the second case it is more desirable and that comes from simply basics simply by simply adding some amount of the surface active elements. But of course, the quantity the amount or the concentration of the surface active elements also having some role; not any amount of the surface active elements can change this surface tension gradient from negative to positive.

So, what we understand from here? That basically the presence of the surface active elements that actually overall effect the direction of the material flow and that actually influence the change of the weld pool size and shape. So, this two types of mode we discussed that is called the Marangoni convection mode probably we observe in the weld pool.

Definitely the surface tension of most of the liquid metals is substantially basically altered or changes by presence of the small amount of the surface active elements like oxygen and sulfur. Normally practically we observe in steel, presence of oxygen and sulfur certain quantity that actually acts as a surface active elements and they have altered the surface tension force and the mode of the material flow and finally, the effect the size of the weld pool.

Now presence of the surface active elements or agent in the liquid metal is significant and that is better represented by the temperature gradient of this surface tension force. And that temperature gradient of the surface tension force, that actually changes from negative to positive changes and depending upon the presence of the surface active agents in this case.

(Refer Slide Time: 12:10)



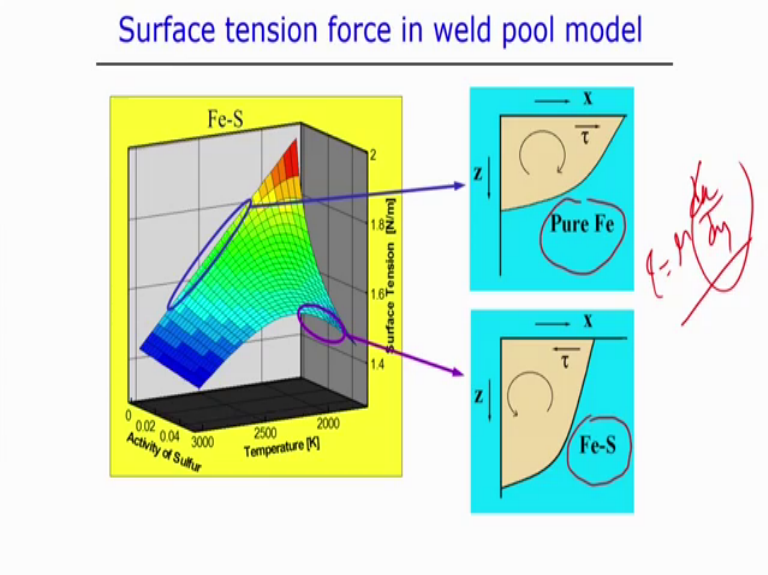
So, the Marangoni convection the flow of the Marangoni convection within the weld pool that that actually influence the weld pool in presence of the in presence or absence of the surface active elements. So, one example is that presence of the sulfur and oxygen in steel normally observed in specifically stainless steels acts as a surface active elements.

So, one practical example of the surface active elements we observed that 180 two 600 ppm within the final weld pool presence of oxygen in SS304; that means, stainless steel. Produce the maximum weld penetration with a certain specific welding condition so; that means, there may be some optimum amount of this surface active elements that can there we can get the maximum benefit of the we can achieve the maximum weld penetration.

But if you further increase the amount surface active elements; it does not influence the surface active agent in this case. So, we can we cannot increase penetration too much and if we abruptly increase the amount of the surface active elements, but at the same time if the very small quantity of the surface active elements also may not be beneficial to increase the depth of the penetration. So, this optimum amount practically observed shows that it actually gets the maximum benefit of the maximum penetration can be achieved.

So, conclusion is from that presence of that surface active elements that some optimum quantity of the surface active elements is always beneficial to get the maximum depth of penetration in case of any welding process. So, we can further analyze this.

(Refer Slide Time: 14:11)



Basically the surface tension force effect of this active eh surface active elements in the weld pool model. Here if you see that one binary system; that means, Fe-S. So, pure iron and sulfur; so, sulfur also can be can acts as a surface active element. See here we can see that it is a combined element of three dimensional figure that once the surface tension force is a function of here the temperature; as well as the activity of sulfur means eh amount of the sulfur and temperature both actually is a makes the combined effect on the surface tension force; here we can see.

So, this figure shows that nature of the surface tension force we can see that with respect if will look into the with respect to the temperature. So, at certain temperature optimum temperature there is a surface tension force is maximum for a fixed amount of the surface active element. And other cases if you see that combined effect very small amount the surface tension force becomes very maximum it is a very small amount of surface active element and probably at the high temperature.

So, this three dimensional figure we better explain in this way that this case that here the surface activity surface active elements is low in this case. So, very small amount of the surface active elements or I can say that there is more surface active elements. So, in this

case that which have to represent the nature of the Marangoni convection in the weld pool like that. So, it is the in case of pure Fe pure iron; that means, there is no surface active elements in this case the Z are in depth direction and the on the on the top surface the what should be the weld pool in this case. So, here the shear stress is basically acting from center to outward periphery.

So, that actually try to drive the molten material from center to outward periphery and we can say its try to create on this plane some material flow occurs it clockwise direction. So, with this nature of the material flow actually try to increase the width of the molten pool. And try to decrease the penetration of the molten pool so; that means, in case of pure iron; that means, without any effect of the surface active elements; normally we can expect the wider width and the low depth of penetration; it depends on the nature of the material flow or nature of the Marangonis convection that happens within the weld pool, but in other cases if you can look into this other part in this case metal is having considerable amount of the surface active elements.

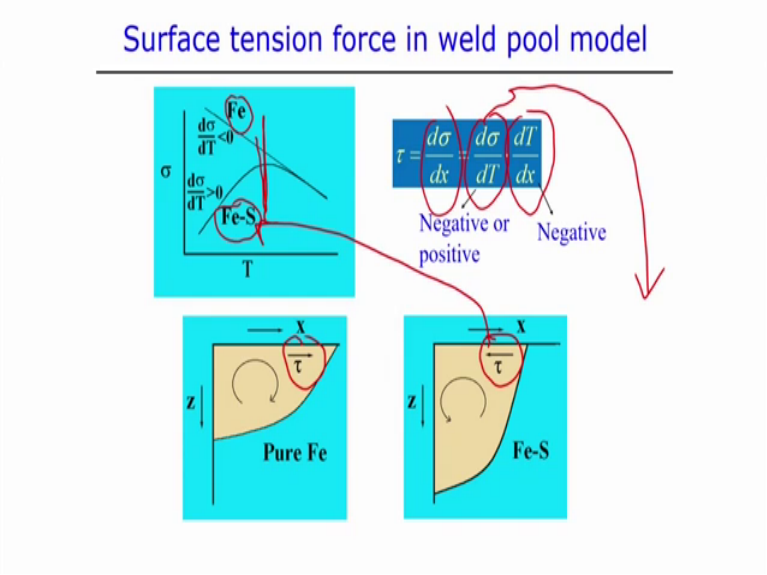
So, I can say binary system Fe s system and we focus on that material is having considerable amount of the surface active elements and certain temperature; it achieve at the certain temperature. So, in this case what happens? That shear stress; shear stress we can find out at shear stress in this case the viscosity into velocity gradient something like that. So, that shear stress is acting on the surface is not exactly outward direction; it is acting the inward direction.

And that shear stress is basically comes from the eco effect of the nature of the surface tension force. And then surface tension force and that shear stress is linked with the velocity gradient so; that means, that metal is flowing from outward periphery to the out center direction. That means, it will try to create the flow of the material flow it is like that some anti clockwise direction its completely reverse from the pure iron system; pure Fe system. So, when it is making the clock wise material flow that impact on the final weld pool shape like that, it actually decreases the weld with, but it try to increase the depth of the penetration.

So, in this way basically that once it is surface tension force changes, gradient changes with respect to temperature and the concentration of this surface active elements and that finally, it influence the Marangoni convection of the weld pool and it basically impact on

the shape of the weld pool. We can further try to look into that try to present this thing that surface tension force temperature.

(Refer Slide Time: 19:12)



And these two cases one is the in case of iron it is represented by the simply negative slope; that means, slope is less than 0 and this temperature coefficients of the surface tension we can say and other cases the Fe-S nature. So, it is a binary system; that means, it the Fe s system it basically takes the includes the effect of the surface active elements. So, in this case with active to temperature it is the optimum value the positive slope up to certain point, then the slope becomes 0 and then again the further increment of the temperature the slope actually changes to the negative.

So, up to that point it behaves the completely different from the pure iron system, but when you cross the optimum point, then the slope becomes again slope becomes negative slope becomes negative; that means, it is the similar phenomena similar situation like the pure iron so; that means, there is no effect of the surface active elements beyond certain optimum temperature.

So, that is better explained in the way that shear stress can be defined by the shear stress is acting of the fluid surface of the fluid in terms of the (Refer Time: 20:42) of the surface tension force because surface tension force is basically represented by the force per unit length. So, then when it is derivative with respect to length then it becomes the stress value. So, then shear stress is linked the surface tension force and then this surface

tension force; derivative of the surface tension force can be written in this two components. One is the temperature differentiation of this surface tension force and second part is the temperature gradient. So, with this decomposition of these two components; it helps to explain the effect of the surface tension force.

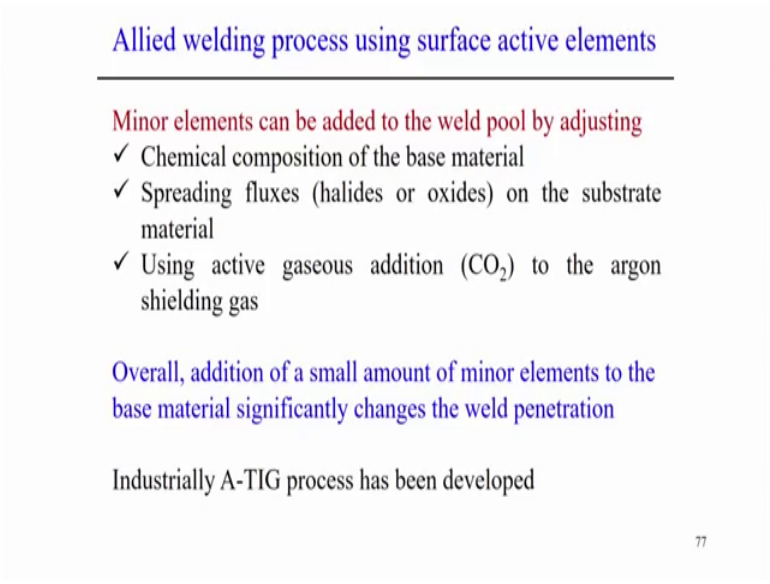
So, that temperature gradient of the surface tension force it can be negative or positive; depending upon nature of the presence of the surface active elements or presence of the surface active elements. It can be for example, in case of pure system it becomes negative; if it is having the surface active elements that slope becomes positive. And the second component is the temperature gradient; it is always negative because at the center point of the weld pool the temperature is maximum and the outward periphery; the boundary the temperature becomes less.

So; that means, temperature gradient is always negative in this case, but the nature of the stress; so, combining this two we can say that the shear stress acting on the layer; of the fluid liquid metal liquid metal, they can be positive or negative. That means, the direction can be that can change depending upon this value of the temperature co piece of the surface tension; whether it is positive or negative, depending upon this value the sign of the ordinary magnitude and the we can say the magnitude and the direction of the shear stress it may take from positive to negative.

So, here the shear stress in this direction when there is a when temperature coefficient surface tension is negative. And it is in the opposite direction when the coefficient of the surface tension is the positive; that means, it is corresponds to the Fe-S system; that means, presence of the any surface active elements.

So, in that way change of the sign of this shear stress is basically the acting on the top surface of the liquid molten metal; when it is interactive with the of course, with the shielding gas. Then there may be the they can change the direction of the material flow and accordingly the size and shape of the material weld pool can also be changed.

(Refer Slide Time: 23:35)



So, with this phenomena or this basic physical or basic observation from the effect of the surface active elements; there are some alive process welding process are also developed by considering the effect of the surface active element. So; that means, if it is possible to add some amount of the surface active elements within the weld pool, but during the welding process that can consider the positive effect of the surface active elements; that means, it can effect on the weld pool shape. So, what are the different way to consider practically the surface active elements becomes a final part of the weld pool?

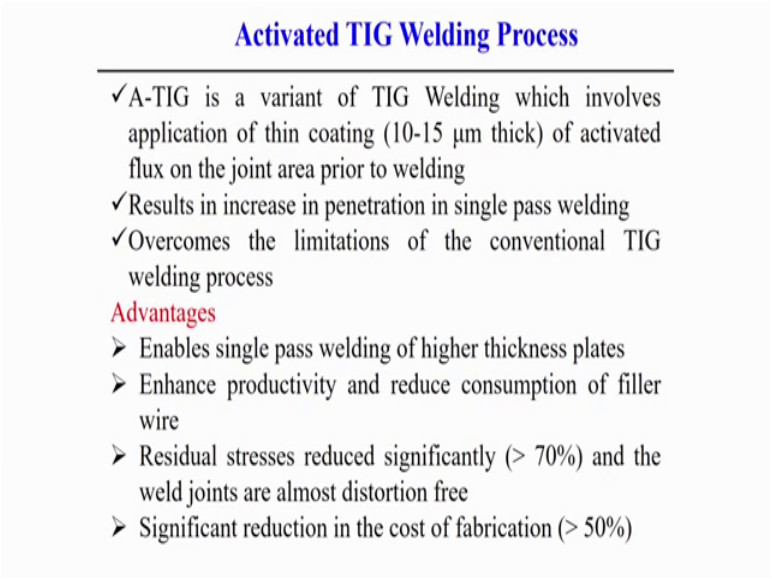
So, there are three different way first is that minor elements; that means, either oxygen or sulfur in generally we consider these two components to the minor elements can be added by adjusting first is the chemical composition of the base metal this is the one way; chemical composition of the base metal. That means, the surface active elements already becomes the part of the base metal and when you try to weld that metal, then there may be the effect of this surface active elements. Or there are other way also simply spreading the fluxes; that means, halides or oxides on the substrate materials. So, simply making the different oxides; the coating of the oxides on the on the material which is supposed to weld.

So, in that way also it is possible to supply the surface active elements and there is the another way; directly using this surface active elements with the shielding gas that is the another option. For example, sometimes carbon dioxide gas co two can be used with the

argon shielding gas and that here the oxygen can impact or act as a surface active elements to alter the shape and size of the weld pool. But overall addition of the small amount of the minor elements to the base material significantly changes the weld pool penetration.

So, based on this three different way we can add the surface active elements; there is a one development of the process that is called industry industrially A-TIG activated TIG welding process has been developed; activated TIG welding process means activated tungsten inert gas welding process.

(Refer Slide Time: 26:21)



So, in this the activated TIG welding process can be defined in the following way that a TIG is the simply variant of the TIG welding process or we can say the gas transfer arc welding process. So, what happens in this process that sometimes we use the application of the thin coating 10 to 15 micrometer thin coating of the activated flux is added on the specifically on the joint area before welding.

So, once it can be done before welding and then we can do the normal TIG welding process; tungsten inert gas welding process or it is also called as rate of gas arc welding process. So, once you do the normal welding process then this surface active elements actually effect on the and it finally, changes the weld pool shape and size impact on the final weld joint properties basically.

So, in this way we can; the A-TIG process is basically this is the way we can overcome the convectional TIG welding process by simply developing this process. So, of course, the A-TIG is the activated TIG; TIG welding process simply buying the coating amounts, but natures are also developed that directly adding the surface active elements for example, carbon dioxide with the shield argon shielding gas.

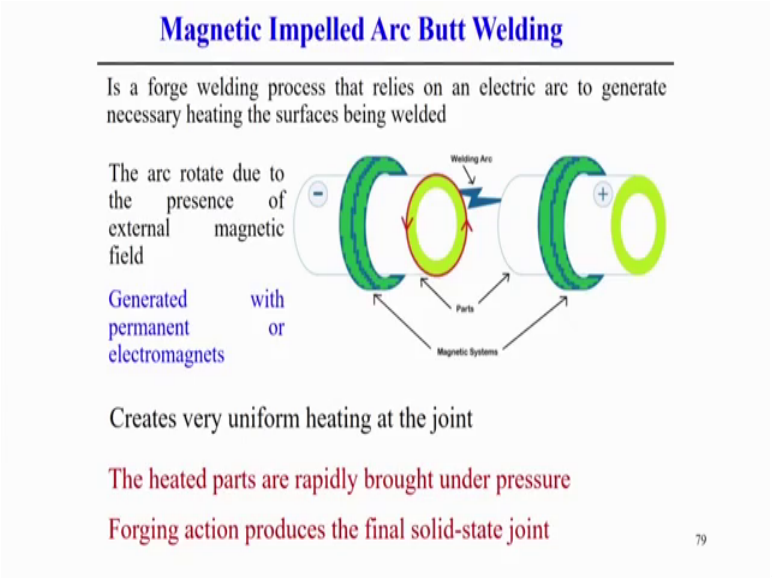
And that can also be used as a modified TIG welding process to include the effect of the surface active elements. But activated TIG; different activated TIG welding process is here normally we use the coating of the activated flux; so, that is the difference here. So, what are the typical advantage of this process? That basic advantage this process is; it enables the single pass welding of the higher thickness plates.

So, single pass welding of the higher thickness plates and not necessary to do the multiple welding because it considerably increase the depth of penetration. So, multiple process is not required in this case that is the one significant advantage of this process. And of course, enhance the productivity and reduce the consumption of the filler material in this case residual stress can be reduced significantly more than 70 percent and the weld joint are basically almost distortion free distortion can be avoided using this activated TIG welding process.

And of course, the significant Redox in the cost of fabrication and more than 50 percent in general because as compared to the say; normally TIG welding process is low cost process as compared to the laser welding processes. So, of course, laser welding we can achieve the high depth of penetration of the high concentrated heat, but even TIG welding also we can achieve the high depth of penetration; only we need to modify this by including the effect of the surface active plate elements.

But practically when you try to use the in incorporate effect of the surface active elements; we need to do a clear investigation is required to find out the optimum quantity of the surface active elements of a specific welding system; that is important to know. Because at any quantity or a this may not possible to achieve the effect of the surface active elements positively.

(Refer Slide Time: 30:08)



So, next topic is that apart from the effect of the surface active elements, we will look into another interesting welding process which normally use welding of the basically joining of the two pipes. And the more efficiently with the less time; with the low cost the pipes can be welded. So that actually develop this process from the basic taking the basic principle of the arc welding process, but by incorporation of the magnetic field here. So, this process is called magnetic impelled arc butt welding.

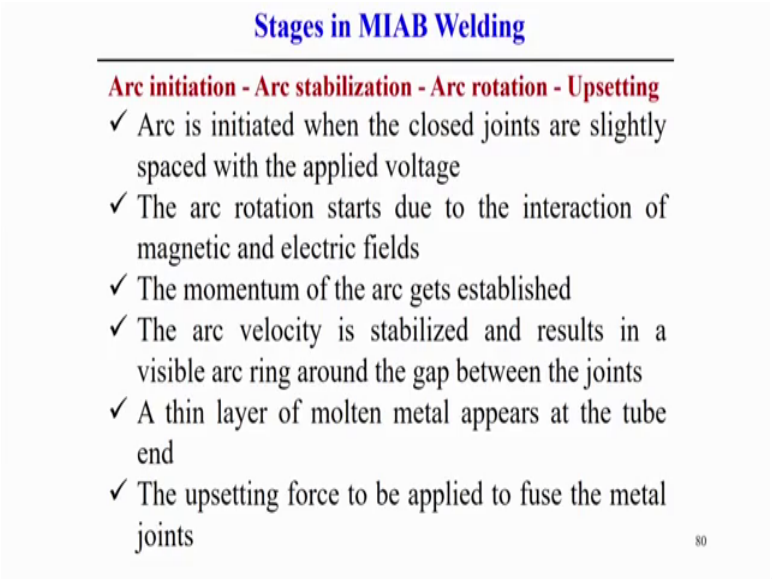
So, what is a principle of this process? So, in a forge welding process; so, it is basically forge welding process that actually rely on the electric arc to generate the necessary heating, but sometimes small melting can also happen and. So, that surface is being the welded; so, what happens? That it is a kind of first we heat the surface; uniformly heat the surface and then after heating the surface we come into contact by the forging process.

And then it becomes welded after the forging process. So, in this case the arc actually it os a because more the cylindrical components mostly use you see the figure that two cylindrical component can be joined here. So, arc is created at one point here between this two and between these two circular component; the arc is arc is created at one point. Then next point is that it is to create the uniform arc throughout the whole circular section.

So, first after creation of the arc then it spreads over through circular section. So, then when it is a melt heated and not too much of melting little bit melting of this two surfaces happen; then we simply do the phrase fitting of this two components and then it becomes welded. So, that is most easiest process in for joining of the circular component, but what is the role of the magnetic field here.

So, basically magnetic field is created here to rotate the arc and after shutting of the arc to rotate the arc the magnetic field is controlled in such a it spreads the rotates the arc so, that it can create the arc between these two components throughout the whole circular section. But this magnetic field are basically generated with the permanent or the magnet or from the electromagnets, but advantage of this process is creates very uniform heating at the joint. So, the heating part are rapidly brought under the pressure; so, quickly brought the under the pressure and the forging action produces the final weld joint.

(Refer Slide Time: 33:20)

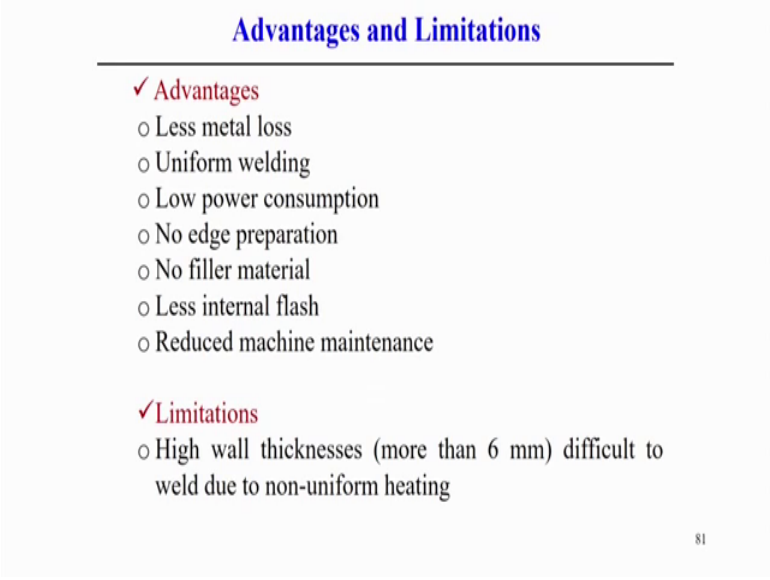


So, what are that stages of the magnetic impelled arc butt welding process? So, four basic steps first is the arc initiation of the arc then stabilization of the arc rotation. So, that and then finally, upsetting; that means, mechanical forging is required in this case also. So, these are the four basic steps; first is the arc is initiated while the two joints are very close joints are slightly spaced with the applied voltage the applied voltage arc is created.

And second part is the arc rotation starts is due to the interaction of the magnetic field and the electric field. So, due to the presence of magnetic field the electric field that start the arc rotation. So, in after the start starting of the arc rotation; the momentum of the arc wants the momentum of the arc gets established. So, momentum of the arc becomes established and the arc velocity is then stabilized and results in the variation level arc ring around the gap between the joint.

So, first initiation of the arc and then stabilization of the arc and then electromagnetic field basically try to rotate the arc. And once the arc rotate uniformly throughout the whole ring; then it try to creates the uniform heat throughout the ring. So, a thin layer of the molten metal actually appears at the tube and so, once it is done then rapidly the upsetting the upsetting force is applied so, that the fused metals can be joined.

(Refer Slide Time: 35:13)

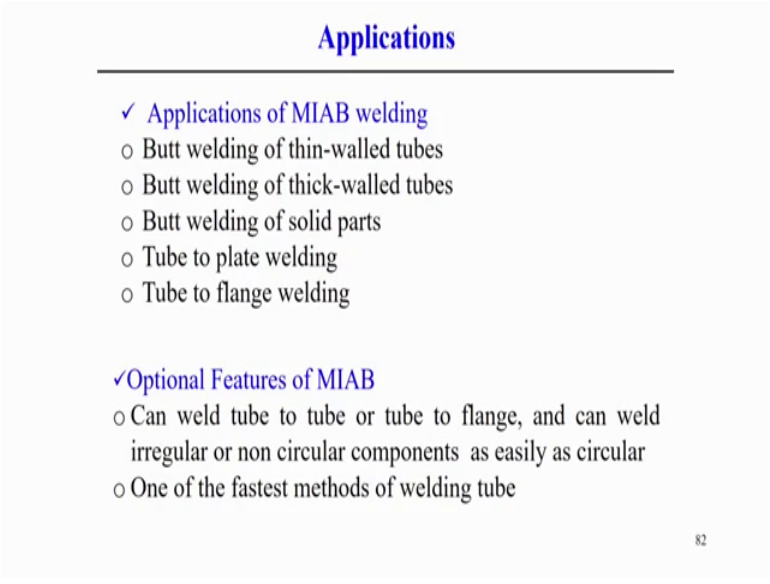


So, if you look into the typical advantages and limitation of this process is that advantage is that very less loss of the metal is also very less in this case and uniform welding. So, that is the basic features when you trying to join; the welding of a pipe and probably this process is very much advantageous in as compared to the other component in welding process.

Because the rotation of the arc throughout the whole structure it actually try to creates the uniform heat throughout the whole circular path of the (Refer Time: 35:49) so, that is the another advantage. So, that is called the uniform welding; power consumptions may

not be very high no edge preparation is required because using the creating the arc, we basically melt the surface and then only we do the upsetting force. So, less material flash also required and no filler metal is not required in this case and of course, the other point of view the its also reduce the machine maintenance, but one limitation of this process is that if thickness is very high; probably it is if it is more than 6 millimeter then it is difficult to weld using this process because at that at very high thickness it is difficult to maintain the uniform heating throughout the whole circular path of the foil.

(Refer Slide Time: 36:53)



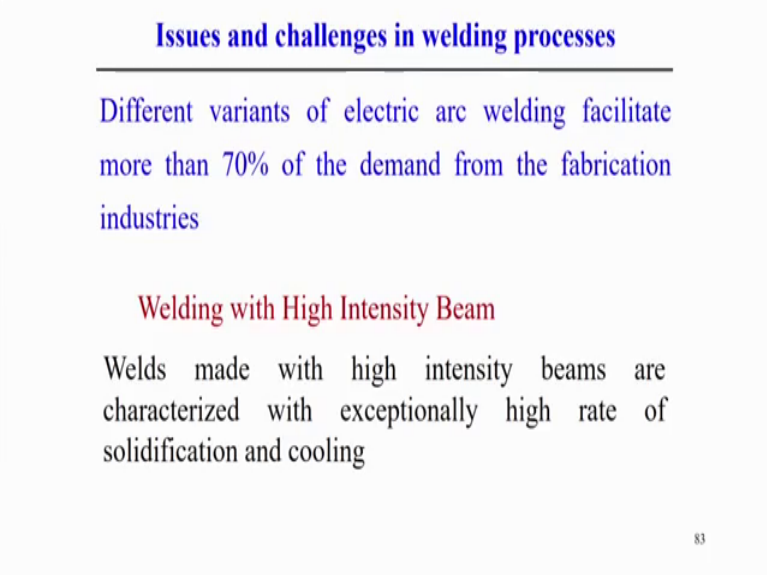
So, that this process is limited up to the 6 millimeter so, far. So, we find out the applications of this welding process in this typical that butt welding of the thin walled thin walled tubes is even thick walled tube also can be done thick walled tubes having some certain limitation. Like just explain its about 6 millimeter thickness tube we join; butt welding of solid components can also be joined and for a larger area.

And then tube to plate tube to plate welding and tube to flange welding can also be done using this process, but this process mainly applicable for the any circular or hollow kind of or basically tube kind of components or materials. But what are the apart from this circular or very circular symmetric components; what are the other options of optional features of the of this process is that, it can weld tube to tube or tube to flange and can weld basically irregular or non circular components as easy as circular. So, sometimes it is non circular components can also be joined by this process or source other one of the

main optional feature of this things one of the fast rate methods of welding of the tube or basically the welding of the pipes is using this process.

So, oil industry basically the welding of the pipes quickly they can use this process; now apart from all these process we this module we have tried to get some overall view of the different fusion welding processes, their basic principle, their application area limitation. But there is a welding overall subject if you if it is a worst area now we will try to focus on the of course, there are certain advantage. So, much of development some limitation also having here I tried to summarize the few issues and challenges generally observed in the welding process.

(Refer Slide Time: 39:08)



First significant point is that most of the fabrication industries; that means, around the arc welding process; basically used more than seventy percent of the demand from the fabrication industry. So; that means, mostly usually in fabrication industry most usually welding process are the different variant of arc welding process this is the information. So, that several development of arc welding process depending upon the need area applicability has been developed of course, if you look into other aspects for example, that thermite welding.

So, need of this welding process actually to apply in the remote area. So, there is no need of the electrical connection in this case; so, that is why this process has been developed from the application point of view basically joining of the railway track, there we can use

remotely in this process. So, in that case thermite welding process is more preferable more useable. So, in that sense of course, there are very precision or there are the welding processes, but till arc welding process is mostly useable process in case of the fabrication industry depending upon the availability or requirement of the welding process of course, cost is the another important factor.

In contrast to that arc welding process the other laser beam welding process; high beam energy welding process. For example, high beam energy process means laser welding process and electron beam welding process that using this process also we can produce the very precise joint with the minimum defect or where there is a difficulty arc welding in the arc difficulty of joining metals using the arc welding process; in that case probably the high beam energy is the more preferable welding process.

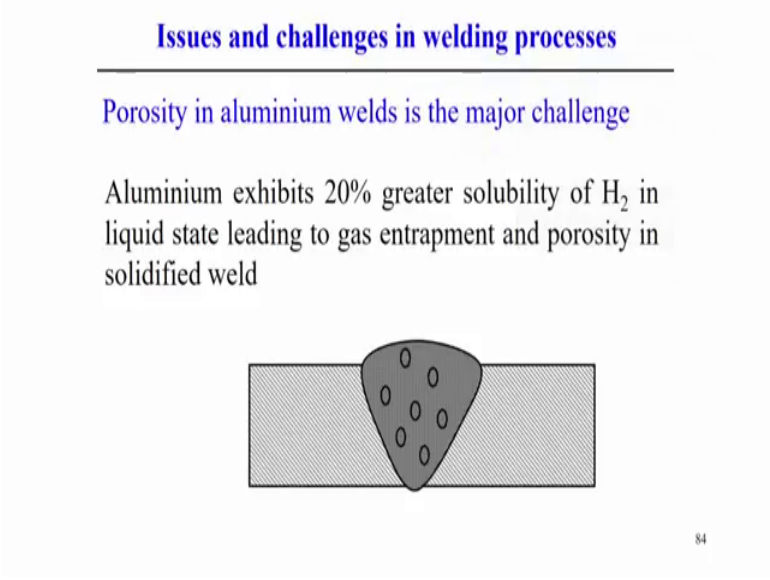
So, arc precision is the most significant and cost is not cost is not the important in that in that aspect probably the laser beam or electron beam welding process is more preferable for example, aerospace industry most of the cases the welded components are from the electron beam welding process and that because electro beam welding process definitely it is a very costly process.

So, that is a need and each and every type of welding process having the one merit and sometimes having the demerit their applicability area. And it depends once the according to the cost on and their importance in terms of the accuracy of the weld joint finally. But of course, the one of the significant aspect in the welding of the beam in intensity beam is that that excessively high concentration of the heat, but at the same times the rate of cooling is normally is very high in case of the high intensity beam welding process. So, rate of the high solidification the cooling is normally; we observe in case of high beam energy process. So, that rate of cooling or process that actually impact on the final weld micro structure.

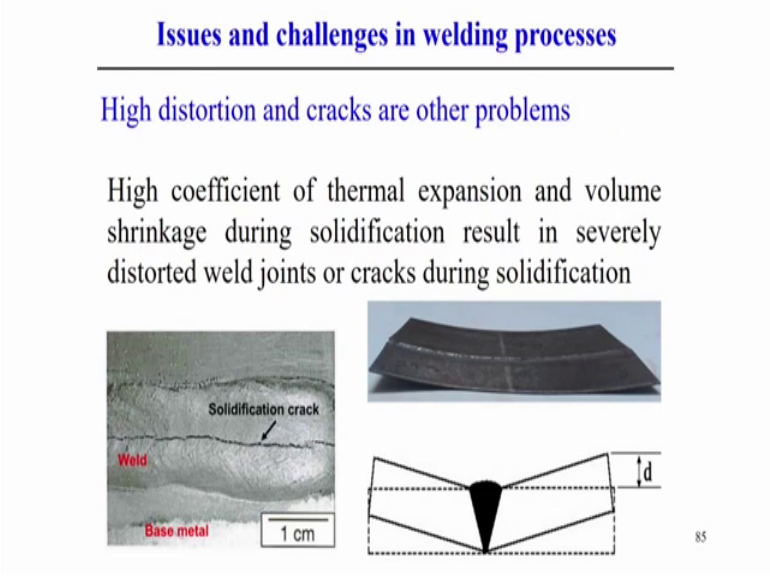
So, apart from that there is a another challenges in the welding process of the aluminium welding process. If you see the most of the cases in welding of the aluminium using the convection welding process is not easy like other type of welding of the steel phrase phase materials. So, porosity in aluminium welds is the major challenge because aluminium exhibits 20 percent greater solubility of the hydrogen in the liquid state and high temperature and that gas may be entrapped and creates the porosity in the solidified

weld so, that solidified weld becomes the part. So, if we use the in conventionally the other welding process the welding of alumimium is really very difficult. So, we can expect that probability of the formation of the weld defects will be more in case of the aluminium welding process. So, that is why not all the welding process is not suitable for the aluminium welding process, specifically sometimes specific design some modification of the welding process is required to join aluminuim.

(Refer Slide Time: 43:46)



(Refer Slide Time: 43:53)



In final welding structure even fusion welding process the high distortion and cracks are also the other type of the problem. Here high distortion of the crack is basically we observe that it that the distortion is mainly comes from the coefficient of the thermal expansion.

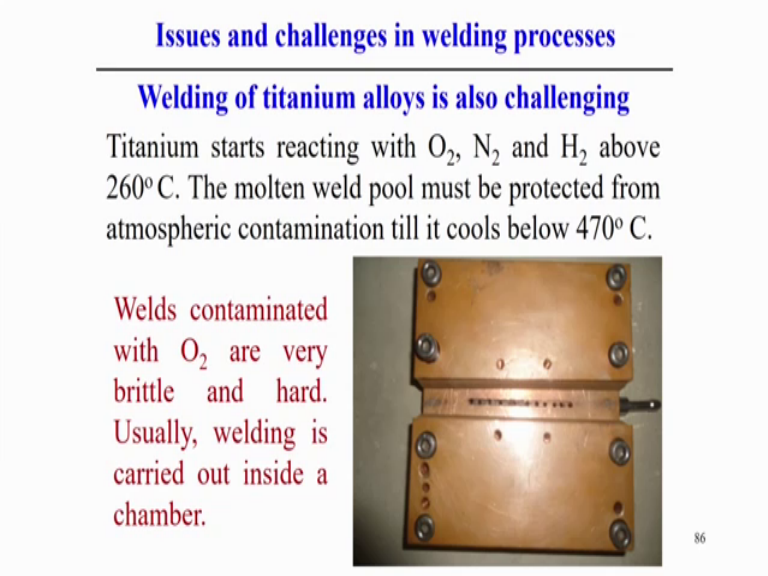
And if we observe that the if happens during the solidification the after application of the heat the molten and molten becomes solidified; the solidified structure can from the solidification cracking may also occur. So, that solidification cracking is mainly is due to the nature large change in the volume or basically volume shrink is very high during the solidification.

So, that actually creates either solidification cracking or creates the large amount of the distortion in the final weld structures or is it can create solidification cracking. So, that is the another problem specifically this problem is eh related to the large amount of the volume shrinkage in during the welding process. And it depends on the typical properties of the mat material the volume shrinkage, but if you look into this figure right hand side that it is simply joining of the titanium alloy and we can see there is a if plate is very high length.

So, we can observe some distortion; so, that distortion also comes that related to the amount of the residual stress generated within the body itself and finally, it creates the distortion. So, if we if we want to overcome this kind of problems; so, definitely we need to know the structural changes after the solidification or solidification behavior; how it needs to study in detail to predict the solidification cracking or different type of metals.

So, it is two or more less the metallurgical structure or changes during the welding process. So, this is different aspect we will having one module to look into that metallurgy of welding processes also. So, in that process its mainly how the metallurgy structure depends on the different rate of cooling during the solidification process, but of course, distortion, solidification, cracking this kind of problem will always be there during the welding process; only thing is that how we can minimize this kind of problems of the different processes.

(Refer Slide Time: 46:42)



Other issues of arc welding process is that basically the welding of the titanium alloy and of course, titanium alloy using the normal arc welding process is really very challenging. Because titanium actually at high temperature titanium or alloy react with the oxygen nitrogen and hydrogen at certain temperature and then molten weld pool must be protected from this atmospheric contamination; till it cools down to the certain temperatures. So, that is the real problem.

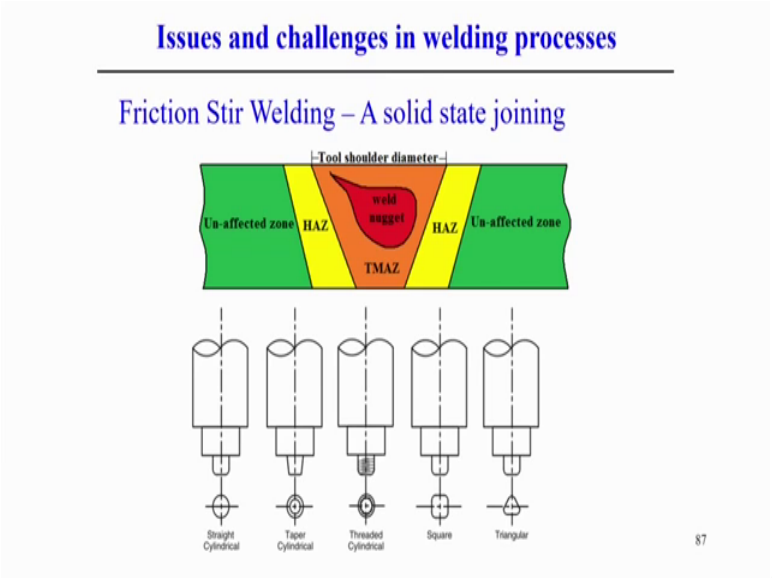
So, it may not be too much severe in case welding of the steel, but welding of the titanium is a very difficult because it is simply react with the oxygen and hydrogen and the oxygen becomes the part of the final weld joint. So, welds can contaminated into the oxygen and it actually creates the very brittle and hard. So, that is why to avoid the atmospheric contamination normal most of the cases; we do the welding of the titanium alloy inside a chamber.

Or some modification can be done when you try to do the welding of the titanium alloy so, that this oxidation problem can be at least it can be reduced. So, the one of the methodology of welding of the titanium alloy is that; if we change simply using the friction using for the welding of the two seat plate for example,. So, here we can use the copper plate and we can use the forging extra shielding gas. So, extra shielding gas actually comes from this small hole; if we look into this friction. So, that actually protect

the titanium alloy during the welding process. So, this is the one of the easiest solution for welding of the titanium alloy.

So, if this type of extra arrangement of the shielding gas may not be required in when you try to do the welding process simply either plasma welding or TIG transfers in a gas welding process. So, that is why to protect it this oxidation problem to some extent in case of welding of the titanium.

(Refer Slide Time: 49:05)



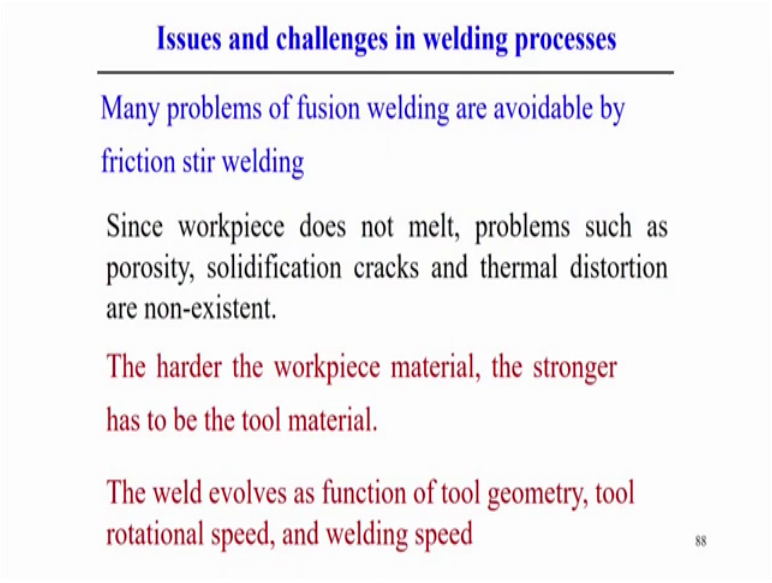
Another advantage; that means, as compared to the friction welding process; there is a recently there is a developed. So, much of development of the friction stir welding happens this is the one kind of solid state welding process. And if we see this solid state welding process that here also; the weld can be created in the different zone that weld nugget in friction stir welding process.

So, let us see the what is the friction stir welding process friction. Stir welding process simply two components are joined by stirring of the plasticized material. So, that temperature should be controlled in such a it should be weld below at least below the melting point temperature. So, frictional heat is generated and the plasticized metal is basically mixing and it finally, makes the weld joint. So, typical characteristics of this solid state welding process is that it creates some nugget zone that nugget zone is basically defined by the certain.

So, temperature thermo mechanically affected zone heat effected zone and unaffected base metal. So, to do this things we need the design of the tool is important to know here the different type of the tools tool (Refer Time: 50:32), cylindrical profile, taper cylindrical, having thread, and square triangular shape of the; so these are the different types of tools can be used for the welding purposes in the design of the different types of tools is merely activated to that that material flow or mixing of the material can be ensured to when to expect a good weld joint.

So, this friction stir is only the recent development in the solid state welding process and now-a-days people are also using these are also having so, many advantages as compared to the fusion welding process.

(Refer Slide Time: 51:09)

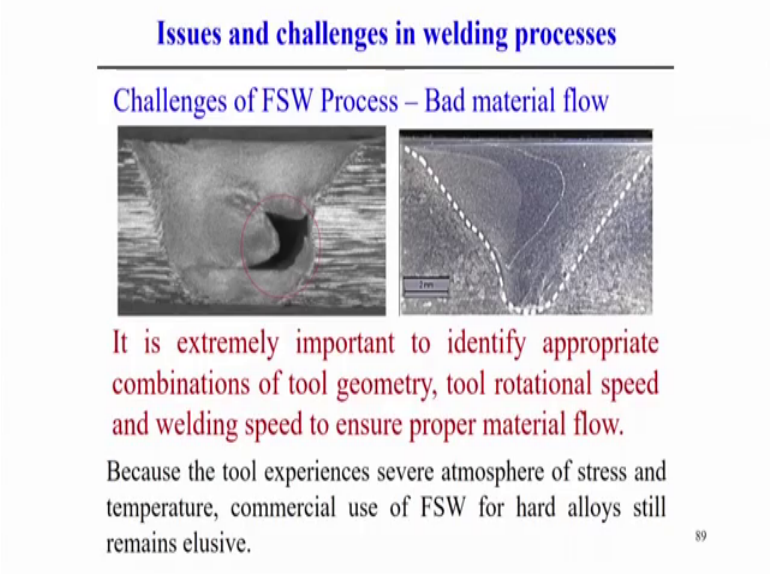


So, like that many problems of the fusion welding process can be avoided if you try to use the solid state welding process; typically friction stir welding process. So, in there is no melting of the work piece; so, the problem like the porosity, solidification cracking and thermal distortion are basically are almost basically nonexistence.

But only difficulty is that friction stir welding process limitation is that if there is a insufficient material flow then it can creates the some defects, but in general the harder work piece if the strength limit is also there; if the work piece is very hard material then the more stronger of the tool material also required. And because the weld actually evolves simply as a function of the geometry of the tool; nature geometry of the tool,

what is the tool rotational speed and the what is the welding piece or that actually impact from the final weld joint in the solid state welding process.

(Refer Slide Time: 52:22)



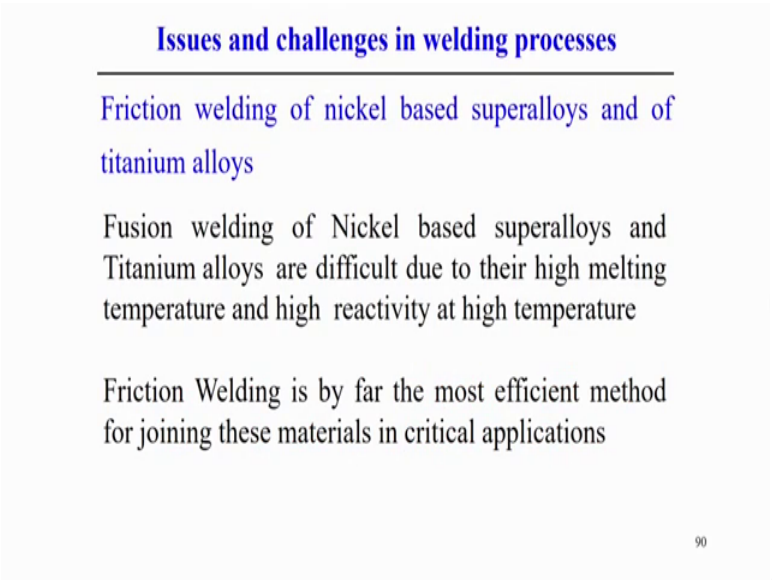
But issues and challenges in the welding process is that and challenge mainly if we find out that insufficient material flow; if we look into this figure that its welded joint, but we can observe some small gap so; that means, there is a this happens due to the material flow; it os not good then it can creates this kind of problem also and right hand side also it is a good weld joint and; that means, in solid state welding process joining these two components.

So, therefore, it is extremely important to identify the appropriate composition of the tool zone appropriate combination of the tool geometry and the other welding parameters should rotational speed weld and also welding speed that actually ensure the proper material flow; then we can use this combination of the parameters and we can expect the good weld joint, but other side the limitation of this process is that because tool experience the severe, amount of the stress, rotation.

So, wear of the tools is and cost of the tool also matter in this process and of course, this process is limited to up to certain if it is very high hard material; it is very difficult to welding this process. So, steel it is not commercially used specifically for welding of the very high hardness material. So, in that case the only solution is the fusion welding process, but few cases it is this process has been get we can expect a good weld joint

solid state welding process. In this case the difficulties or having porosity and cracking all this phenomena can be avoided this type of welding process these solid state welding process.

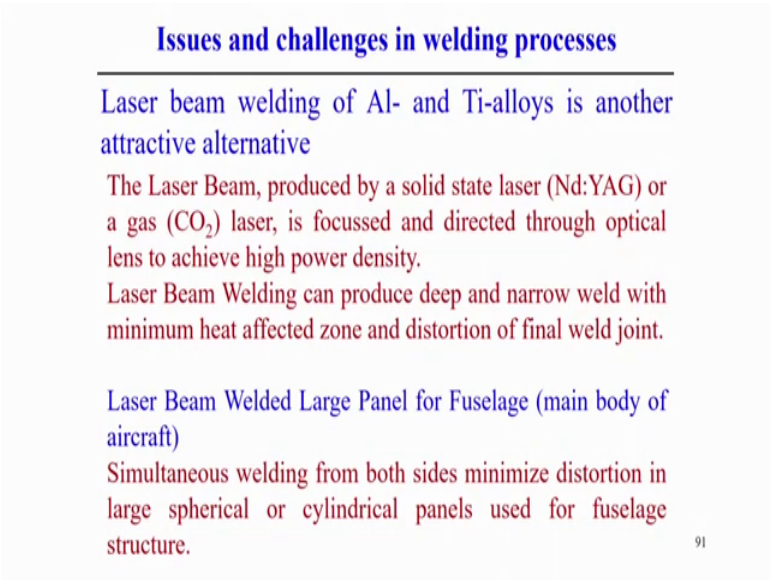
(Refer Slide Time: 54:18)



But another issues on in welding process that is called the friction welding of nickel based super alloys and titanium alloy.

So, this type of welding material we generally use the friction welding. So, of course the friction welding of the nickel based alloy super alloy and the titanium alloy is very much difficult because of their high melting temperature and the at the same time high reactivity with at the very high temperature. So, that is a limitation of using the fusion welding process specifically nickel based super alloy and titanium alloy. So, friction welding is the most efficient method by joining of this materials and is very (Refer time: 55:00) critical application probably in case of aerospace industry.

(Refer Slide Time: 55:06)



Now, other welding processes for example, laser beam welding process of aluminium and titanium alloy is another alternative method. So, laser beam can also be used welding of the aluminium or titanium alloy; we know the different type of the solid state laser. And gas lasers are also there and that laser bam beam can be produce the very narrow weld and with the minimum heat effected zone and high depth of penetration and small distortion as compared to the other welding process.

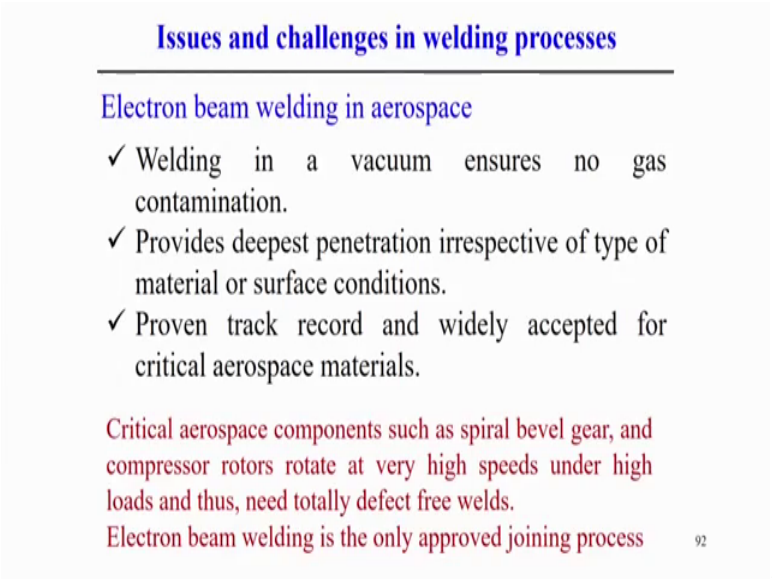
So, in that sense the difficulty of welding aluminium titanium in very convectional arc welding process. So, that can be used in the laser beam welding process; so, probably for example, in welding of the titanium alloy; if we try to use the laser welding process. So, extra shielding gas sometimes may not be required probably the shield shielding provided by the laser is during the laser welding process; if sometime is advantageous.

Or other way the welding can be done this for this material in a separate way from chamber, but merely in case of the large funnel few fledge; that means, it is the main body of the aircraft is basically we generally apply the laser beam welding process. So we because simultaneous welding from both sides; that is path of the welding in this case is very important.

So, if we choose proper path of the welding process; that means, simultaneous welding from the both side that actually try to minimize the distortion in a very large or spherical or cylindrical panels that used for the main part of the eh aircraft body. And electron

beam that is the another welding process that is the electron beam that is the another which is more welding process which is the more mostly used in case of the aerospace industry. And that beam that electron beam welding process in aerospace industry mainly used in a vacuum.

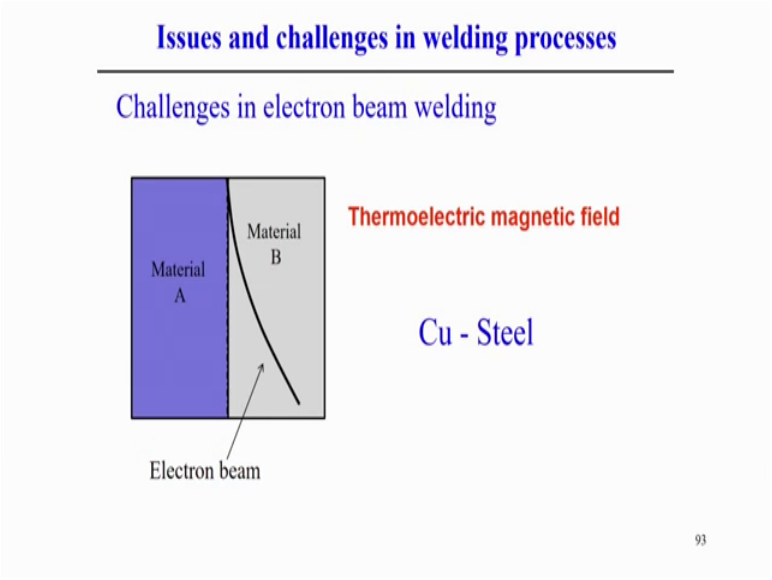
(Refer Slide Time: 57:15)



And that actually ensures no gas contaminations and that actually provide the very high depth of penetration irrespective of the type and nature of the service condition of the material. And this is very proven or widely accepted for the critically aerospace material. So, most of the aerospace component is used in case of used by the electron beam welding process.

So, critical aerospace component such as gear compressor rotor; this type of component of the aerospace industry they actually using the electron beam welding process because here the defect free is the main constant here. So, therefore, electron beam is the only is the good solution for the one of the approved joining process specifically used for the aerospace industry.

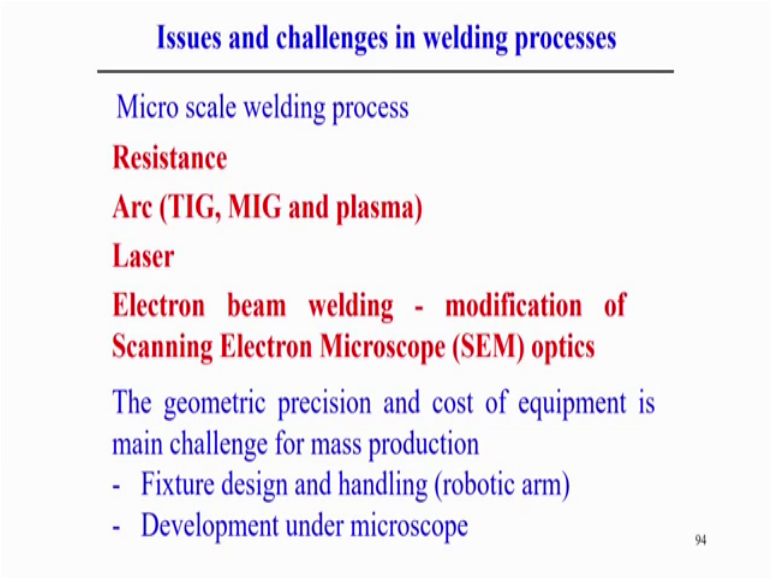
(Refer Slide Time: 58:17)



But one main channels of this electron beam welding process is that; there is a in electron beam welding process when you try to join the two dissimilar material. And because electron beam is flow of a electron with a defined path and there is may be the due the thermo electric magnetic field effect and that actually better explained by the sea back effect. Because of that the path of the electron beam actually get deflected in one side of the material depending upon the magnetic permeability of the both material.

For example, combination of the copper and steel; most of the cases the electron beam is basically deflected towards the steel material. So, it is very difficult to focus using this different combination of the material and exactly at the joint interphase. So, that is the one of the difficultly of the or challenges exist in case of the electron beam welding process.

(Refer Slide Time: 59:21)



Issues; now recent development also happen in the fusion welding process that actually occurs in case of the so, much of development happens the micro scale welding process. So, micro scale welding process is nothing, but the reduction in scale of application and from the convectional welding processes. For example, the development happens so, far in micro welding process is that resistance welding process is basically scaling down in case of micro scale application, arc welding.

For example, TIG, MIG and plasma these are the not exactly make basically TIG and plasma is mostly developed the application in the micro welding cases and the laser and finally, the electron beam welding process that all scaling down to the micro scale application. So, definitely now a days the specifically the different small very small component in a very smaller scale when you are try to join; then it is we generally use the different micro welding processes.

And that micro welding process say this typically micro welding process registers TIG and plasma welding processes, laser electron beam welding has been developed, but electron beam welding processes normally we use the electron beam welding process to apply the high electron high density of the; high heat generation and the it is a very focused small area and high depth of penetration. In that purpose normally we use electron bean welding process, but in micro scale application the principle simply by

modifying the scanning electron micro scope optics, then the electron beam welding has been developed the micro scale application.

So, in that case maximum 6 watt power can be generated in the micro scale application, but mostly widely applicable or most preferable welding process in micro scale application is the laser. Because laser can be very precisely controlled and powered can be scaled using even using the different types of the pulse. So, that is why laser welding is more advantageous in the micro scale application process.

But main challenge of this micro scale welding process is that geometric precision, cost of the equipment is the main challenge. Because sometimes we need to do the friction design of the friction and handling of the small component basically rebooting out can be used and of course, if micro scale application sometimes we need the development of the whole welding set up under the microscope. So, in that sense the cost of this equipment or cost of the process becomes very high and that is the main challenge of the micro scale welding process.

So, with this several issues and challenges existing in the welding process I conclude that first module of this basic fundamentals of the welding and joining process. Here I have tried to give some idea the basic mechanism with principle of the different type of welding process, different direction, advancement in the different types of welding processes also happened. And that what are the current issues and what are the current development in this welding process also happen that try to explain this module not in brief, but in try to give some in a introductory level, but in the subsequent modules we will try to discuss in details about the different types of the welding process or different directions or the different development happens in the welding process so.

Thank you very much for your kind attention.