Finite Element modeling of Welding processes
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Module - 01
Introduction to welding processes
Lecture - 05
Advanced welding processes

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Hello everybody, today we will discuss the remaining part of the module 1; that Advanced Welding Processes. Basically several welding processes and what are the advancements so happens in these particular welding processes that we will try to discuss today's talk.

So, after that we will discuss the wire additive manufacturing processes, but advancement in the welding processes may be mostly associated with the either laser beam welding process or electron beam welding process. So, these two processes are normally considered as the very high cost and high precision welding process as compared to that and conventional arc welding processes.

So, we will see what are that advancement normally happens in particular pertinent to the welding processes and that may helps to develop the numerical model or and the our finite element model in particular welding processes.

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So, in advanced welding processes we will try to discuss on the several processes for example, one is the laser welding process then laser assisted hybrid welding process and then electron beam welding process and then we will try to focus on the micro welding. What are the developments happens in the small scale application of the welding process, and then advances in laser micro welding processes.

What are the recent developments in the micro welding processes, laser micro welding processes that we will try to discuss in this module.

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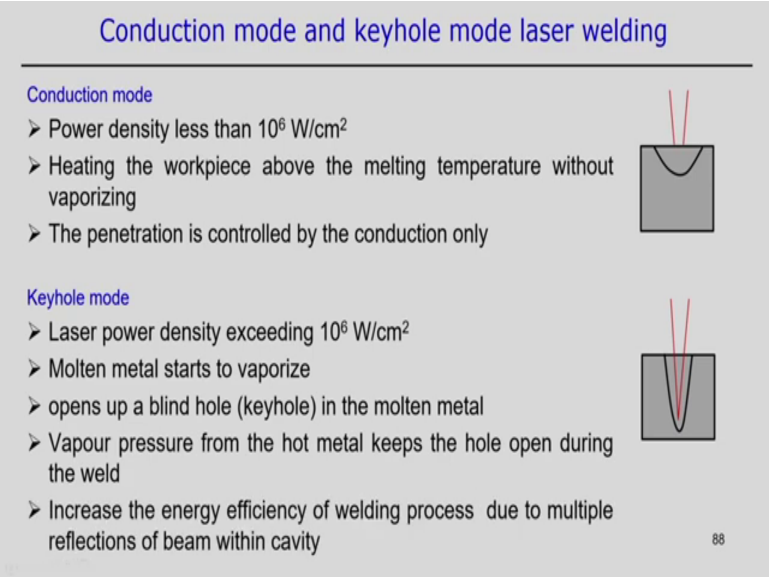

So, once we try to discuss the laser welding process then first things which is maybe significant from the mathematical point of view or for the model development in particular pertinent to the laser welding process is that whether the welding process is conduction based model or is there any formation of the keyhole that we will try to understand the first what is conduction and what is the keyhole.

So, conduction mode it is a very thumb rule to differentiate what are the power density is normally associated with the conduction mode welding that is we can see that power density less than 10 to the power 6 watt per centimeter square. So, in general if this is the power density then we can say it is a conduction mode welding process.

So, conduction mode welding process the workpiece is going the above melting point temperature, but without vaporization of the material. That means the maximum temperature can should be below the vaporization temper of this particular material that is we normally call the conduction mode laser welding process.

And see the penetration is controlled by the conduction means it is a through the heat conduction its maybe the molten material flow is there inside the weld pool, but heat transferred through the heat conduction equation, there that type of mode of heat transfer is normally called the conduction laser welding process.

Even we can see the conduction mode welding process is associated with the most of the arc welding process. So, that means, the arc welding the maximum temperature in the workpiece it should not go beyond the vaporization temperature of the particular material.

In that sense keyhole mode laser welding process is something different from the conduction mode welding process in this case. If laser power density is relatively higher side which is more than that of 10 to the power 6 watt per centimeter square, then it produce a keyhole. Keyhole means inside the molten material starts to vaporize; that means, once the laser is focused on the substrate material there is a vaporization of the material.

But it is not like that it is a complete vaporization of the material and then it may not be able to weld the particular component able to not able to join this thing, see complete vaporization is there then that is normally called the material ablation process. So, that is different phenomena, but in conduction keyhole mode laser welding process metal starts to vaporize and opens up a blind hole.

If you see the figure also if you see the it is a blind hole is opened and the very long hole. Such that very high depth of penetration can be achieved using the keyhole mode laser welding process. So, blind up in hole in the molten metal that is called the keyhole, but remaining part is a as a molten metal stays within this workpiece.

And vapor pressure from the hot metal keeps the hole open during the welding process. So, it is a kind of dynamic balance from the vapor pressure and for the formation of the keyhole and it becomes keyhole become stable during this process depending upon the other process parameter other condition.

Such that; the energy is entrained inside the workpiece material and up to a very high depth of penetration energy can enters and that is small blind hole keyhole forms in this case and then once it moves it becomes gradually the keyhole moves in a particular direction and along the moving direction of the laser and then behind this it is filled by the molten material and then after solidification we can get the joint.

So, laser welding mostly preferred to use in case of keyhole mode because it is difficult to achieve the keyhole mode welding process in case of other conventional arc welding process. So, that is why if there is a need to join very high thickness material then normally we prefer the keyhole mode laser welding process.

So, mechanism of the keyhole formation is completely different from the conduction mode and we will discuss in a separate module that, what way we can model the keyhole in case of laser welding process.

Now in case in energy efficiency one other important aspect of the keyhole mode laser welding process is that efficiency is much more; that means, absorption of the laser is much more as compared to the conduction mode laser welding process because when there is a small hole keyhole forms though.

So, there is a multiple depiction of the laser light happens within this molecule. So, that absorptivity of the laser is normally increases. So, in that sense the efficiency for this laser keyhole mode laser welding process is more than that of the conduction mode laser welding process.

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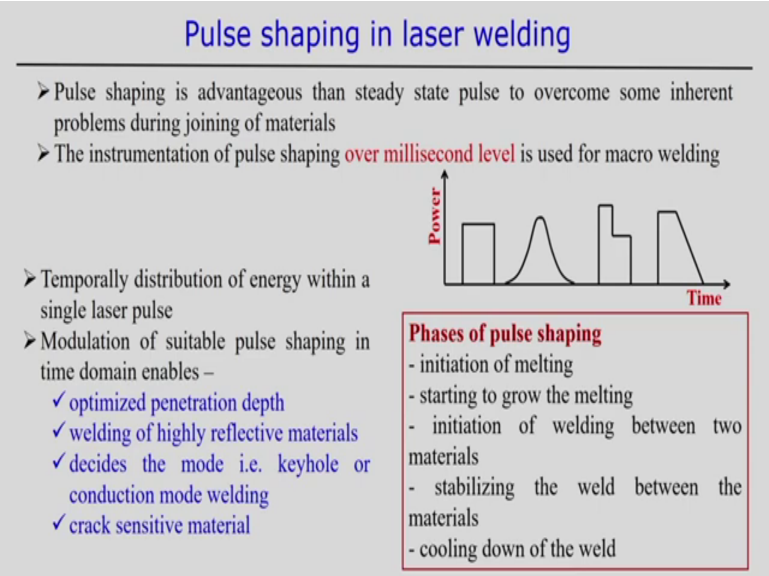

Now, one of the intricate part is that and when you will try to deal with the laser welding process the shaping of the pulse; in case of laser welding can be in the continuous mode or it can be the pulse mode. Pulse is nothing, but the variation of the power with respect to time; so temporal variation of this power; so that is called normally pulse. So, pulse can have the different shape it is like that only depending upon the shape the amount of the energy depends as a function of time.

So, that is why shaping of the pulse is sometimes advantageous that steady state pulse to overcome some inherent problems during the joining of the materials. We will see there are different kind of problems may arise, when you try to use the laser as a source in the joining of a different kind of materials.

For example, cracks sensitive materials and very high conductive material. So, in this particular situation that shape of the pulse is basically helps to overcome this kind of difficulties in case of laser welding process, we will see what we can do these things. So, the instrumentation of the pulse shaping; that means, shape of the pulse, if you see in this figure that with respect to time.

There are different shape of the power pulse; for example, it may be kind of rectangular it means that at time particular time t, the maximum amount of the heat flux heat energies power is supplied to the surface then remains constant for the pulse on time duration then it becomes 0.

And remaining time may be in this case it is a depending upon the frequency remaining time of the of a particular cycle time, remaining is gathering pulse of period. That means, we supply the energy for a small duration of the time and then remaining time becomes there is no power supply during this laser welding process and then it is a cyclic repetition of the similar phenomena.

So, that is why the shape that it means the shape of the pulse is indicates the whether it is rectangular shape or whether there is a gradual increment of the power; that means, it can follow the kind of Gaussian shape or some stepwise we can apply the power. So, this way the different shape of the pulse is possible and it is possible only for the in case of the laser welding process, but it is having some importance we can look into these things.

So, therefore, pulse shaping maybe over millisecond level is much is used for macro welding process it is a very significant, when the macro welding process means a lots, there is not in the micro scale. So, macro welding process the shape of the pulse is one of the important parameter is normally utilize to control or to overcome certain difficulties in case of laser welding process.

So, we can see these things the temporarily distribution of the energy with respect with the single laser pulse it is a shape decides depends on the what way the temporal distribution of the energy over the time. Now modulation of different pulse shaping mean the shape of the different pulse in the time domain helps in this way optimize penetration depth.

That means, particular shape of the pulse can be optimized, the depth of penetration can be achieved as a optimum depth of penetration can be achieved. When welding of the particular highly reflective materials we can design a particular shape of the pulse is suitable more suitable for the highly reflective material.

And then decides the mode of welding whether it is keyhole or conduction welding process that can also be decided by the shape of the pulse. Even in case of crack sensitive material also then we can design the different shape of the pulse.

So, in general there are several advantages on the shape of the pulse in laser welding process and that is normally called the pulse shaping in laser welding process. What are the different phases of the pulse shaping? That means, that pulse shaping decides the different phenomena for example, initiation of the melting.

So, particular shape, initiation of the melting then starting to grow the melting points initiation of melting, but this can grow melting over melting happens over a certain period of time and then initiation of the welding or joining between the 2 components or 2 materials, after that stabilizing the weld between the materials that also helps to particular shape of the pulse.

And then finally, cooling down of the weld can be designed the by the shape of the pulse we will see. That means, there are several advantages, several function or the different phases of the pulses is normally associated in case of the pulse shaping of the laser welding process we will see the how it helps.

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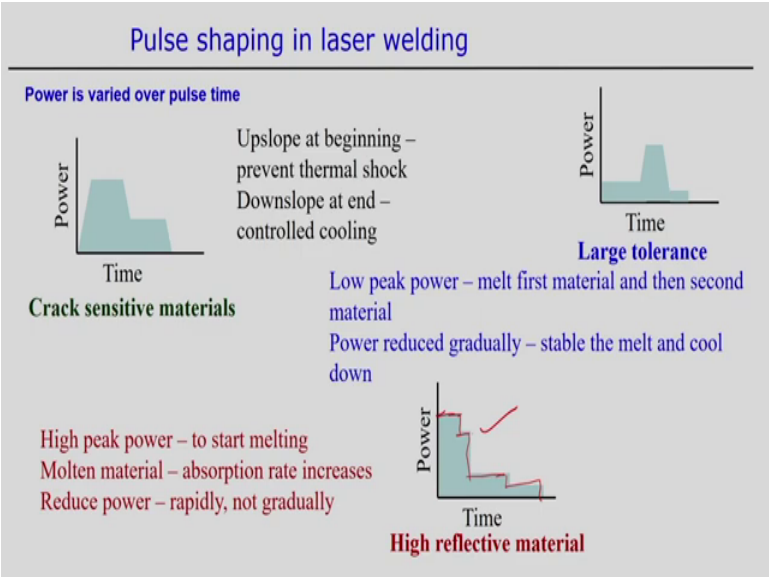

So, let us look into this first things and simply pulse shaping we understand the pulse varied with respect to over the pulse time whatever it varying. For example, you look into this first figure and in this first figure is this shape of the pulse, if you see the shape of the pulse means that the shaded zone indicates the when power is supplied with respect to time scale.

So, there is a gradual increment not exactly sharp increment of the power, gradually increment of the power then keep a for a constant time for then gradual decrement of the power. Then after that keep for a some period of a time keep on the same power on then finally, gradually decrement of the power then after that there is no supply of the power.

So, this is the particular variation of the energy supply in the laser welding process as a function of time. So, this is the particular shape of the pulse. So, this shape of the pulse is very much useful in case of the crack sensitive material which material normally brittle metal they are normally try to found out or during the during solidification phase they may create the cracks.

So, in that that type of material this pulse shape actually helps to get the good quality weld joint. Here you can see the upslope at the beginning if there is a upslope at the beginning its basically prevent the thermal shock instead of applying the power at the airs instantaneously.

Then also down slope at the end down slope at the end it helps when there is a down slope at the end it actually helps the controlled cooling of the workpiece material. So, that is way this kind of shape of the pulse is very much suitable for the crack sensitive material.

So, other can kind of thing we can see, that if there is a large tolerance between the when you try to join the two components the tolerance become these two components is gap may be very high.

In this case the shape of the pulse something is like that initially magnitude is at instantaneously apply the low magnitude of the power keep on long time relatively long time the same power then gradually increment of that. And peak power keep in certain time then gradual decrement of the power and that way we can shape the pulse.

So, what way the low peak power is basically melt first material and then the second material try to melt the first try to melt the first material and then the second material for the low power peak power initially. Then power reduced gradually then it is not sharply reducing the power reduced gradually, it is basically stable the melt and finally, cooled down to the ambient temperature cooling of this.

So, this kind of shape of the pulse is very much suitable in case of the material when you try to joint having the large tolerance. Similarly very high reflective material, if there is a high reflective material the shape of the pulse also shown in this figure you can see here.

That power versus time here the initially there is a high peak power is very high, then stepwise we can lowering the power amount then keep little bit more stepwise, which is the reduction of the power step wise.

So, this type of shape of the pulse; that means, supplying of the energy with respect to time is most suitable in case of the high reflective material.

So, high peak power is basically in the high reflective material when laser light falls on the surface the reflectivities becomes very high; that means, there is a low amount of the laser is basically utilized to melt the substrate. That is why initially there is a requirement of the very high power and that means high peak power then to start the melting for a high reflective material.

Then once start the melting then molten material, next phase there is a molten material develops. That means, if you get the molten material after application of the high power initially, then molten phase try to absorb the most more amount of the laser energy.

So, at that point when these absorbing the more amount of the laser energy then next step we decrease the power and finally, reduce power rapidly. That means, in this case the not the gradually because it is the high conductive material high reflective material. So, when the reduction of the power should be done rapidly, but not gradually in this cases. So, these are the typical pulse shape is most suitable in case of the high reflective material.

So, this way we can explain that if there is a even in case of laser welding process it is possible to generate practically different shape of the pulse and the different shape of the pulse is are designed in such a way that it may helps to get the good quality weld joint for the different situation or different type of the material; which may not be possible using the simple conventional arc welding process.

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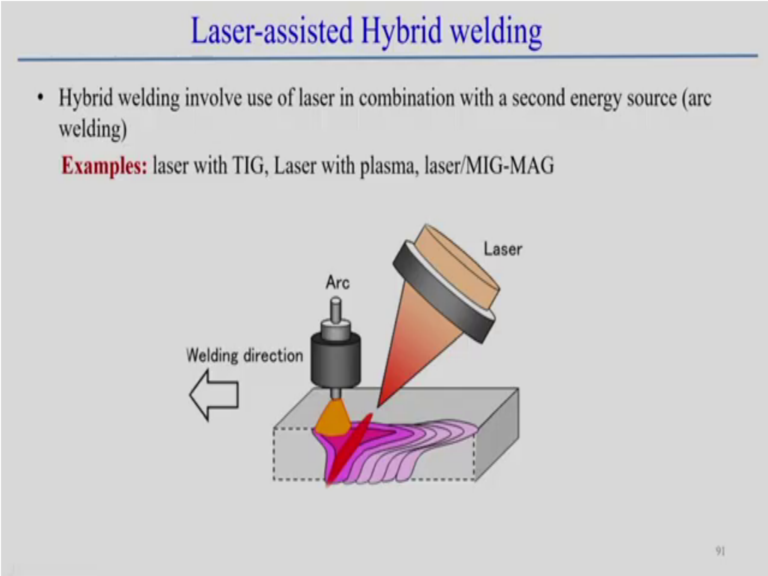

Now, we will look into that laser assisted hybrid welding process. So, we know that hybrid welding process is somehow use the combining of the laser as well as the another secondary source.

The secondary source can be most of the cases it can be the arc welding process. So, example is the laser with TIG welding process and laser with the plasma arc welding process and laser with the MIG or MAG welding process these are combining of this process is normally called the laser assisted hybrid welding process.

So, it gets the advantage of both the cases because in case of arc welding process it is not possible to achieve very high depth of penetration. So, in that case along with the arc if you use the laser then effectiveness of the arc can we increases by using the laser also and other way also it is correct in the sense that.

Absorptivity of the laser is also influence by the arc also in this case because in normal laser welding process the efficiency is very low say around 10 to 20 percent. So, absorptivity of the laser is basically enhanced with the application of the arc. So, then combining these two the laser assisted hybrid welding process has been developed.

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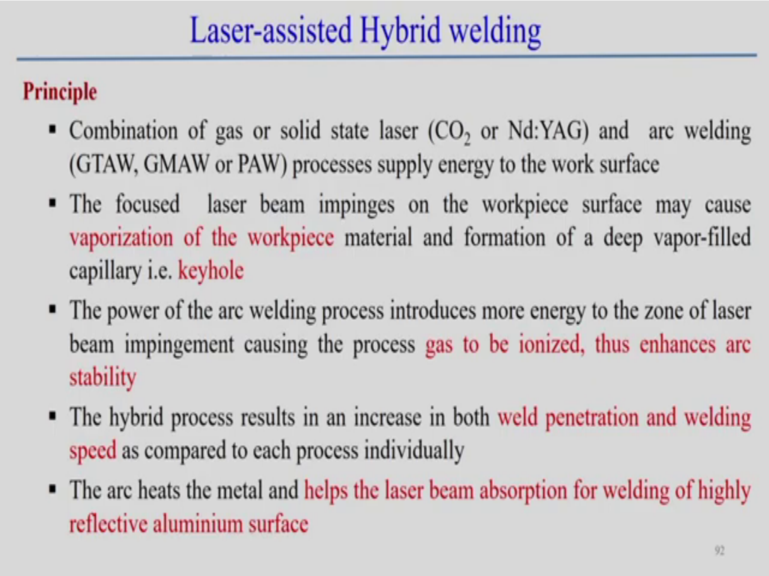

So, here in principle the combination of the gas or solid state welding process for example, CO 2 Nd:YAG laser can be used with the arc welding process GTW, GAW, GTAW, GMAW and plasma arc welding processes and that both are supply energy to the workpiece.

Now the focus laser beam impinges on the workpiece surface and may cause the vaporization of the workpiece material and the formation of the deep penetration vapor filled capillary and the keyhole is formation is normally used in these cases and it enhance the formation of the keyhole with the presence of the arc.

Now, power of the arc also arc welding process introduce the more amount of the energy to the zones of the laser beam impingement causing the process gas to be ionized that enhances arc stabilities or in presence of the laser the arc stability of the arc welding process also enhances.

Therefore, hybrid welding process increases both weld penetration as well as the welding speed, it means that in case of a arc welding process there may be some limitation the welding speed because using the arc welding process there may be the possibility of the stability of the arc can be an issue.

So, then in that case if you use the hybrid laser welding process along with the laser and arc then it can be used at the high welding speed, which is normally we cannot use only along with the arc welding process.

So, therefore, helps the laser beam other way also I already mentioned that at the same time the arc also hits the material and helps to the absorptivity of the laser absorption for the welding of the highly reflective aluminum surface. It means that; using the conventional arc welding process there may be difficulty of the high reflective aluminum alloy maybe in the arc only alone arc welding process or only alone laser welding process.

But when you are combining this arc and laser in the hybrid welding mode then it will enhance the absorptivity of the laser even for the high reflective laser in presence of the arc. So, that is why both way it can be benefited using this hybrid laser welding process. Actually hybrid laser welding process is mostly developed to for joining of the, which is in which cases difficult to achieves individual welding processes.

In that case is for example, high reflective material, in that one cases and particularly in the dissimilar material mostly joined using the hybrid laser welding process.

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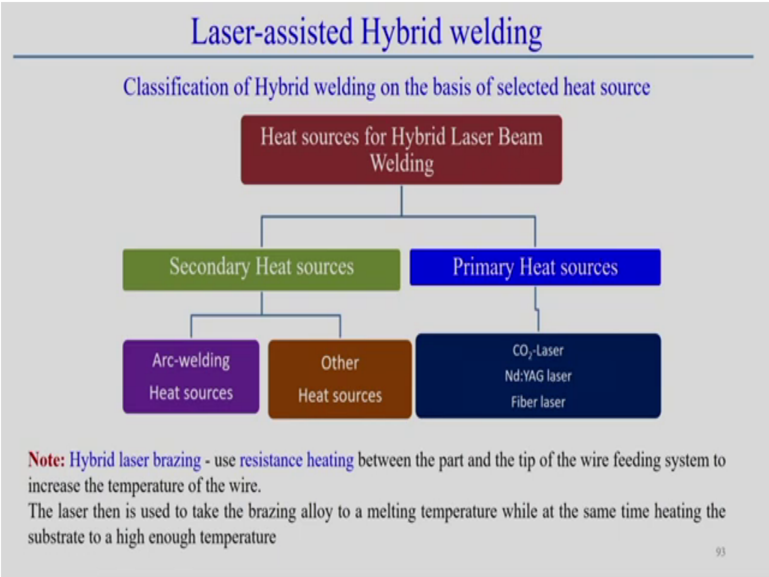

Now, if you classify broadly the hybrid laser welding process that based on the heat sources for the hybrid laser one is the heat sources can be the primary heat source can be the laser, CO 2 laser Nd:YAG laser fiber laser normally you can used and the secondary heat source can be arc or arc welding processes and can be other heat sources also.

So, we can give an example also for example, that one of this other heat sources can be like that hybrid laser brazing process has also been developed. So, we know the brazing process the in principle the brazing process we use the resistance heating between the part two to the tip of the wire feeding system to increase the temperature of the wire.

So, in case of the resistance heating in the wire and that actually helps to deposit the material quickly in a within the parent material when you try to join by principle of the brazing process. So, what happens in this case the hybrid laser brazing process the resistance heatings helps resistance heating some preheat the wire tip.

So, that the wire can be easily deposited at the substrate material and at the same time laser can also be used to melt the wire, but in this case the laser does not melt the parent material.

So, in principle it following the brazing process, but the heat source can be laser as a heat source and laser. That is why it is called the hybrid laser brazing laser is the heat source to melt the substrate material, but at the same time some resistance heating may also present in the wire also, that is why it is called the hybrid laser brazing system.

So, this way there are several possibility or several way the hybrid welding process can also be developed. Even and friction stir welding process that is the solid state welding process that can also be hybridized using some other secondary heat sources.

So, it in general the in hybrid welding process normally we use the one primary heat source and there will be another secondary heat source and combining these two, we can achieve the particular benefits which is not possible alone using the single type of the heat source.

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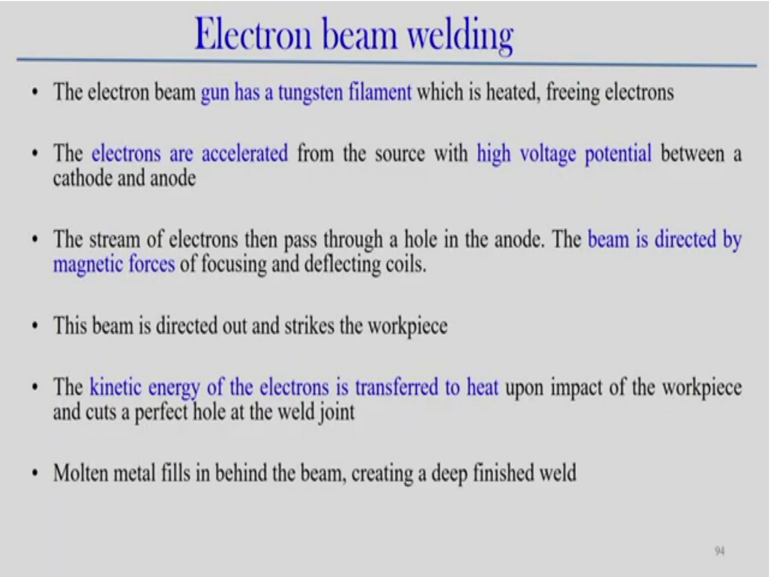

Now, come to this point the next one of the mostly usely or most high costly and welding process that is called the electron beam welding process. We know the principle of the electron beam welding process is that tungsten filament is there and that is heated or then it emits the electron.

So, then electron be accelerated and once the electron accelerates with the application of the high potential difference or high voltage then stream of the electrons impingement on the passes through a hole to the anode and that beam is directly focusing and using some deflecting coil.

So, steam of the electron is basically using some kind of the magnetic forces it focus in a particular position, then kinetic energy of the electron is released when it is bombarding on the workpiece surface and then generates the heat transfer the heat upon the implement of this thing.

This is the in general this is the principle of the electron beam welding process and this molten metal fills behind the beam creating the deep finished welding process, but in this case the once the electron beam the it is when create the electron beam it is focused on a very small zone.

That means, the power density becomes very high in this cases even in as compared to the laser welding process. So, its clears the very very thin long stream of the electron and it also creates the joining can be done in the keyhole mode that it actually creates the keyhole and the joining can be done in the mode of key hole like laser welding process.

But in this case power density and the focused beam is power density is very very high at the same time focused on diameter or over which the on the workpiece over which the beam is impingement, that is the very low as compared very small as compared to the laser beam welding process, that is why the power densities becomes very high in this electron beam welding process. But everything happens all this under the vacuum.

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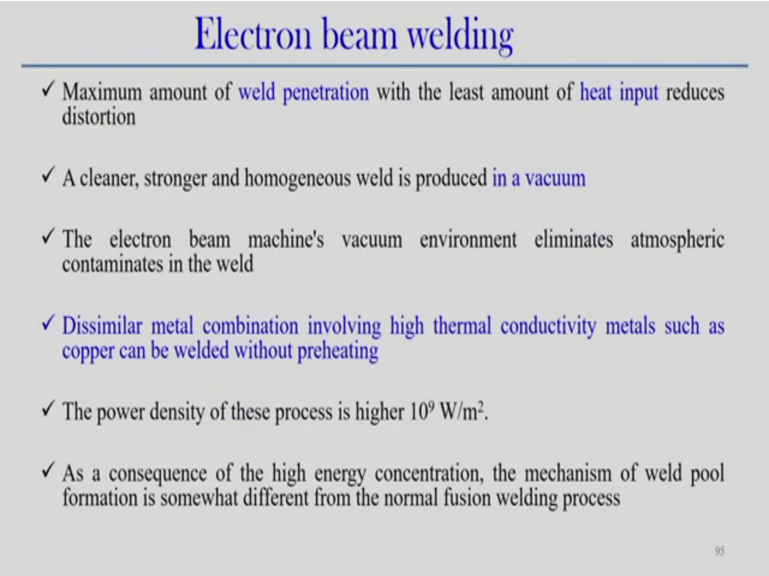

So, then in that sense that electron beam welding having good advantages that maximum depth of penetration can be achieved even more than that of the laser welding process and this the heat is focused in this very small zone. Therefore, it is will not get much heat affected zone in this case also and may not create the very high distortion.

And process which is also one advantages in case of the laser welding process, but the heat effected zone is more than that of in case of laser welding process as compared to the electron beam welding process, but of course, as compared to the arc welding process it is less in laser as well as the electron beam welding process.

A very clear stronger and homogeneous weld is produced in a vacuum because the vacuum in that environment it is there is no chances of contamination from the outside atmosphere, which normally we found in any other welding process. So, that is why it is a very clearer stronger weld joint is produced in case of electron beam welding process.

Dissimilar metal combination having involving the high thermal conductivity metals such as copper can be welded without any preheating its in case of the high conductive weld material normally copper or any dissimilar combination of the metal is most easily can be or most efficiently can be joined by using the electron beam welding process.

Because in this case the power heat input is very high or power generation. That means, as compared to the other welding processes power density for example, this process as high as 10 to the power 9 watt per meters kg is possible. Now 10 to the power it should be I think centimeter square.

So, therefore, as a consequence of the high energy consumption the mechanism of the weld pool formation is somewhat different from the normal fusion welding process. So, mechanism of the weld pool formation is completely different as compared to the arc welding process. So, these are the typical maybe more general aspect or in associated with the electron beam welding process.

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Comparison between laser and electron beam welding

Perspective	Electron beam welding	Laser welding
Weld zone and HAZ	Narrow/smaller	Narrow/smaller
Penetration	Deep penetration	Moderate penetration
Welding speed	Very high	high
Shielding gas	Not required	Nitrogen or argon shielding
Vacuum chamber	Required	Not required
Cost	Very high	Comparatively low
Generation of X-ray	Possible	Not-possible
Power efficiency	80-90%	10-20%
Size of work piece	Limited due to vacuum chamber	Not limited

Now, we some get idea overall view between the laser and electron beam welding process, if you see the weld zone and heat affect zone electron beam welding process it is very narrow even smaller even laser welding process narrow and smaller. But it is possible to produce more narrower zone in case of electron beam as compared to the laser.

Penetration very deep penetration is possible to electron beam welding process, but moderate penetration we can say as compared to the electron beam. Welding process welding speed is very high is possible to very high and then laser welding as compared to the electron we can rate as high welding speed.

Shielding gas do not use we do not never used in case of the electron beam welding process or not required at all, but laser welding process also we can use some kind of shielding gas nitrogen or argon shielding gas or any other shielding gas can also be used. Vacuum chamber in case of electron beam welding process this is required.

But laser welding process it is not required in vacuum chamber cost electron beam setup is relatively very costly it is a very high cost is very high, but laser welding process comparatively low as compared to the electron, but laser welding system is cost is high as compared to the arc welding system.

But one difficulty is the electron beam welding process is the generation of the X-ray it is quite possible to in this principle that there is a possibility of X-ray generation in electron beam welding process, but laser welding process it is not possible to generate any kind of the X-ray. Power efficiency is very high in case of electron beam welding is around 80 to 90 percent, but laser welding process is the power efficiency is very low around only 10 to 20 percent.

Size of the work piece because in case of electron beam welding process because its everything happened in the closed chamber in the vacuum environment. So, size of the workpiece is limited by the size of the chamber vacuum chamber, but that kind of limitation is not there in case of laser beam welding process. So, these are the in general the difference between the laser and electron beam welding process.

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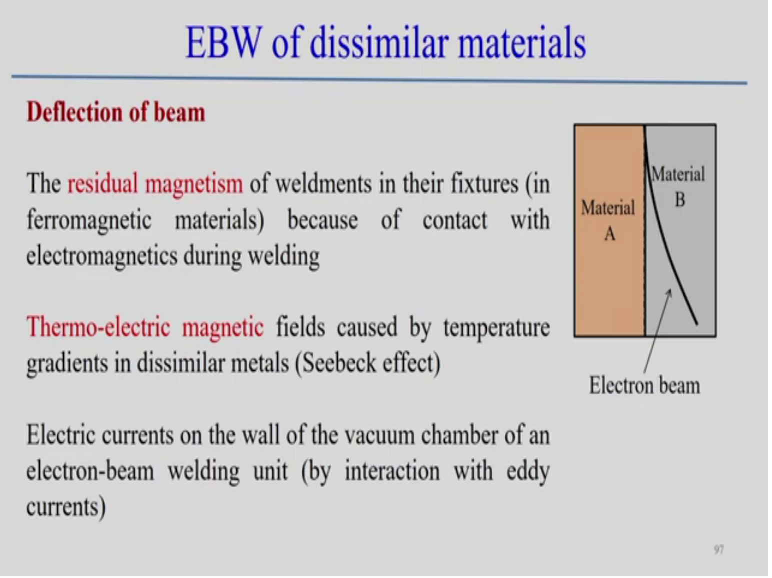

Now, one of the typical aspect normally associated we follow issues electron beam welding process of dissimilar materials and that is necessary to mention here also, that deflection of the beam normally happens. So, electron beam can be deflected one particular workpiece material when you try to join the dissimilar material and normally happens because the magnetic permeability of the dissimilar material are different.

So, therefore, its highly chance to get any one of the sided, it can be small amount, but can be most of the cases you find out the electron beam can be deflected any one of the side of the material. So, it is schematically we can see for example, material a and b having the different magnetic permeability of these two material.

Therefore, once we start exactly are the interface focusing on the electron beam, but it may get deflected is one side of the material, but what we can explain this phenomena.

So, therefore, residual magnetism of the weldments in their fixture there may be possibilities there in case of ferromagnetic materials because of the contact with the electromagnetics during the welding process. Because there is a thermo electromagnetic field caused by temperature difference if you follow the principle of the Seebeck effect in joining this thing.

So, that with the effect of the magnetic field created during the welding process and because there is a temperature difference gradient is there. So, temperature difference in principle of the Seebeck effect they will create the electromotive EMF can be generated there.

And then because of that the beam gets deflected in one side. So, therefore, electric currents on the wall of the vacuum chamber of an electron beam welding unit by interaction with the eddy current these are the three different possible reasons to deflect beam gets deflected in one side of the material.

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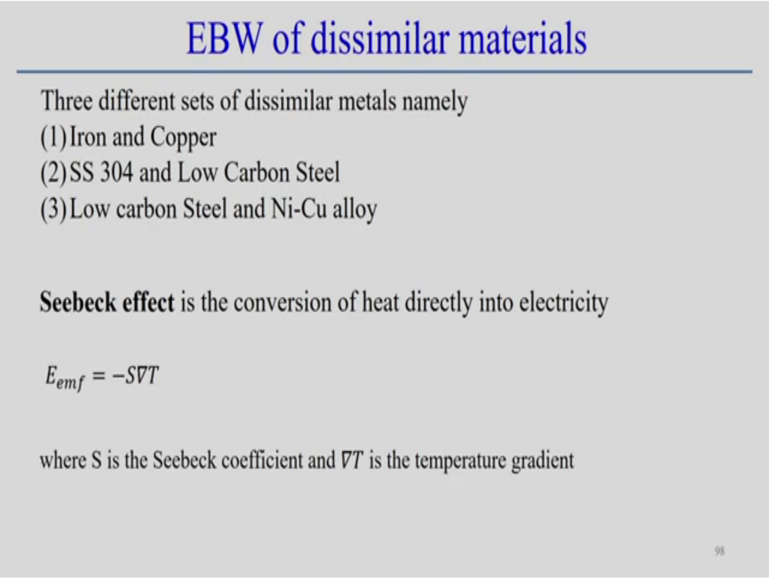

So, three different set of the dissimilar materials namely for example, iron and copper if you want to join iron copper using the electron beam welding process and thickness becomes very high in this case. And then there may be the beam gets deflected any one side of this thing depending upon the magnetic permeability of these two process.

For example such combination this kind of difficulty may arise even if you try to join SS 304, the stainless steel and the low carbon steel; even if low carbon steel as well as a nickel copper alloy. So, this combination of the metal if you try to join the beam gets deflected in one side and then one of the important aspect is the Seebeck effect is the basically conversion of the heat directly into electricity.

So, emf can be generated minus S delta T the delta T is the temperature gradient and S is the Seebeck coefficients based on this principle the electromotive force will be generated and then it is influenced by the magnetic field there. So, these are the typical issues associated of the joining of the dissimilar materials for electron beam welding process.

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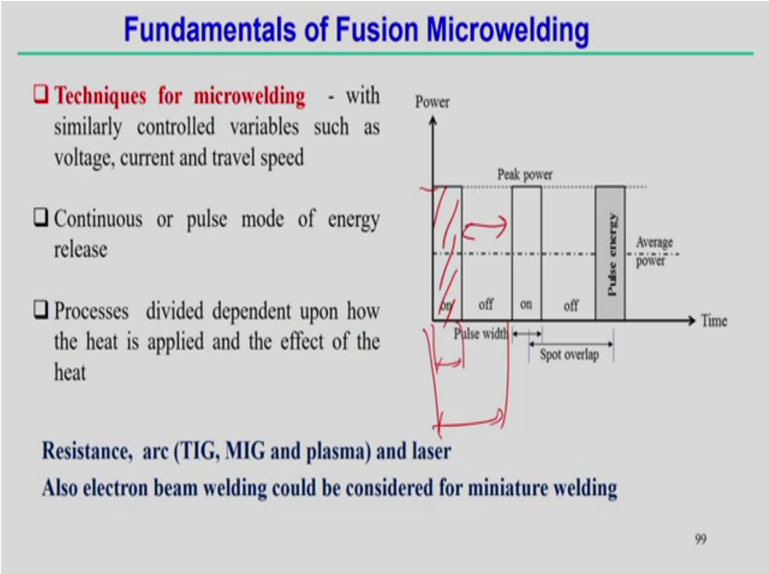

Now, come to this point the advance because we are talking about the advancement in the welding processes. So, now, we try to look into the micro welding process because it is very much important nowadays with a miniature of the components. So, micro welding process is simply the most of the cases.

It is the scaling down of the conventional welding process and such that the conventional process can be apply in a micro scale application and sometimes it is possible to develop these micro welding process under the microscope. So, just look into this thing we will do what way we can scale down these things that we will try to look into that techniques for the micro welding process.

So, it is essential to know that although there are several micro welding processes, but most suitable source in a micro welding process is using the laser welding process and development normally happens using a laser.

Because it is very much possible to very precisely control the laser heat source for example, I have already mentioned that even there is a shape of the pulse can be we can create the different pulse shape. Even nowadays also ultrasonic pulse laser is also available.

So, that can also be used some particular purposes even for the micro or micro scale application. So, that is why are there is a one advantage is that very precisely the pulse can be created in case of laser for example, we can see in this case that power versus time the different pulse on time off time.

So, that kind of modulation is possible using the laser and may be the pulse on time very small pulse on time even in the range of the millisecond, nanosecond pulse duration can be created using the laser, but nanosecond pulse in microsecond pulse it is not possible to create using the arc welding process.

So, that is why laser is always advantageous for the development of the micro welding application. So, if you look into this figure there is a pulse on and pulse off period and this total represent the one cycle time and the repetition of the same thing and the area within this for example, we can see this area if you calculate this area this indicates the pulse energy.

So, this is the peak power and this is the duration of the pulse on period. So, if you multiply the power into the time that indicates the energy of the pulse sometimes we define the in the form of a laser pulse energy. So, that is and this part is remaining off time. So, this indicates the cycle time and some time the spot overlapping is also possible to create and in case of the laser welding process.

So, that is several flexibilities there to use the modulation of the different kind of the pulses in laser. That is why it is more suitable for the application or the for the development of the different micro welding setup. So, in this case the control variables means in case of even for the micro welding application the mainly controllable variable is the voltage current the travel speed in this cases and in case of a laser it is a power and speed.

Continuous pulse mode both of energy can be used or release can be used, but the flexibility is there to increase more on the pulse energy in case of the laser, process divided depending upon the how the heat is applied and the effect of the heat is basically based on that we can the development of the different micro welding has been done.

But if you look into that in general till now mean micro welding application we can find out in the literature also the resistance arc for example, arc mean TIG welding process or gas resistance arc welding process not exactly the MIG welding process in the micro welding application, but plasma and laser these are the mostly used in the micro welding application even electron beam can also be used consider for the miniature welding process by electron beam in micro welding application has been developed in the different way.

So, for example, I can say that electron beam welding process can also be used in case of micro welding application, but development has been done using the scanning electron microscope.

Simply if we have the scanning electron microscope which is possible to convert the scanning electron microscope to for the application of the application of the micro application of the micro welding process and that is possible to develop, but that is not our scope in case this thing, but in general we can say these are the 4 steps 4 different kind of the micro welding processes has been developed.

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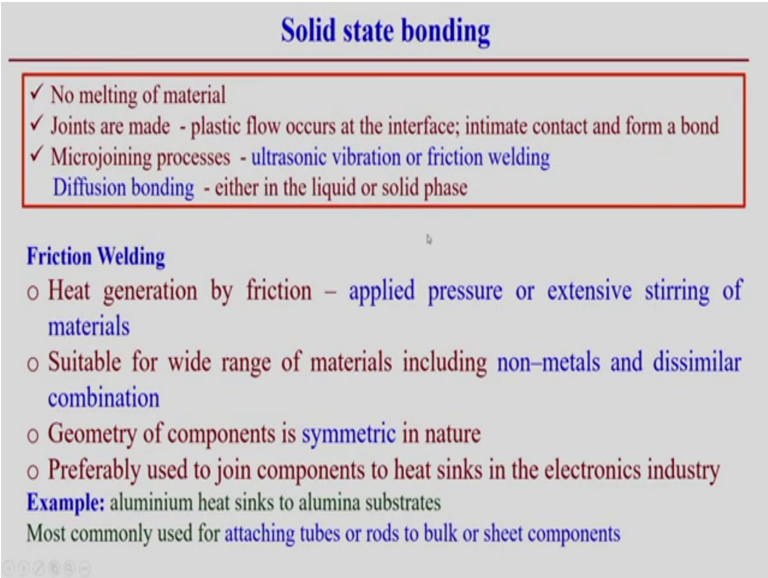

So, apart from that there are solid state bonding. So, many solid state bonding process has also be developed in specifically to micro welding application, one is that you know that solid state welding process there is no melting is there and joints are there mainly the plastic flow of the material at the interface and intimate contact between these two and finally, they form a bond. So, these are the steps associated with the solid state bonding process.

But micro joining processes using the in the solid state normally use the ultrasonic vibration or friction welding process and or diffusion welding principle normally used and in which comes under the solid state bonding processes. And diffusion bonding can be either liquid or solid phase can also be used. Now we will look into that different solid state bonding process normally using the micro welding application.

First is the friction welding process. So, in friction welding heat generation by friction is there and applied pressure or extensive stirring of the metal is required, what we know that friction stirring process this is the kind of friction welding process. Suitable for wide range of materials including the nonmetals dissimilar combination all these things.

Because dissimilar combination of the materials is most suitable in case of the solid state bonding process because in this case normally we can find out if you do the fusion welding process there may be the formation of the inter metal compounds and that can be the one of the difficulties with the application for joining of the dissimilar material and using the fusion welding process.

So, that is why for the most of the dissimilar materials joint can be done using the solid state welding process. Geometry of the components is symmetric in nature in particular the friction welding process and for example, preferably used to join components. So, heat sinks in the electronics industry.

So, with the component or the heatsink of the electronics industry we normally use the friction welding process. Example, aluminum heatsink to aluminum substrate can be done joint can be done using the friction welding process and most commonly used for the attaching tubes or rods or bulks or the sheet components it is possible to use the friction welding process. So, this is one of the solid state bonding process.

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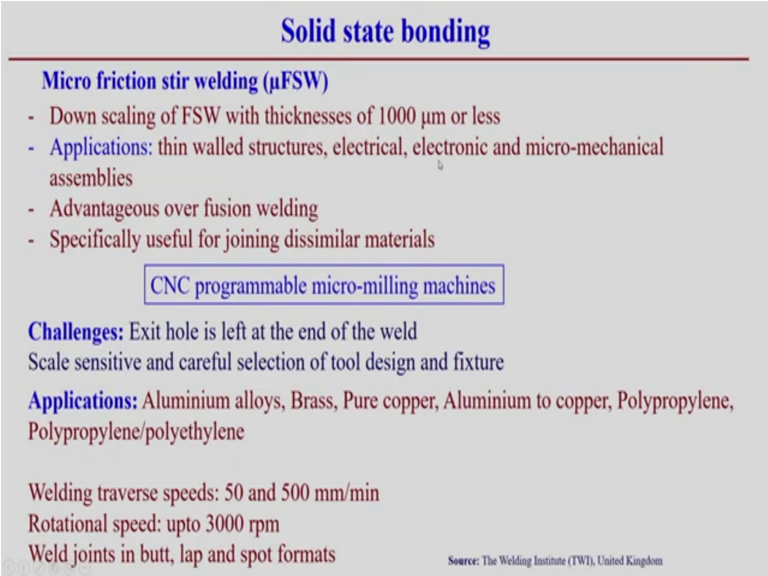

Now, we can see that micro friction stir welding process. So, it is just simply conventional scaling down of the conventional friction stir welding process, but still it is developing this thing what in micro friction stir welding process we can see the downscaling of the FSW with thickness 1000 micrometer or less can be joined using this the same principle of the FSW process.

Application thin walled structure, electrical, electronics, micro mechanical, assemblies there we can find out all this application. Of course, advantageous over the fusion welding process it is always there and FSW process in general and specifically use for joining of the dissimilar material.

So, that is why micro friction stir welding process most application for the joining of the dissimilar materials, but in this case if we want to develop an micro friction stir welding machine then CNC programmable micro milling machines is required, that can be converted to the along with the fixture attachment the micro FSW process can also be developed.

Challenges in general also FSW percent exit hole left because we use the tool and tool is basically string the material, but at some point of time once or the ending of the at the end of the weld, we just there may be the left out a hole is always there that is one of the difficulty and scale sensitivity in the careful selection of the tool design and fixture.

It is very important because once we scaling down of the conventional fsw to the micro scale application then the fixture design has to be very properly designed and then tool fixture everything is very much sensitive to the work piece material. That means, sensitive for the joining to produce the good quality weld joint.

Application the aluminum alloy brass, pure copper, aluminum to copper, even polyethylene to polypropylene, polythene. That means, polymeric metal can also be joined using the micro friction stir welding process.

So, it is a get some idea about this thing the traverse speed can be 50 to 500 milli meter per minute rotational speed can be 3000 rpm and weld joints in the butt lap and spot format can also be joined using the micro friction stir welding process.

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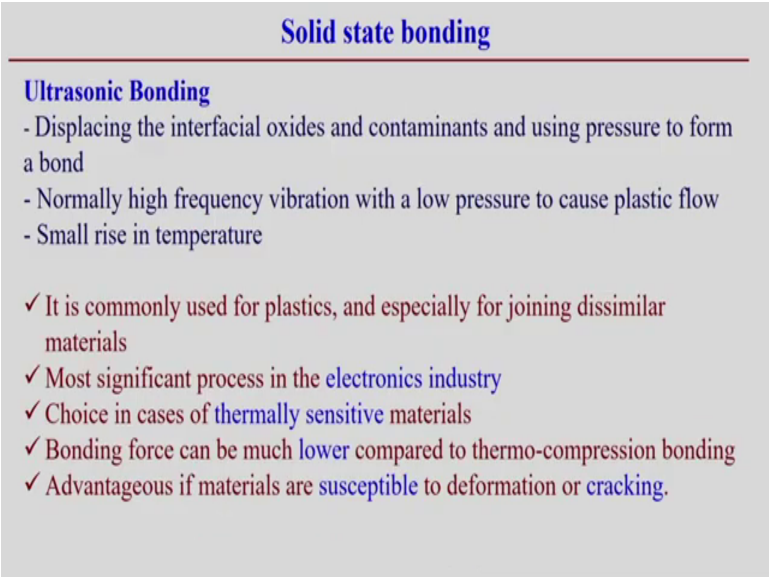

Now, one of the important solid state bonding process is the ultrasonic bonding. So, if you uses the simply ultrasonic principle or its uses the principle of the ultrasonic welding process and like that that first ultrasonic the vibrated energy is converted the interfacial oxide has or contaminants can be removed using the pressure to form a bond.

And normally high frequency vibration is used with the with the application of the low pressure that cause the plastic flow of the material as small rise in the temperature and these 2 components can be joined and this it is a hitting normally done let us say various localized area. It is commonly used for the plastics and especially for the joining of the dissimilar material.

So, for plastic component normally you use this ultrasonic bonding mechanism and mostly used in the electronics industry and choices is cases of thermally sensitive materials in cases if there is a requirement of the thermally sensitive materials means the temperature difference or temperature gradient developed during this process then there may be the crack maybe generated.

So, that kind of material is most suitable using the ultrasonic bonding process and that normally done in the electronics industry and bonding force can be much lower as compared to the thermo compression bonding and that can also be see we can see and that advantageous if the material is susceptible to deformation or cracking; that means, the application in general.

If material is prone to produce some cracking during the welding process with application small application of the force or application of the heat. In that case the ultrasonic bonding is most suitable joining mechanism in the micro scale application.

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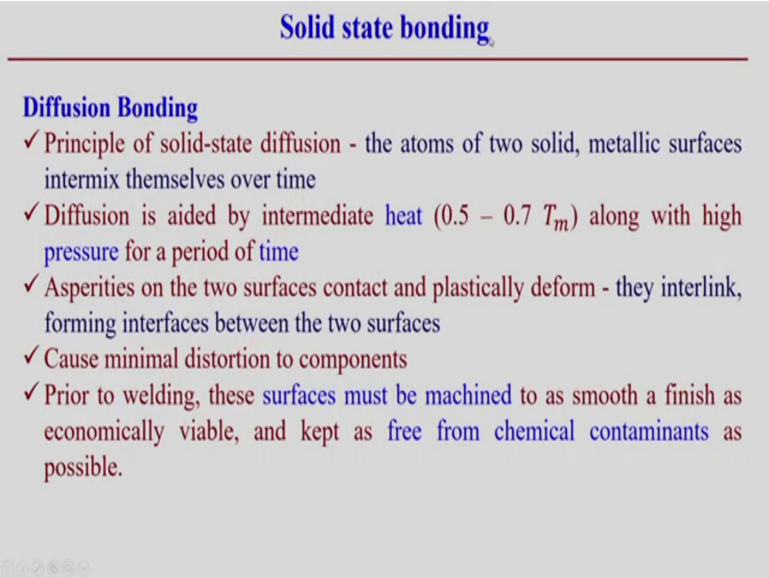

Similarly, diffusion bonding can also be possible and I am talking all this in the pertinent to the micro scale application and principle of the solid state diffusion process is there. That means, 2 surface in contact and sometimes it is aided by the heat also along with the high pressure for a period of time.

So, 2 surfaces in come in contact with the aided by the heat and the with the application of the pressure high pressure, such that diffusion of atoms may be allowed between these 2 surfaces, but it entirely depends on the surface preparation of these 2 components. So, therefore, when the asperities between the two surfaces come in contact with respect to each other they plastically deform and interlocking with respect to each other at the surfaces.

Of course, this process causes the minimal distortion. Because this mostly this diffusion we are allowing some diffusion to happen for a long time that is why we keep the pressure for a long time. And the most significant part is this thing prior to the welding the surface must be machined, the smooth surface can be generate.

Such that by removing the oxide and contaminated layer the surface coming in come in contact with respect to each other. And facilitate the facilitate to from the diffusion to occur between these two surfaces and that is the principle of the diffusion bonding

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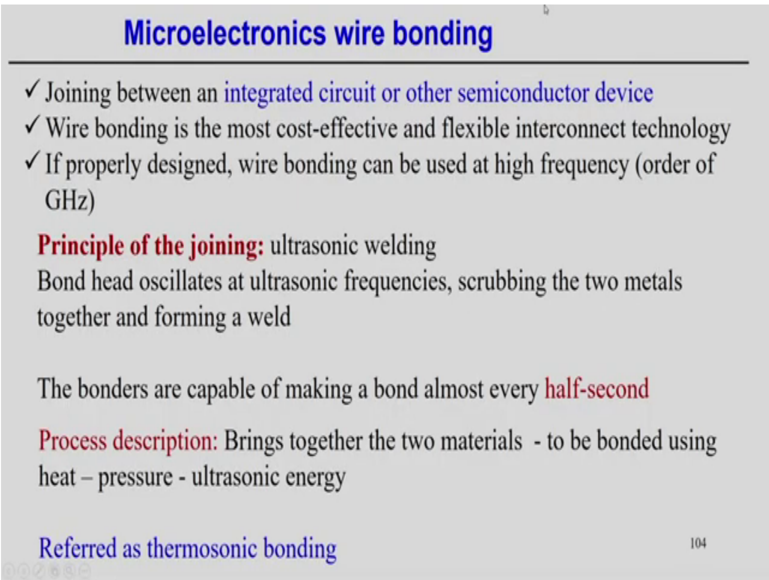

Similarly microelectronics wire bonding we can observe the microelectronics wire bonding in the particular welding process. Its say basically joining an integrated circuit to other semiconductor devices, we normally use the microelectronics wire bonding.

So, wire bonding is most cost effective and flexible interconnection technology in particular the electronics industry and properly designed wire bonding can also be done using the order of the gigahertz, that means, with the high frequency can also be done. But principle of the joining is that, its follow the principle of the ultrasonic welding process, what are the; principle of the ultrasonic welding process?

That is followed in case of microelectronics wire bonding it means that bond heat oscillates the high frequency ultrasonic frequency is scrubbing between the two materials and then together to form a weld.

So, therefore, the bonders are capable to making a bond almost every half second. That means, it is a very first process as compared to the other processes that is why this process is more economical that is microelectronic wire bonding process.

Process description it is that brings together the 2 materials to be conducted using heat pressure and ultrasonic energy. So, the process can be done in something in that way either only application of the ultrasonic energy; that means, only vibration or sometimes along with the ultrasonic energy some heat and pressure also applied.

So, this way when along with the ultrasonic energy heat and pressure applied at the bond area, then that is called are the thermo sonic bonding process. We can see the difference between the these what is thermo sonic wire we can use the temperature all these things and in some cases we may not use the temperature also.

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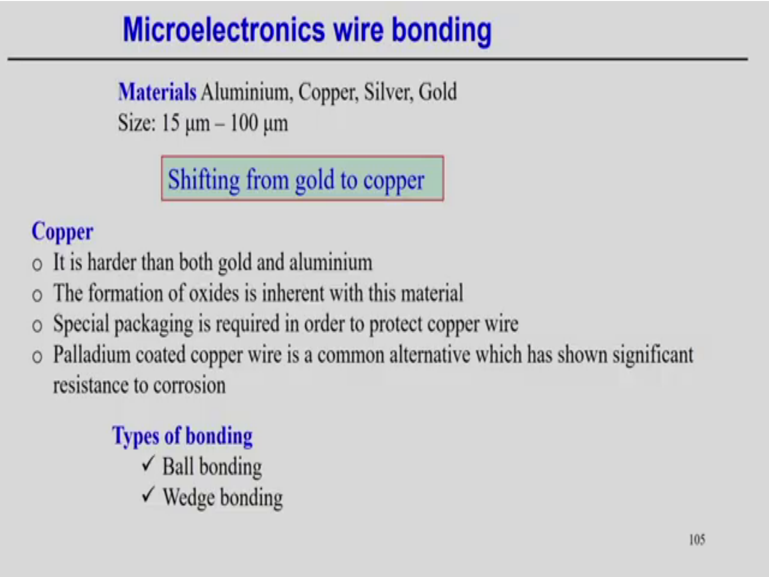

Microelectronics wire bonding is mostly applicable materials aluminum copper, silver, gold and the size maybe wire size can be between 15 micro meter to 100 micro meter. But nowadays the gold is costly material and in that sense and the shifting from gold to copper.

Now people try to utilize more copper as compared to the gold and if you look into the typical issues associated with the copper is that, copper is harder than both gold and aluminum. So, copper in that sense it is more suitable the formation of the oxides is inherent with this material. So, that is that one difficulty the formation of the oxides.

So, therefore, special packaging system is required to protect the copper wire in this case palladium coated copper wire is mostly used nowadays. Common alternative which has shown the significant resistance to the corrosion. So, palladium coated copper is most suitable in this particular purpose, what type of bonding? Can be both ball bonding and wedge bonding.

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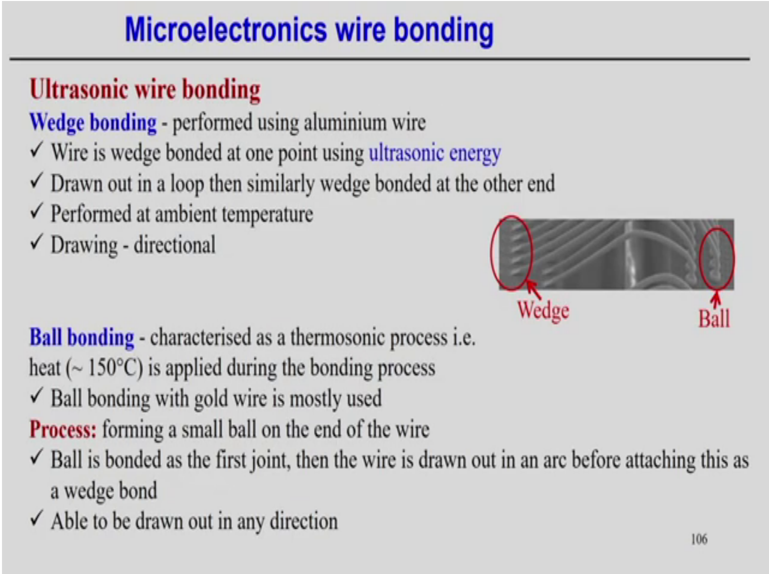

So, we can differentiate what is the bonding, ball bonding and wedge bonding. We can see here also, what is ball bonding? What is wedge bonding? If you see that both are we can say the both are following the same principle of the ultrasonic welding process, but first cases the wedge bonding; in this case normally performed with the aluminum wire.

So, wire is wedge shape bonded at the one time if you see this figure first figure here you can see that, it is the kind of wedge shape can be created here. So, using some kind of the tool one point and the application of the only the ultrasonic energy. So, once it is joined in particular then drawn it out in directionally and we can join the other part using the ball bonding.

So, therefore, loop similarly wedge bonded at the other end and drawn in loop then similarly wedge bonded at the other end; that means, same kind of the wedge bond can be done in the other end or it can be done in the other end also and perform at the ambient temperature.

So, it is not we are not applying any kind of the external added temperature in this case. So, therefore, drawing is direction. That means, one is wedge bond is there on particular then we it can draw the wire in particular direction only. So, that is normally called the wedge bonding process.

But in case of ball bonding process characteristic as a thermo sonic process; that means, the heat pressure and ultrasonic all are used in case of ball bonding process and if you can see the other figure it can show how the ball bonding process it is like that it gets kind of the ball wire at the end. So, around 150 degree centigrade heat is applied during the bonding process and ball bonding if there is a gold wire normally we use the ball bonding process.

So, it is clear the forming of the small ball on the other side at the end of the wire and ball is bonded as the first joint then the wire is drawn out in an arc before attaching this is a wedge bonded this is also possible. So, if there is a compress that this is the able to drawn out in any direction. That means, once you create one particular ball bonding then it is possible to drawn in any direction.

It is not like the directional properties what we can form we can we observe in case of the wedge bonding, but in case of ball bonding any direction we can draw it out and then we can create the another wedge bonding or we can create another ball bonding in other side.

So, these are the basic difference of the wedge and the ball bonding which normally we can find out the in general these are the two processes we can find out in the microelectronics wire bonding process.

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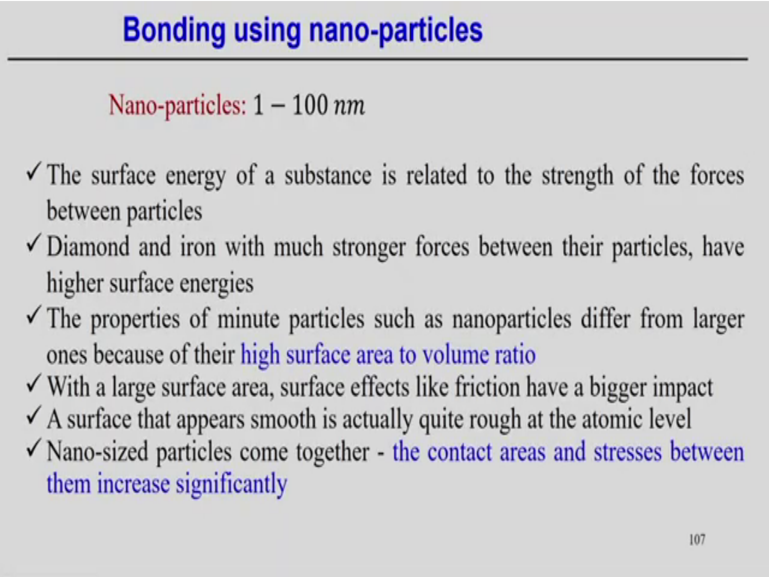

Now, bonding with nano-particles is also possible in this case the 1 to 100 nano meter sized particles can be used at the interface, when you try to join the two components. Of course, this is most suitable this is in case of a small scale application; the surface energy of a substance is related to the strength of the forces between the particles. That is true that the surface energies associated and for example, diamond and iron with a much stronger forces between their particles having the higher surface energy.

So, surface energy is very important aspect to look into in principle that, how this bonding energy is different from as compared to the normal size of the particle in the nano-particles? Because the nano-particles one important property the surface energy by volume ratio is very high as compared to the any other size particle. So, the property bonding mechanism is completely different as compared to the other processes, but other size of the particles.

So, properties such as nano-particles different from the larger ones because they are high surface area to volume ratio. And therefore, with a large surface area the friction becomes more active bigger impact is having much more impact. So, therefore, a surface that appears actually smooth is may not be quite rough at atomic level, atomic level look into the surface it may not be the rough. Some we can see the some rough surface roughness values may be important in this case.

So, therefore, nano sized particles when comes together the contact area and the stress between them increases significantly, that is the difference the contact area the frictional properties are completely different in the nanosized particles because only because of the their surface area to volume are different. Therefore, using this property can be utilized in case of bonding with the nano-particles.

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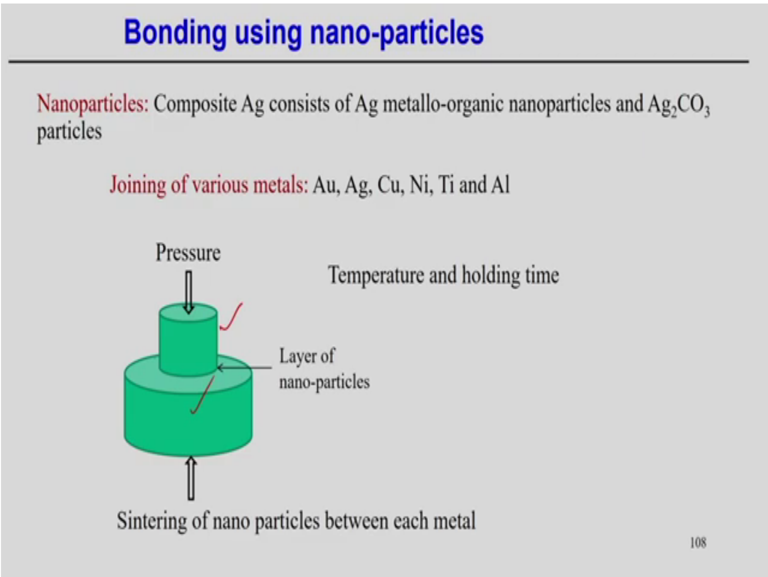

So, therefore, example the composite is a silver consists of the silver metallo-organic nano-particles for example, Ag 2 CO 3 particles can be used. And then if you look into this figure these two components are there and in between it is filled by the nanoparticles.

Now, if we apply the high pressure layer of the nano-particles and if it is possibilities on temperature and holding depending upon the temperature apply or the interface and the holding time the sintering of the nano-particles happens in between, then bonding between these two components can be done.

So, this is the in general in basic principle of the joining of the two components using the nano-particles. So, joining of the various metals for example, gold, silver, copper, nickel, titanium, aluminum that can be done, but if we compare the strength between all these materials.

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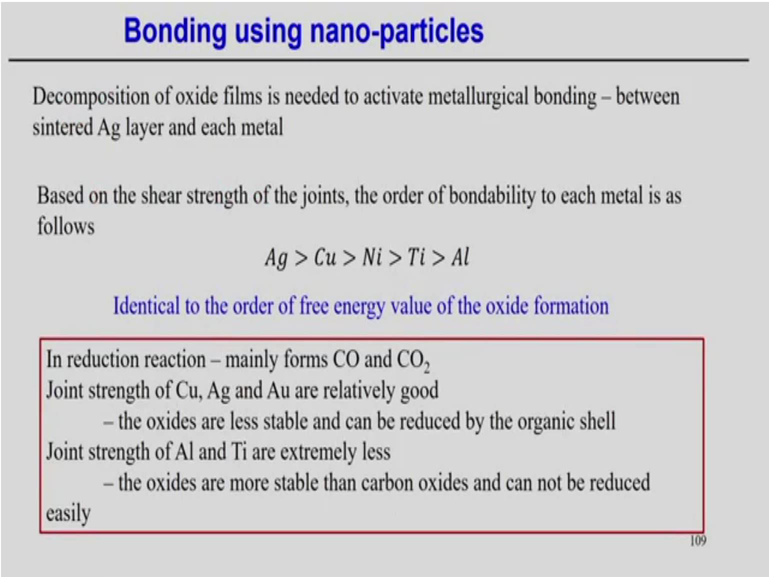

We can see that normally when is the Ag 2 silver CO 2 CO 3; that means, decomposition of the oxide films is needed in these cases to activate the metallurgical bonding between the sintered, silver layer and the each metal. So, when you using Ag 2 CO 3, so, that means, decomposition of the oxide; that means, separate out of the oxides competencies required such that Ag particles will be there and that is made the sintering or bonding between these two components.

Now if we compare based on the if we after joining the different nano-particles. That means, for example, silver, copper, nickel, titanium, aluminum and if we compare the their shear strength using these different kind of the bondability of different kind of these materials, we can see the increasing order of the joint strength.

For example in case of silver we can get the maximum joint strength and in case of aluminum joint strength will be minimum. It depends on the free energy value of the oxide formation; that means, what way the how whether, how is to remove the oxides at the layer? At the depending on this thing joints strength depends on that for example, in general the in reduction mainly we has to be remove the CO and CO 2 in there in their component metallo component.

Therefore joints strength for copper, silver and aluminum are relatively good because the in this cases oxides are less stable and can be reduced by using the organic shell. So, that means, oxide can be easily removed from this from this component, but if you look into the aluminum, titanium take for the strong oxide formation is there.

Therefore, in that case is the oxides as more stable it is difficult to remove using the organic shell that is why the joint strength is less in case of the titanium, aluminum as compared to the silver, copper and nickel.

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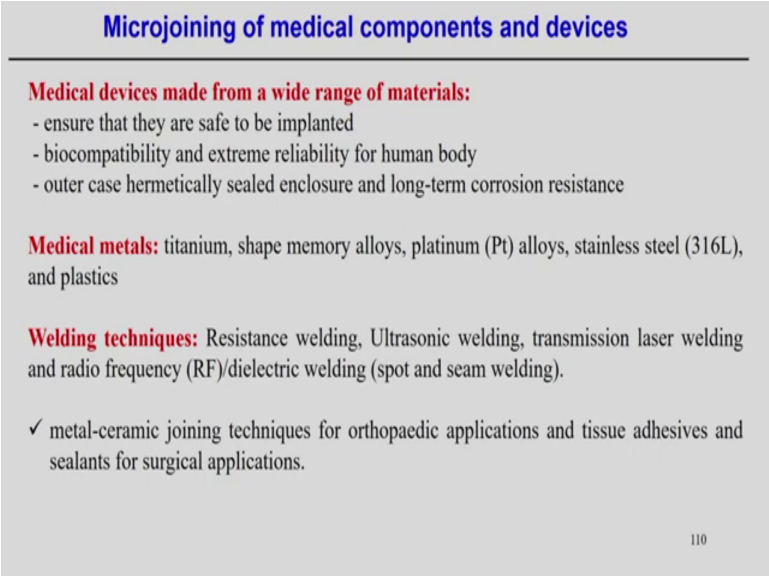

And now we will try to look into the certain aspect of the micro joining of the medical components and devices we will see the different application of the micro joining in medical components and devices. So, it is very important the medical devices made from a wide range of the materials.

For example, ensure that has to be ensure that the safe and implemented it biocompatibility in extreme reliable for the human body that we have to look and at the same time should have very good corrosion resistance properties. A looking into all these properties then we can decide the, what are the metal is basically suitable for the medical devices.

Now, common medical materials are the titanium shape memory alloy platinum alloy stainless steel and plastics because it is having the it satisfy all this the first is the corrosion resistance properties and may be reliable for the human body at the same time biocompatibility, but there are several welding techniques normally used in the medical devices.

For example, resistance welding, ultrasonic welding, transmission laser welding and the radio frequency welding, dielectric welding and radio frequency and dielectric welding will normally using for the polymeric material. And in the form of both the spot as well as the seam welding, that is the requirement in case of the application particular welding in the medical industry medical devices.

Even sometimes metal ceramic joining techniques for the orthopaedic application and tissue adhesives and the sealants for the surgical application we can find out the application of the different welding process in case of medical components.

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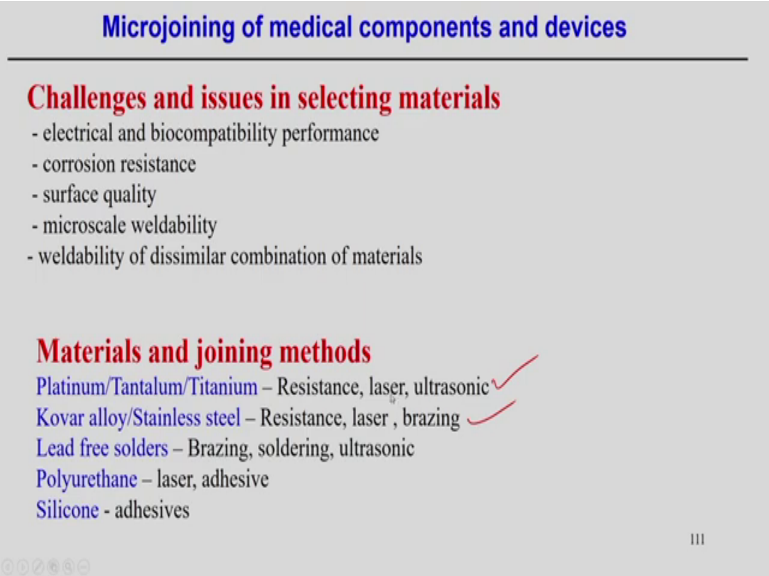

But what are the challenges and issues in the selecting the materials is that electrical and biocompatibility performance is sometimes we required the electrical and biocompatible performance you have to look, when you before choosing the material corrosion resistance surface quality of the weld joint.

Then if you choose the material, but whether weldability is good or not that has to be decided or has to be look into that and of course, there are huge application of the welding of the dissimilar combination of the materials for example, metal to metal at the same time metal to non metal also possible find the application in case of the medical devices.

So, if we will review on the literature we can see that these are the different type of the materials and there are methods also here we can see the first one the platinum, titanium or tantalum is we for this particular metal we can find the application of the resistance welding laser and ultrasonic welding this is the most suitable.

Copper alloy, stainless steel we can find the application of the resistance laser even brazing process also can be used. Lead free solder, in that cases brazing soldering adhesive and ultrasonic welding process can also be used.

Poly polyurethane in these cases laser welding can also be even sometimes adhesive bonding can be used, silicone we normally use the adhesive bonding. So, all this particular materials which is basically using the medical devices. So, this particular metal we can use a different type of the welding process. Here I have listed a few of them that corresponding what are the materials and what are the type of the welding process normally used in this particular materials.

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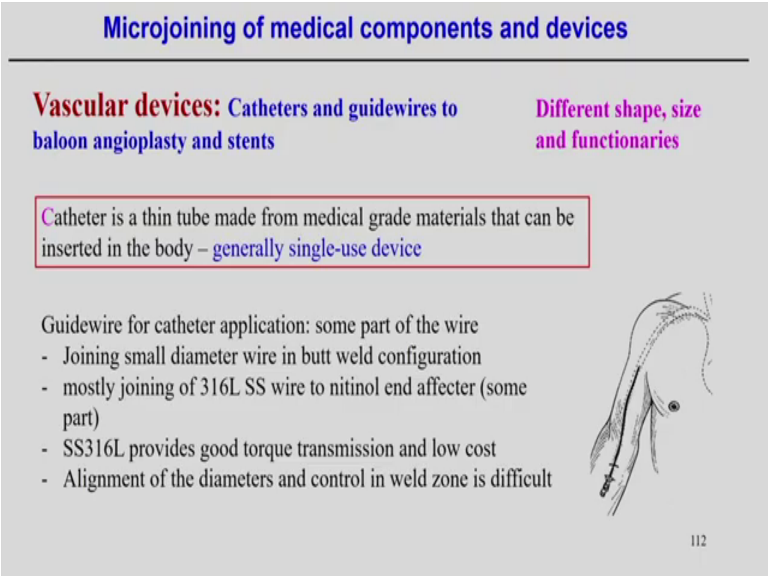

Now, some idea about the where the application we can find out or the medical components for example, vascular devices catheters and the guide wires to balloon angioplasty and stents. Stents is the which just permanent component in the body normally we apply externally. So, we can see that there are different shape and size and different functions are there. So, catheters is basically a thin tube made from the medical grade material, that can be inserted in the body generally single used devices.

So, catheter can be used and inside the guide wires can be used through the catheter and some part of the wire made up the stainless steel and some part of the wire maybe possible to the nitinol. Because stainless steel having the good properties.

In the sense that joining of the stainless steel wire to nitinol at the end effector some part, it is maybe required because stainless steel for which the good torque transmission and the low cost. But for example, in the catheter guidewires sometimes it is required we can use completely in made up the nitinol, but that becomes costly and some sometimes part of the which some part we can made up the nitinol and some part we can replace with the stainless steel, but in this case we have to join the nitinol to the stainless steel.

That may be the challenging may be the application of the welding in this particular application, but it is required sometimes the part of the replaced of the nitinol wire in the stainless steel because sales is provide the good transmission at the same time cost becomes low. So, that sense the joining of dissimilar combination of nitinol as well as a stainless steel is required in this particular application.

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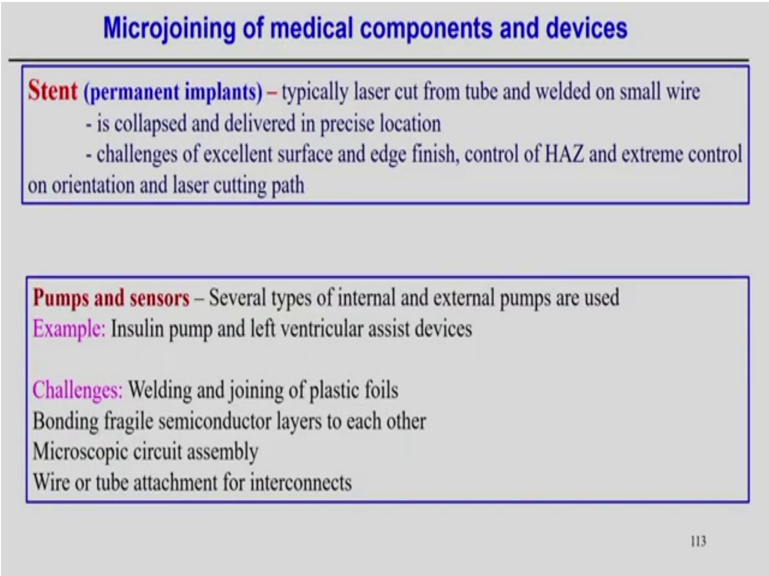

Similarly, stent the permanent implant is normally used, is basically laser cut from the tube is can be done laser cut from the tube and, but at the same time the same stent can also be made using the simply the joining of the wire also that is also there. But it is collapsed and the deliver in the precise location.

That means, once is stent join and it can be delivered deliver one particular location and challenges is that excellent surface and the HAZ is required and once is delivery in particular the control heat affect zone is required an extreme control on the orientation the laser cutting path is also required in this cases if we produce the stent using the laser cutting path. So, we have to take care of the heat affected zone can be very small.

So, that is that maybe the challenging in this case even it is a small scale application. Similarly pumps and sensor similar insulin pumps internal external pumps can be used for example, insulin pump the left ventricular assist devices that can also be required to inserted these things challenges this is the welding of the joining of the plastic foil it is associated with this thing.

Bonding of the fragile semiconductor layer with respect to each other, then microscopic circuit assembly is also involved in this particular process and where our deep attachment to interconnect between these two. All kind of involvement is associated some joining of the competition in the pumps and sensors is there.

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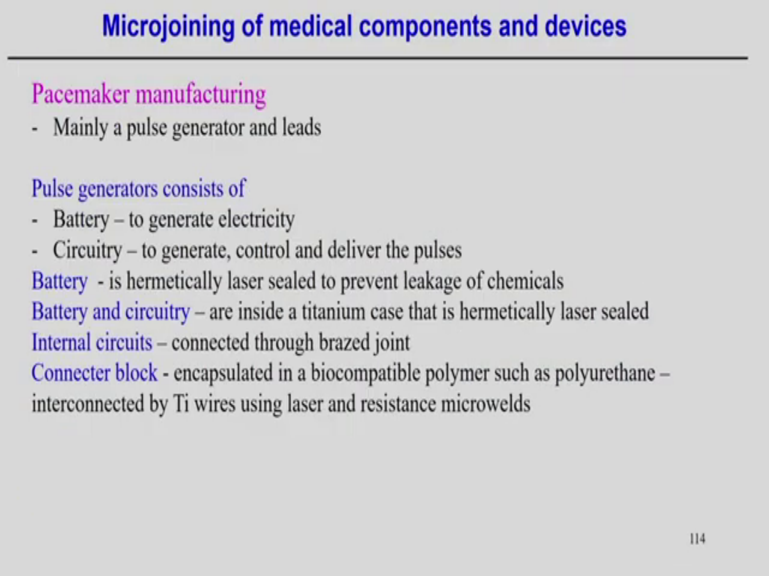

So, I am just trying to look into different kind of application this thing even pacemaker manufacturing mainly a pulse generator and the leads to the. These cases the pulse generator consists the battery and the circuitry, the basically to generate the electricity batteries used and the circuitry that to generate control and deliver the pulses, but this can be make a complete setup.

Such that it can be used as a medical devices for example, battery can be sealed hermetically sealed to prevent the leakage of the chemicals and the circuit which are inside the titanium case and that is also hermetically laser sealed.

So, once is the titanium case we put it, but that has to be sealed and during the sealing of the see laser case that is there is a requirement of the laser welding process there. Internal circuits connected internal circuit is normally connected through the brazed joint process and then connector block.

So, encapsulated the biocompatible polymer such as the polyurethane that is encapsulated. But that is maybe connected by some titanium wire. So, therefore, is the laser and resistance micro welding process this can be done.

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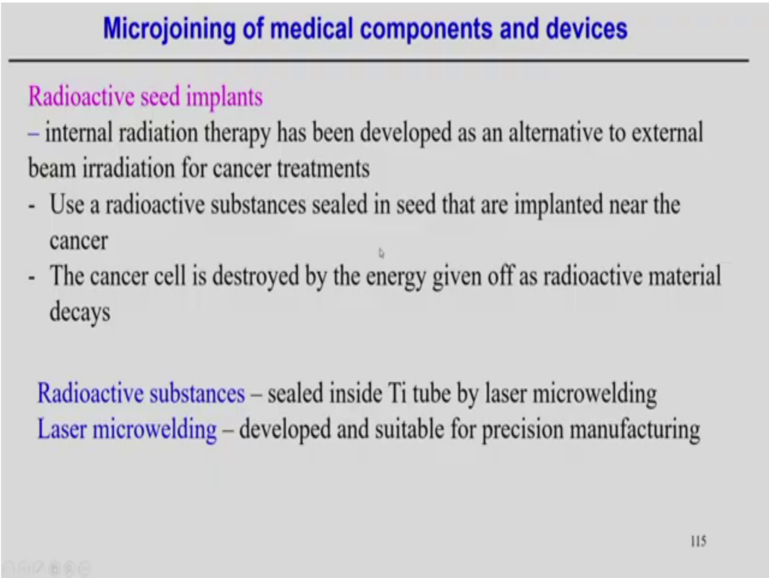

So, it means that each and every aspect in the medical devices we can find out the lots of application of the different welding process joining process and there are similar challenges also. Another example is the radioactive seed implants.

For example; internal radiation therapy had been developed as an alternative to the external beam radiation for the cancer treatment. In this case we use the radioactive substances in the seed and that is implanted near the cancer cell therefore. So, we want to implement these things, but the cancer cell is destroyed by the energy given of the say radioactive material decays this is the principle we follow in these things, but what way the welding is associated with this process.

In this case the radioactive substance is there. So, therefore, seal inside a titanium tube by laser micro welding process. So, radioactive substance has to be sealed inside a titanium tube and that we normally has to be joined using the laser. We have to be very careful this when we joining these 2 components and it is a challenging because it is not affects the radioactive substance during the welding process.

So, in that sense it is very challenging even developed and the suitable for the precision manufacturing that is why laser micro welding is basically utilized and people are looking for this thing for the development and suitable for the precision even more precision manufacturing processes.