Advances in Welding and Joining Technologies

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Lecture – 15
Micro and Nano Joining Processes Part II

Hello everybody, today we will discuss about one of the mostly use the fusion welding process this is the laser micro welding process. So, already we have defined that the domain of the micro welding process in terms of the geometric size and shape of the fusion zone and heat affected zone.

So, in this case at least one of the dimension of the part is less than 100 micrometer probably we can consider that under the category of micro welding process and here the source of the heat from the a laser. So, we know that there is a unique advantage of laser welding process the one thing is that it is a non contact nature and high intensity of laser is focused into very small area.

So, it is possible to define that laser micro welding process which is in terms of the power density. So, normally the laser welding process; the power density power density means the power per unit area which is focused on the surface roughness substrate material that is very high as compared to the other arc welding processes.

So, this is one advantage here in laser process at the same time since it is non contact nature and both metallic and nonmetallic substrates can be processed using laser as a heat source. So, the general configuration of the laser welding process or in specific laser micro welding process is similar to that laser welding processes. Only thing is that the dimension of the what which it is focused is less. And the mode of the laser may be in both continuous as well as pulse mode can be used in case of laser micro welding process.

So, one of the typical laser micro welding process that that is a laser transmission welding.

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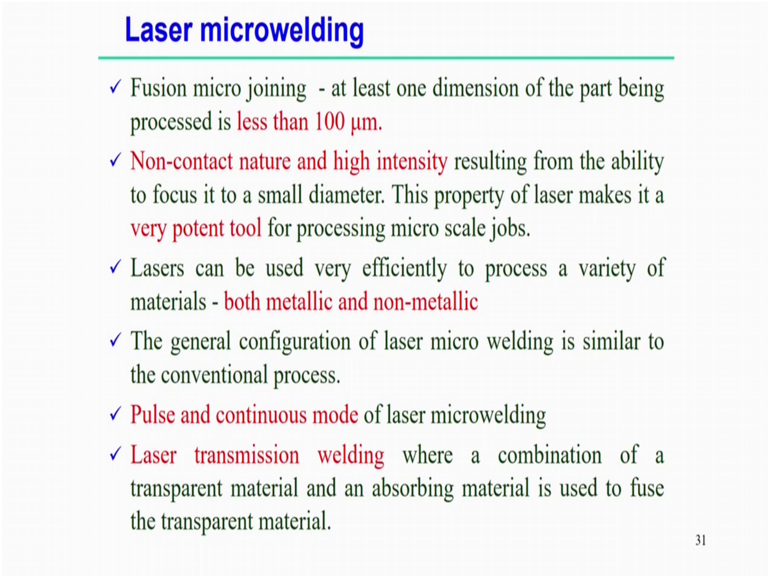

Here the combination of the transferring material and the observing material can be placed in the different way. So, that laser energy will be absorbed on the absorbent. So, we will look into the further on the laser transmission welding, but before doing that we will try to focus on the other aspects of the laser welding process.

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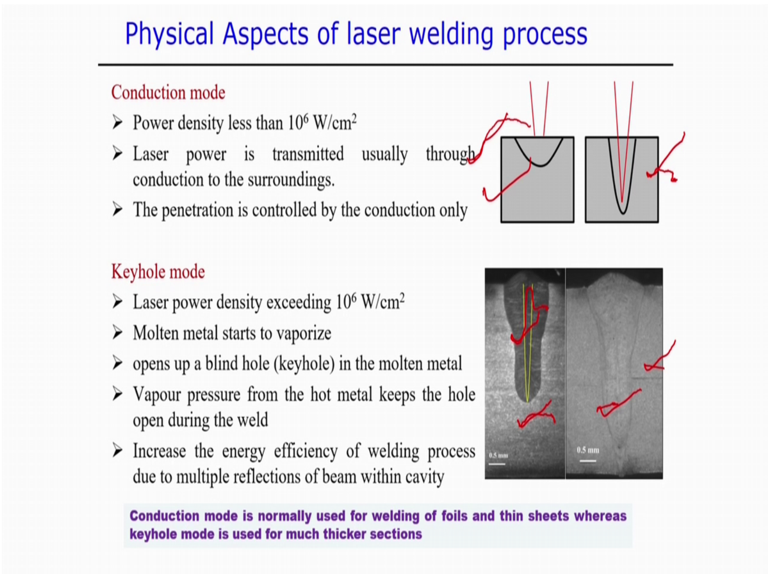

If you see that physical aspects of the laser welding process already we know or we have some idea about the laser welding process that there is a two modes. One is the conduction mode another is the keyhole mode. So, in conduction mode if we see that which when the laser is focused on the surface then it do not produce the much penetration within the weld pool and there may not be any vaporization of the material. So, probably it can be relate in terms of the power density of the laser which laser we are using and we measure the power density when the laser is interacted on the surface of the substrate material.

So, first one is the conduction mode laser welding process. So, in this case the shape of the weld pool is little bit shadow type not much penetration. But on the other side we can define the keyhole mode laser welding process, but before that we may look into the what are the typical aspects of conduction mode laser welding process.

First is that power density is less than 10 to the power 6 watt per centimeter square. Normally we can consider that is a conduction mode laser welding process and the laser power is transmitted usually through conduction to the surrounding and the penetration or depth of penetration or shape is mainly controlled by the heat conduction only.

So, this conduction mode laser welding is we found out we found out the typical applications, but mostly if we try to do the high depth of penetration probably in this case the keyhole mode laser welding is more suitable. Now if we see the right hand side figure that that laser is penetrated into the substrate material and it produce the high depth of penetration. So, this type of welding is generally considered as the key hole mode laser welding process.

So, what is the typical characteristics; of this keyhole mode laser welding process? First is in terms of the power density we can define that keyhole mode laser welding process. So, in this case the power density is normally 10 to the power 6 watt per centimeter square, but apart from that how actually the how the keyhole con forms in keyhole laser welding process. So, since power density is very high it try to vaporize the material since the maximum temperature within the domain of the substrate material; it cause the vaporization temperature of that specific material.

So, it forms a typical shape and over which a vapor domain exist within that substrate material. And that molten metal, start vaporize and basically it creates a blind hole that is called the keyhole and that within the fuel that existence of the keyhole or its reaches with some steady state situation, when it forms a vapor domain. And that vapor pressure actually keeps on life that formation of the a keyhole, but we over sometimes we confused that if there is a formation of the keyhole, then what may be the how why you cannot see after the taking the sample that keyhole size.

So, if we see that these two figures these two figures here it is very clearly defined that the fusion zone and I think these materials are stainless steel. So, and it is a laser welded material and we have taken on the sample or laser welded sample. And then after polishing and itching we find out there is fusion zone; we can identify the fusion zone, but we cannot identify the keyhole zone in this case.

Because keyhole forms during the welding process; so, once that switch of the laser mode for switch of the laser source then that space is filled by the molten metal and after solidification; we cannot we cannot see the size of the keyhole, but it is possible to theoretical calculate the keyhole size. So, that yellow line probably indicates the theoretic theoretical calculation of the keyhole during the welding process and there exist several mathematical model to estimate the size of the keyhole.

And other figure also you see in sort of stainless steel material and this is the weld shape and if we observed typically the shape of the weld pool that indicates that there must be some formation of the keyhole in this case. Also we can identify that if the power density in this case is much more above 10 to the power 6 watt per centimeter square. So, based on that also we can say this is the keyhole mode laser welding process.

But one advantage of this keyhole laser welding process because that the due to the multiple reflection of the beam within that small cavity that cavity means the size of the keyhole that actually increases the absorption of the laser energy during the process. So, when there is a requirement of the high depth of penetration probably the keyhole mode laser welding is more preferred as compared to the conduction mode welding process.

But in terms of the micro welding process since the conduction mode is normally used for the micro welding process because micro welding process we handle rethims it may be less than 500 micrometer or around 100 micrometer. So, in that case probably there is no requirement of the keyhole mode laser welding process.

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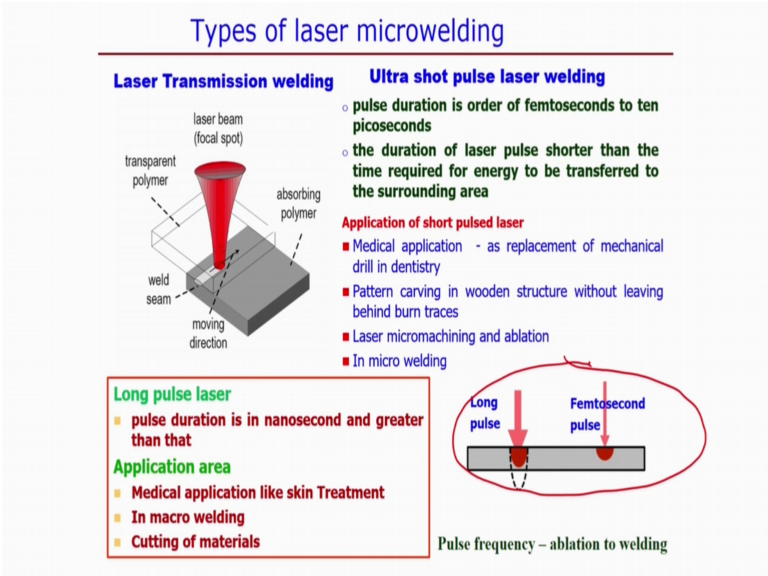

Now, further what are the different types of laser micro welding process? First we see that laser transmission welding; now we will try to explain the what is the laser transmission welding. From the figure it is very clear that laser beam is focused on the substrate material and over this transparent polynomiar polynomial is a polymer is there and the bottom side that absorbing polymer is there.

So, laser is used in such way that wavelength of this laser (Refer Time: 10:15) such that it can transfer to the apart polynomial upper side the polymer, but it is that within that will wavelength it should be absorbed by the bottom side polymer. So, that the heat will be released on the at the interface between the two substrate material. So, this is the typical mechanism of the laser micro welding process sorry laser transmission welding process.

But in this case if we try to join two transparent polymer material using the laser transmission welding process. So, in this case if the laser beam or laser light is transparent for the both the material; then it is necessary to put an one very thin absorbing layer between the interface. So, that that layer will absorbed the laser energy and finally, it will melt the substrate material and then we conform the welding process.

At the same time the laser transmission welding is possible to join between one polymer to another metallic material. So, first polymer in the first layer of the polymer it is transparent to the laser. And the second we choose the metal in such a way that the second metal will try to absorb the laser energy and the there is a interface melting between these two met between these two substrate materials and then we can from the world between these two metal. So, this is the typical mechanism of laser transmission welding and mostly several micro welding application, we can find out this type of welding process.

But there is another type of welding process based on the pulse duration that is called ultra short pulse laser welding process. So, actually ultra short pulse laser is generally used for the material ablation or maybe we can say the metal removal processes, but this laser can be used for the welding purposes.

But before that we need to know that what are the typical characteristics of this short pulse laser ultra short pulse laser? Normally for ultra short pulse laser we use the femtoseconds pulse laser femtoseconds or pico seconds pulse laser. So, femtosecond pulse laser the duration of the pulse is around 10 to the power minus 15 seconds. So, within such small duration if the laser energy is transmitted to the substrate materials, but the substrate materials specifically; if we consider the metallic materials for example, it is a metallic material like gold.

So, in that case the within the such duration that there is a finite time is required to transmute the energy to the surrounding area. So, that finite time for any specific metal is even higher than there of the duration of the laser pulse; so, in specific to ultra short pulse laser welding.

So, that pulse duration and the finite train of the heat transfer or maybe energy transfer within the metal is these two are comparable. Then there is a effect of the delay; that means, there is a some delay in transmitting the heat flux needs to considered; that means, this can be characterized by the some relaxation times.

So, relaxation times in terms of the development of the temperature gradient within the substrate material or relaxation time in terms of the heat flux applied to the substrate material or maybe after applying the substrate material; what is the development of the; that means, development of the specific heat flux within the substrate material that can also be delayed.

And there is two types of relaxation probably we will consider need to consider in case of ultra short pulse laser. And it is not required in case of when the large or medium pulse laser processing or maybe medium or laser pulse wielding processes. But theoretical aspect we will look into ultra short laser is very much different from the normal or medium or long pulse laser.

Long pulse laser means we understand that is a nano second and microsecond and millisecond in that pulse duration probably the in the application of the energy from the laser is instantaneously transmitted to the substrate material. So, there may not be any lag phenomena.

So, normally this ultra short pulse laser welding; we analyze using the non Fourier heat conduction or maybe two temperature models assuming that there is a phonon and electron scattering or coupling between the phonon electron or scattering between the phonon and phonon. Based on that principles we can estimate the different relaxation times when some substrate material is interacted with some ultra short pulse laser; that means, it femtosecond pulse laser.

Now, in that respect we can explain that application of the pulse laser; if we see that in medical application which can be considered as the replacement of the mechanical drill in dentistry. So, that is the typical application of the very short pulse laser and pattern carving in the wooden structure without leaving the behind urn that burn traces can also be observed a typical application of the short pulse laser. And of course, the short pulse laser is very much applicable for the micro machining and the ablation process and of course, it is suitable for the micro welding process.

But as compared to that long pulse laser if we see the pulse duration is may be nano second or the greater than the; so, that type of laser typical application the medical application is like skin treatment in macro welding processes. Of course, that long process can also be application in micro welding processes and cutting of the materials; these are the typical application for the long pulse laser.

But if we see that right hand side this figure here there is a comparison between the long pulse laser and femtosecond pulse laser; that means, long pulse laser and short pulse laser. So, normally we see that long pulse laser the size of the heat affected zone or molten size is little bit more as compared to the femtosecond pulse laser.

So, if you see the femtosecond pulse laser is very precisely focused into a very small area and there is may not be much sufficient time to transmission of energy around the surrounding material. So, whatever processing is required; it is may be confined into the very small area. So, that is the advantages of using the femtosecond pulse laser.

But how point is that whether this femtosecond pulse is the laser is suitable for welding or not. So, it was investigated that; so, pulse frequency may be pulse having a role whether the femtosecond laser can be used for laser ablation process or can be used for the welding purpose.

Normally, if pulse frequency is very low frequency is low ah; then it is suitable for the laser ablation materials. Because frequency is low means within the small time gap small time gap there is a application of a continuous pulse energy; So that energy actually ablated the material and without affecting the surrounding material.

But in other way, if pulse frequency is very high say the range of megahertz. So, in that range pulse frequency this femtosecond laser is more suitable for the welding purpose. Because the application of the application of the pulse within the one cycle the duration is very low in this case. Of course, in these two cases the average for may be the same, but there will be the change of the peak power and the frequency of application of the laser pulses is maybe it is the span is very lapse is very high. So, in that case this situation is more suitable for the welding purposes.

So, nowadays that ultra short pulse laser is more effectively used for the joining of the dissimilar metallic materials apart from the nonmetals. Because, so far the ultra short pulse laser is used welding purposes were more specific to the nonmetallic material maybe that in terms of the laser transmission welding.

We will try to review the what are the are in ultra short pulse laser domain what type of materials we can use for welding purposes and what type of laser we will generally used for the welding purposes of metals or non metals or maybe dissimilar combination of the materials. So, it is very much significant that still there is a development happens the in welding processes using the ultra short pulse laser.

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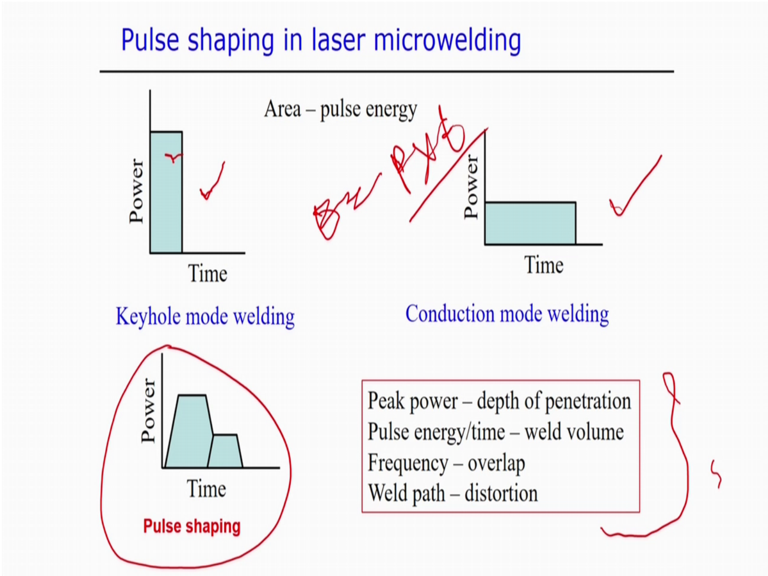

Now, before doing that we can discuss about the shape of the pulse of course, shape of the pulse is very much influential in case of the laser micro welding process. So, depending upon the type of the material; so, there is a several type of material we try to weld using the laser, but we normally consider the shape of the once maybe square shape of the pulse.

And maybe within the pulse duration, but theoretically or logically if we try to see that shape of the pulse having influence on the laser micro welding process or in general the welding processes. So, let us look into investigate what is the shape how is the shape of the pulse influences the laser welding processes.

If we look into the first figure here the shape of the pulse rectangular shape of the pulse, but pulse duration is small in this case, but peak power is very high. So, when peak power is very high and pulse duration is small. So, these type of pulse is more suitable for the keyhole mode laser welding because within the short span of time there is a release of the huge amount of the laser energy. So, that is suitable for produce the high depth of penetration in specific in substrate material. Remember the area actually that area of this rectangle represents the pulse energy.

So, that pulse energy actually the power into the duration of the time; so, P into t. So, that actually represent the energy of the pulse and physically represents this the area of this is basically represents the pulse energy, but if you look into the other things also in the second figure.

So, in this case if we see that there is a release of the energy, but the duration is little more as compare to the first case. So, of course, the same amount of the pulse energy second case, but peak power is less and duration of the pulse on time is more. So, these type of pulse is suitable in case of conduction mode welding process. Because conduction mode welding process the peak temperature relatively less and there is a power density, we control is relatively low so, that it may not vaporize the substrate material.

So, that type of pulse is very much suitable for conduction mode welding processes. So, if we look into that; so, shape of the pulse having in general having some influence on the laser material processing. First if you see the peak power if peak power is very high probably that mainly controls the depth of penetration if pulse energy per unit time that actually controls the weld volume.

So, weld volume is morely more sensitive to the pulse energy per unit time theoretically. And other way if we want to keep the depth of penetration is very high then probably the peak power is the more sensitive parameter in this case and then frequency of the application of the laser energy that actually creates the overlap or maybe overlapping spot in the sense.

So, the frequency control that overlapping of the energy on the substrate material. And we will path in general the path of the welding path maybe since laser welder is confined it is very small area as compare to the arch welding processes. So, path may be more related to the distortion level of the sample.

So, these are thus parameters and how it is sensitive to the different conditions where we try to desire the whether high depth of penetration we need the large volume of the metal maybe conduction mode or may be if there need of the overlap or if you want to control the distortion for all these purposes; we should effectively use the different shape of the pulse or maybe different laser parameters we can control we can link with this requirement according to the requirement.

Now, point is that since if we see the two types the more suitable in this case that keyhole mode welding and conduction mode welding which are simply changing the shape of the pulse. Similarly if it is possible to create some complex shape of the pulse then it is possible to weld difficult material for example, very crack sensitive materials and high materials.

So, in that cases in that type of materials which is very much difficult to weld probably can be done if we properly design the shape of the pulse. So, that is why setting of the pulse is advantages in the sense that when you try to weld the difficult materials in the case of you correctly shape of the pulse that is always will be able to produce some weld joint which is which is otherwise very difficult.

For example here the shape of the pulse in complex in nature maybe combination of the some triangular shape or rectangular shape or some other shape; so, that shape having certain influence on the welding process. So, that will try to understand what are the shape of the pulse and what type of material we can weld in this case.

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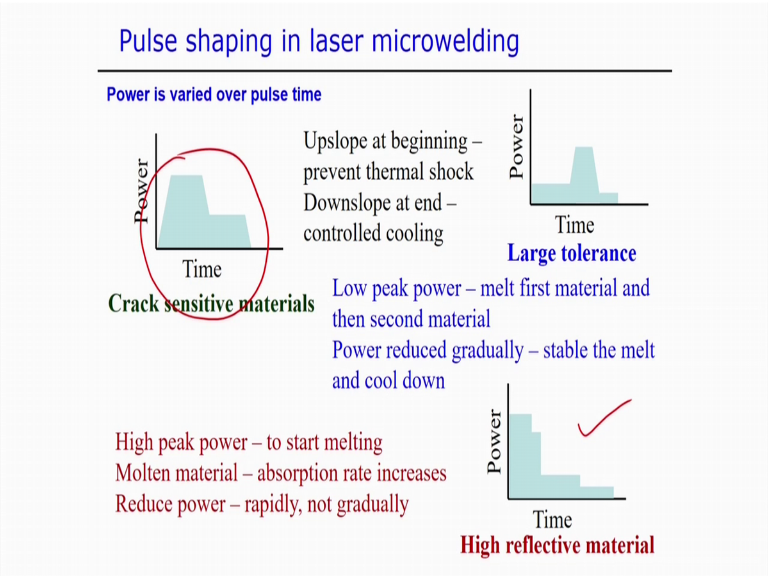

Let us look into this part that first thing is the crack sensitive materials. If you see the design of the pulse in case of the crack sensitive materials first is the upslope at the start there is a upslope; that means, gradually increment of the power beginning. So, this type of shape of the pulse actually prevent the thermal shock; that means, with respect to the suddenly application of the pulse at time t equal to 0.

Next finally, that down slope at the end that also controls the a heating process. So, if it is possible to control the heating and the cooling process; so, then it is possible to develop the welding process depending upon the shape of the pulse to when crack sensitive material. So, these are the typical shape of the pulse in case of crack sensitive materials, but if you look into that other type of welding process when there is a tolerance is require.

So, in that type of welding process we can start low peak power, but there is no gradual increment of the power maybe power amount of the peak power in this case is very small. So, and if you keep it over of sufficient time actually melt first material and then afterwards its melts the second material.

Now, at the finally, there is a gradual decrement of the pulse. So, that actually helps to stable the melt material and cool down to the weld joint cool down to the ambient temperature. So, these type of shape of the pulse is basically helps when there is a large tolerance is require during the welding process.

Now, if you look into the other type of the pulse shape; it is a high reflective material. So, high reflective materials is really very difficult to weld using the conventional welding process, but in using the laser welding process it is possible to weld high reflective materials. So, in that case a good design of the pulse shape of the pulse is advantages for discus.

So, if you see the shape of the pulse here we can see that high peak power. So, high peak power is facilitates to start the melting point; because this high conduct high reflective material there may be reflected the most of the laser energy. So, in that case initially we can start with the very high amount of the power to start the to initiate the melting process. Then once the molten material molten material forms; then that then only there is absorption of the laser power is actually increases after formation of the molten pool.

Then finally, reduce power and rapidly, but not gradually that actually helps to the wilding of the high reflective material. So, in this case first very high power then gradually reducing, but we can do that reduce power we can reduce the power rapidly and then rapidly and then gradually it we can reduce the magnitude of the laser power.

So, these type of shape of the pulse is very much suitable in case of the high reflective material. So; that means, the there is a role of the shape of the pulse in case of the welding of the different types of the material when there is a difficult and possibly it is useful when there is a difficulty in welding for the different types of material.

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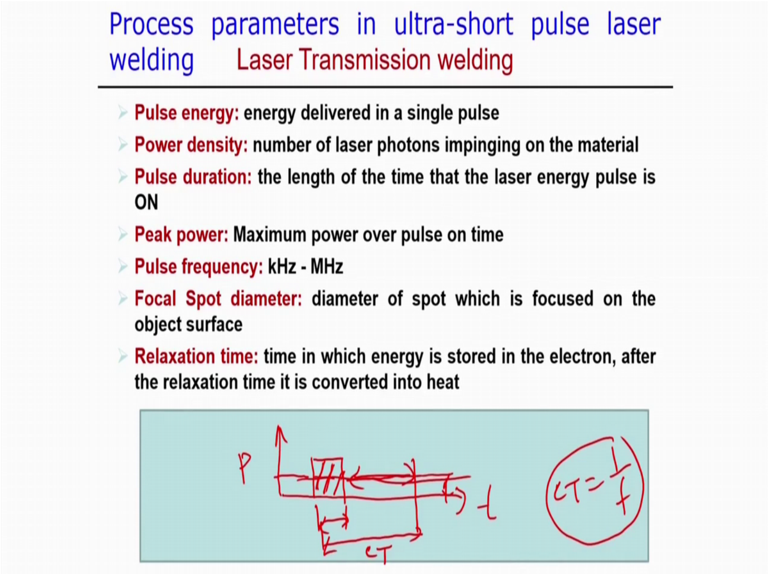

Now, what maybe the pulse per meters normally we consider or sorry process parameters we consider in case of ultra short pulse laser welding process and it very specific to laser transmission welding process.

So, here if we see that pulse energy we know that pulse energy delivered in a single pulse that is that is the that is represent the pulse energy. And power density that number of laser photons impinging on the material or in mathematically, we can measure the power density that simply application the power divided by the cross sectional area over is it pulse of one.

Then pulse duration the length of the pulse time that the laser pulse is on and then peak power peak power is the maximum power over overviews the it is focused on a specific object.

And then pulse frequency then its normally in case of welding process normally it ranges from kilohertz to megahertz and spot diameter that diameter overviews the laser is focused that that is a representation of the spot diameter and the in case of relaxation welding laser transmission welding process laser relaxation time is important when we use the ultra short pulse laser.

So, in that case the relaxation time is basically defined that there is a lag to development of the heat flux or development of the temperature gradient within the domain. So, that lag time is very much important when there is a interaction of the substrate material with the ultra short pulse laser. So, we will try to explain that a typical shape of the pulse if we see that it is a pulse shape over the time and this is the power.

So, normally we start with the this is the over the time, this is this area actually represents the pulse energy. So, and this time spend actually represents the pulse on time and this total time is basically represents the cycle time. So, that cycle time is if frequency laser application pulse application frequency is f then cycle time is basically 1 by f; that means, this is the cycle time. So, over the cycle time some part of the time is we apply the pulse remaining time there is a up time; so, there is no application of the pulse energy.

So, these are the typical pulse say pulse and we generally use in case of laser welding process, but the shape we are assuming the reacting level shape can be different. But sometimes we use the average power also, but average power is maybe in between the peak power and the base power. So, for example, this is the average power this is this average power is simply representation the n some constant power over the duration of the welding process. So, it actually it actually reduce the effect of the or maybe eliminate the effect of the pulse; pulse on off, on off in that mode that we generally use in case of the laser welding processes.

So, sometimes we generally most of the cases we do the analysis of the process based on the average power. And sometimes we analyze the process based on the that peak power or may be pulse duration of the pulse is depending upon the different types of welding process the analysis method can be different whether we should consider the if we consider the average power it is very much equivalent to the continuous mode of laser welding process.

So, it basically eliminates the effect of the pulse session, but if you want to do the actual analysis of the laser welding process based on the pulse, then we need to consider the characteristic in terms of the peak power pulse duration pulse up time, cycle time ah; that means, in terms of frequency that all parameters are significant to analyze the pulse laser welding process.

Now, we will further analyze the shaping of the pulse in micro welding process and here what we have try to do some simulation. So, that actually give the actual idea or maybe some feedback based on the simulation we can find the difference of the in terms of the output parameters when there is a change of the shape of the pulse.

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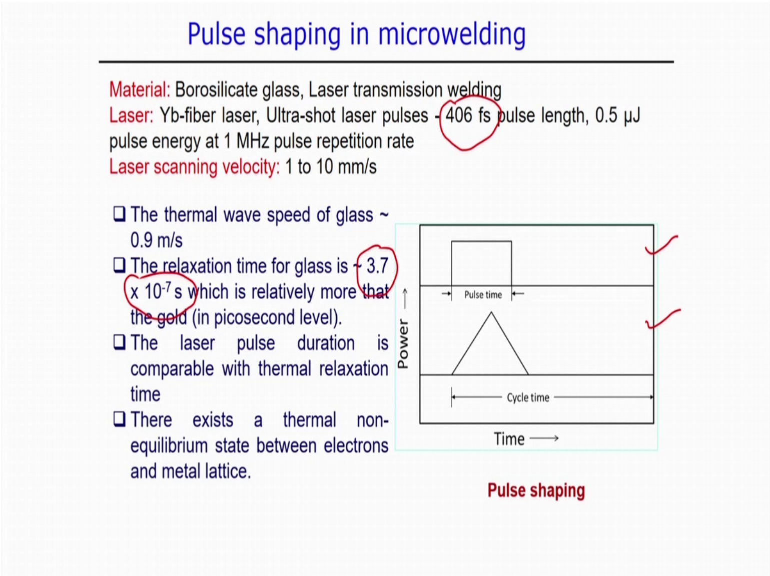

Let us see that consider the material borosilicate glass and the laser welding process is the laser transmission welding fiber laser has been used ultra short pulse laser pulse duration is 406 femtosecond pulse with and pulse energy is 0.5 micro joule. And that pulse repetition rate or maybe frequency that 1 megahertz and laser scanning speed the 1 to 10 millimeter per second.

And in this case two different shape of the pulse has been consider; one is rectangular pulse another is the triangular pulse, but in this two cases pulse energy are same, but geometric shape of the pulse are different. So, when you try to consider the effect of the pulse shape we can see that we need to consider the other parameters.

For example the thermal wave speed of glass we estimated that 0.9 meter per second. So, with respect to that the relaxation time for glass is 3.7 into 10 to the power minus 7 second. So, these relaxation time is little bit more as compare to the metallic material for example, gold that the relaxation time in case of gold is around 10 to the power in around 10 to the power minus 12; that means, in pico second level.

Now, when we consider this things that relaxation time this actually comparable as compare to the pulse width; So, this relaxation time is more as compared to the pulse on time; that means, 406 femtosecond which is comparable with respect to the 3.7 into 10 to the power minus seven that is the relaxation time.

So, when the relaxation time is less sorry relaxation time is more as compared to the pulse duration then it is better option to analyze this phenomena using the non Fourier effect of the heat transfer mechanism. So, and this mechanism in this mechanism is this mechanism based on that they are exist some non equilibrium state with the application of the femtosecond level pulse on the substrate material.

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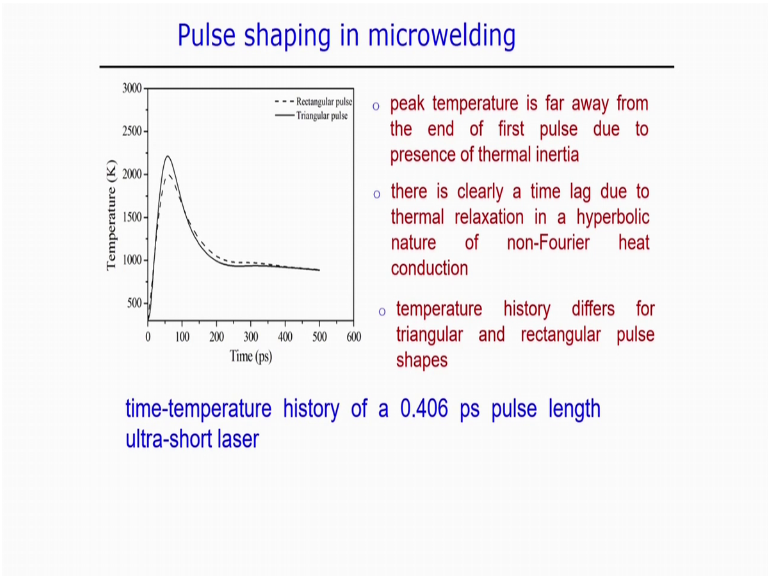

So, using these two shape of the pulse we will try to see that there is a time temperature history for this femtosecond pulse or maybe 0.406 picosecond pulse length using the ultra short laser and here we can see for a single pulse there is a there is a little difference as com that time temperature history within the substrate material.

So, the peak temperature is high in case of triangular pulse shape as compare to the rectangular shape of the pulse. At the same time peak temperature is actually far away from the end of the first pulse due to the presence of the thermal inertia.

Actually the in case of when you try to analyze the effect of the heat transfer in case of normal or maybe large pulse duration case. So, in that case we assume the Fourier heat conduction; so, there the with the application of the pulse energy within the surface instantaneously there maybe some development of the temperature. So, there is no lag or no gap between the application of the flux and the development of the temperature within the body that is the basic assumptions in case of Fourier heat conduction.

But when you try to use the ultra short pulse laser, there may be some gap with the application of the heat flux and there is a development of the temperature within the body that gap is characterized by the relaxation time for this specific material. So, that why, but here if we see that there is a gap to reach the peak temperature and the at the end of the pulse and even to reach the peak temperature there is a little bit gap.

So, these gap actually happens due to the thermal inertia effect within the body and that and that is because of the femtos there is a interaction of the femtosecond pulse with the substrate material.

Another observation is that there is a time lag due to the thermal relaxation in the hyperbolic nature of the non Fourier heat conduction that we have considered in this case. And of course, temperature history differs with respect to the triangular and the rectangular pulse.

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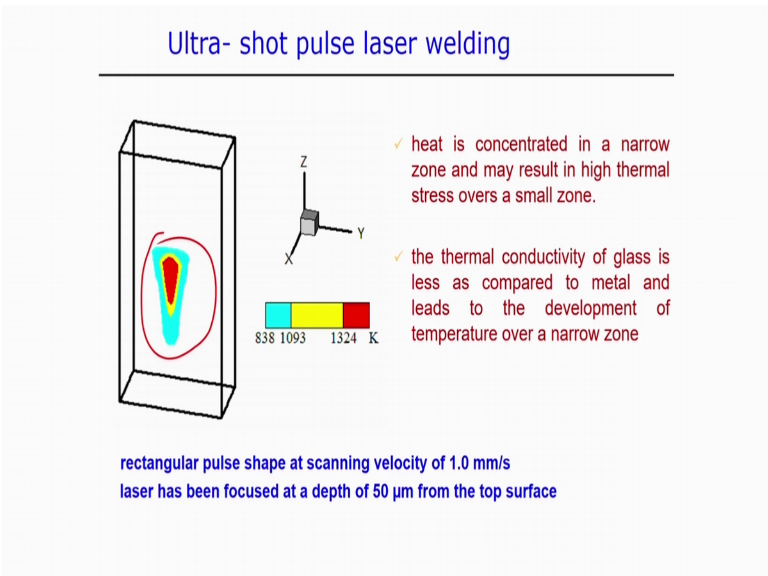

Here is the typical simulation of the rectangular pulse shape at the scanning velocity of 1 millimeter per second and the laser beam because this is a laser transmission welding. So, laser beam is focused 50 micrometer from the top service then we can create this kind of weld profile. And of course, this analysis has been performed using the non Fourier heat conduction mode.

So, heat is concentrated is very narrow zone that is obvious from this simulation results and the thermal conductivity of glass is actually less as compare to the metal. So, that actually leads to the development of the temperature over narrow zone that is also one reason for that.

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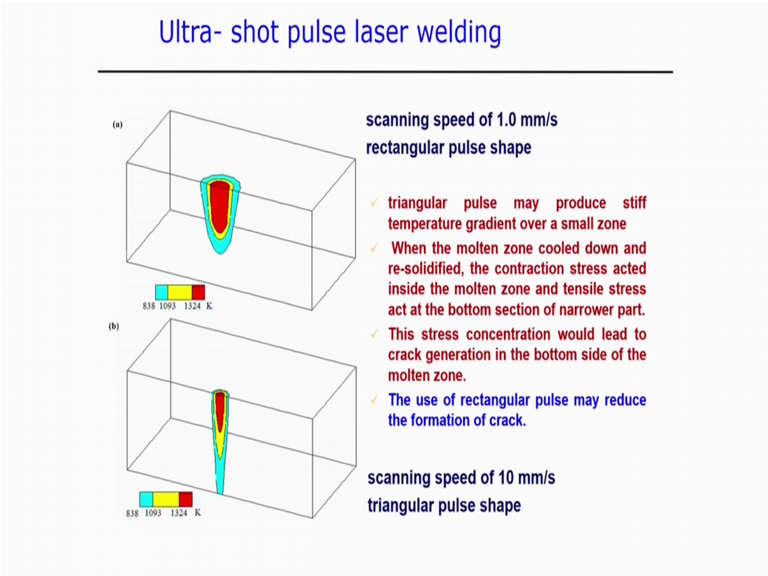

And then we did some simulation at the two different cases one cases is the scanning speed; that means, laser moving speed is 1 millimeter per second, but in that case we consider the rectangular case of the pulse. In another case the scanning speed is 10 millimeter per second, but in this case the triangular shape of the pulse has been used. Now you can see there is a huge difference in the time temperature profile at the two different shape of the pulse.

But triangular pulse probably producing the more stiff temperature gradient as compare to the rectangular pulse this is one case, but due to the there is a difference from the contraction stress acted inside the molten pool and the there is a with respect to the bottom surface. So, probably at the bottom surface there is a narrow part and that actually creates some difference in the stress distribution on the molten pool and the bottom surface when the material become solidifies.

So, that stress concentrations can lead to the crack generation basically at the bottom side of the plate. So, in this case if we try to avoid the crack formation probably the rectangular shape of the pulse is more suitable because the rectangular pulse is produce the least temperature gradient as compare to the triangular shape of the pulse.

So, purpose of this analysis is to find out that shape of the since shape of the pulse actually influence the temperature distribution within the body and that temperature distribution is also responsible; to create whether any distortion or residual stress at the same time whether there maybe the formation of the crack that actually may can also be linked with the distribution of the temperature.

So, distribution of the temperature is also influence by the shape of the pulse. So, when you try to do some welding process in very smaller scales specifically micro welding scale in that case the shape of the pulse probably so, very significant very important it may not be much important when you try to do.

So, welding in case of the macro scale may be a normal scale welding process the shape of the pulse having little influence or may have may not have any influence at all, but in micro welding process or smaller scale welding process or even nano welding processes also the shape of the pulse probably significant.

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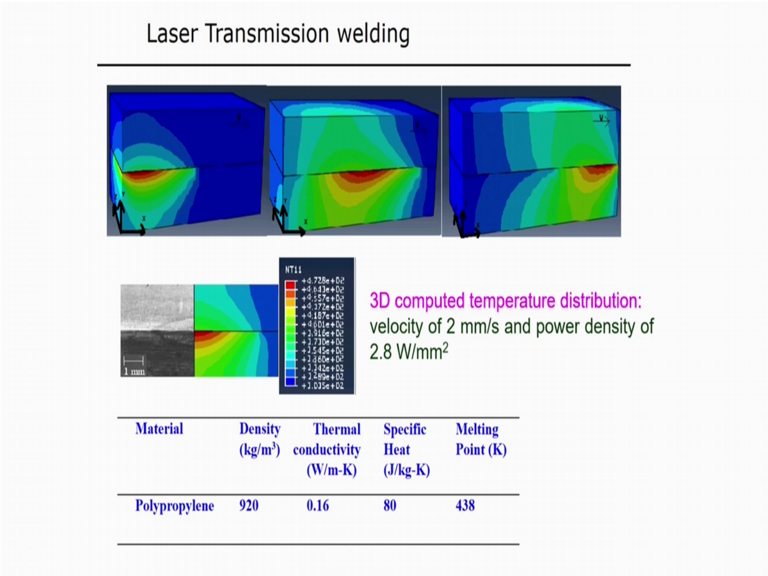

Now, some simulation for the laser transmission welding material poly polypropylene we have used the other material properties are also defined. So, in this case the similar type of materials can be joined and the two sets considering the contact resistance between the two surfaces. And we can see the temperature distribution between the two surfaces in the laser transmission welding mode. And this figure also represents the comparison between the actual experimental and the some simulation profile.

So, in this case that we can observed that in laser transmission welding the in case of even there similar material, but maybe in the one both material transparent, but at the interface if you some observing material that actually influence the temperature distribution of these two substrate material. And we can get this type of temperature distribution in case of the laser transmission welding.

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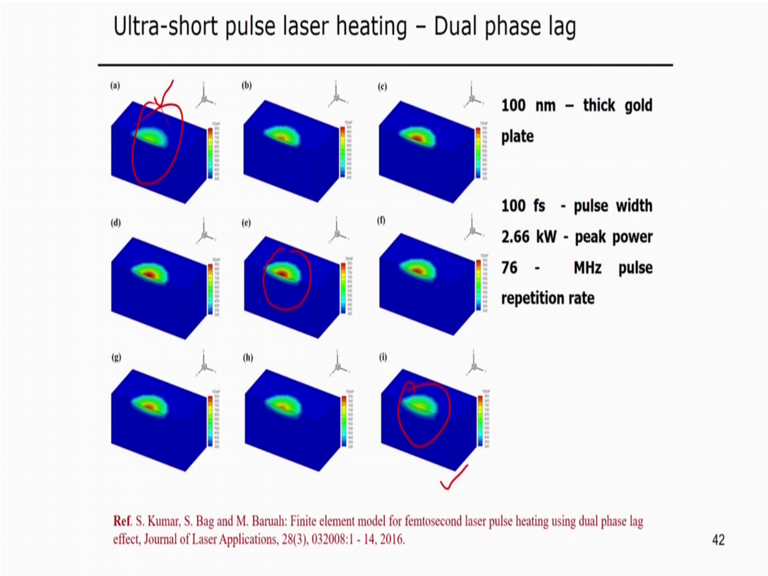

So, further analysis on the laser micro welding, but in this case the ultra short pulse laser heating process using the dual phase lag effect. If we see that since there is a phase lag if we see the figures actually if we observe the figures that from the first figure to the last figures that peak temperature achieved is somehow in between maybe in figure e the peak temperature is achieved.

But in this case if you look into the depth the depth of penetration is low as compare to this last one. Of course, in the last figure there is a the it is not the peak temperature is low as compare to the figure e, but depth of penetration is more as compare to the figure e; that means, this actual this simulation is signifies that with a application of the flux on the surface, there is a movement of the development of the temperature distribution that actually define the penetration there is a some relaxation exist; that means, with the application of the heat flux it is not instantaneously developing the temperature distribution with the certain depth.

So, some time lag is required some time lag is obvious some time lags exist and that is obvious from this all these simulated results. So, of course, this simulation has been performed using the effect of the dual phase lag over the 100 nano meter thick gold plate. And in this case 100 femtosecond pulses has been used whether peak power is very high 2.66 kilo watt and the pulse repetition rate or maybe frequency 76 megahertz.

So, with this conditions we can find out that there is a clear effect of the relaxation time in case of ultra short pulse laser heating process.

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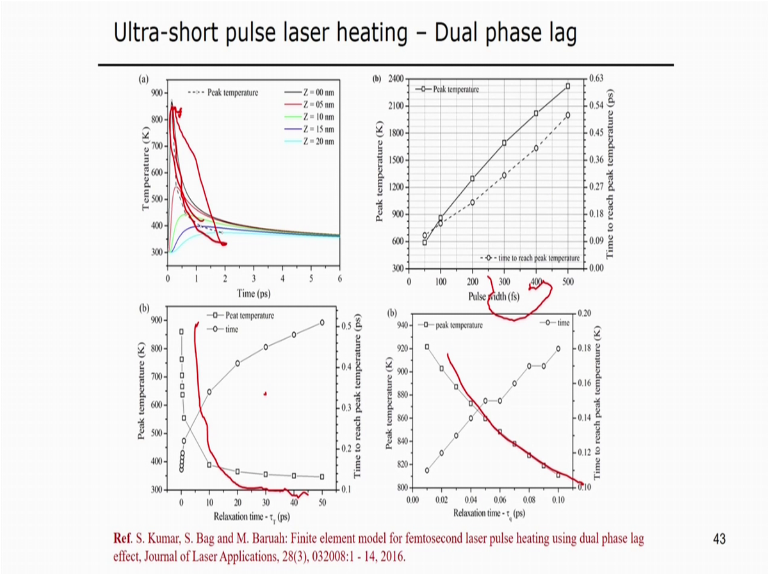

So, these some other some results that is the we try to analyze the effect of the ultra short pulse or phase lag effect.

So, here if we see the first figure there is a typically shifting of the peak power which is not obvious in when there is a pulse length is very high maybe in the nanosecond or micro second or millisecond level; there may not be the shifting of the peak power. And these shifting of the peak power only because of the lagging effect.

So, similarly pulse with effect having the if you increase the pulse width there is a increment of the peak power at the different if you increment the pulse width. So, peak temperature actually increases in other cases if you see that there is a effect of the relaxation time, since the relaxation time is very difficult to measure accurately and of course, it also depends on the temperature.

Then the there maybe the if we do the variation of the relaxation time; there is a maybe change of the peak temperature also. And the both the figure also shows that peak temperature actually reduces with respect to the higher relaxation time here also peak temperature reduces in the with the high relaxation time.

But both these cases the nature of the geomet the increment or maybe non-linear behavior generally observed in the with the with respect to the relaxation time with the with the variation of the peak temperature.

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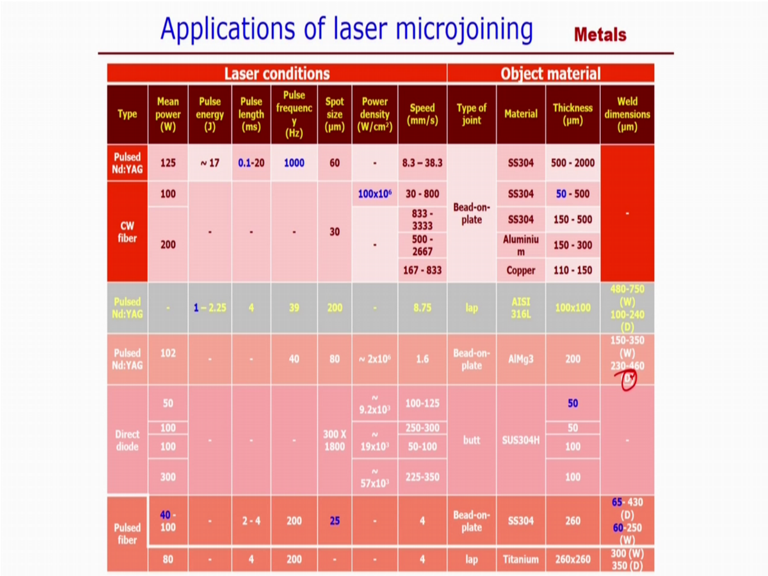

Applications of laser microjoining — Metals

Laser conditions								Object material			
Type	Mean power (W)	Pulse energy (J)	Pulse length (ms)	Pulse frequency (Hz)	Spot size (μm)	Power density (W/cm²)	Speed (mm/s)	Type of joint	Material	Thickness (μm)	Weld dimensions (μm)
Pulsed Nd:YAG	125	~ 17	0.1-20	1000	60	-	8.3 – 38.3	Bead-on-plate	SS304	500 - 2000	-
CW fiber	100	-	-	-	30	100x10⁶	30 - 800		SS304	50 - 500	
	200					-	833 - 3333		SS304	150 - 500	
							500 - 2667		Aluminium	150 - 300	
							167 - 833		Copper	110 - 150	
Pulsed Nd:YAG	-	1 – 2.25	4	39	200	-	8.75	lap	AISI 316L	100x100	480-750 (W) 100-240 (D)
Pulsed Nd:YAG	102	-	-	40	80	~ 2x10⁶	1.6	Bead-on-plate	AlMg3	200	150-350 (W) 230-460 (D)
Direct diode	50	-	-	-	300 X 1800	~ 9.2x10³	100-125	butt	SUS304H	50	-
	100					~ 19x10³	250-300			50	
	100						50-100			100	
	300					~ 57x10³	225-350			100	
Pulsed fiber	40 - 100	-	2 - 4	200	25	-	4	Bead-on-plate	SS304	260	65- 430 (D) 60-250 (W)
	80	-	4	200	-	-	4	lap	Titanium	260x260	300 (W) 350 (D)

So, after looking into that ultra short pulse laser welding mode probably; we can see the application of the laser micro joining processor. So, for that in practical use of the micro joining process in case of metals from the table, it is very much obvious that what are the different types of laser is used for the micro joining applications or using as laser.

So, first pulsed Nd YAG laser continuous way fiber laser pulsed Nd YAG laser and direct laser and pulse fiber laser these are the typical laser. So, for practically applied in case of the micro joining processes and specific to joining the metallic materials; So, if we see the from the tabulated format from that here the mean power is around minimum mean power is around 40, 50 watt.

But maximum is I think from the stable around 300 watt pulse energy where is; so, one case is it is 1 joule, another case is may be 17 joule pulse length also varies 0.1 to 20 millisecond other cases 2 to 4 millisecond or maybe 4 millisecond.

So, in this case; that means, if you observe for the joining of the metal using the ultra using the pulse laser welding process; we here the from the pulse length we can find the most of the cases we use the millisecond pulse for the micro joining process specific to the metallic material.

So, here if you see the other power density reaches to as maximum of 100 into 10 to the power 6 watt per centimeter square; probably it is on the around to the formation of the keyhole. And that comes from the continuous wave fiber laser and normally we do not plate welding, lab joining, butt joining these type of welding join has been performed using the different types of lasers.

And on different materials stainless steel, aluminum copper and titanium mainly these type of materials is applied in the pulse laser in the micro joining form where the thickness actually minimum thickness is formed out from the literatures that it is a 50 micrometer minimum to maximum it goes to 2000 micrometer.

And weld dimension if you see the W means here width and D means the depth. So, here if we see that is width and depth is around 65 micro meter to 300, 200 and 150 that in that that level the weld dimension can be produce. And this is the typical observation from the literature that for metallic materials the three or four types of laser can be used on the for the microwelding applications and a different types of materials.

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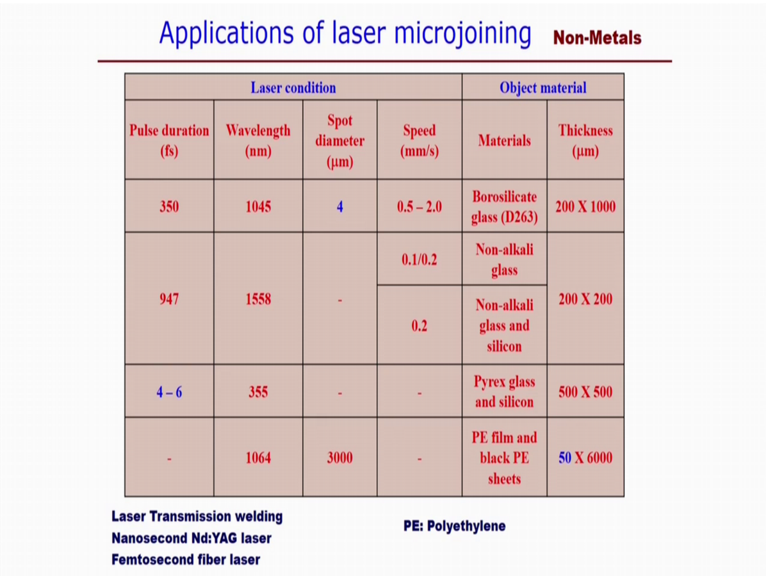

Applications of laser microjoining **Non-Metals**

Laser condition				Object material	
Pulse duration (fs)	Wavelength (nm)	Spot diameter (μm)	Speed (mm/s)	Materials	Thickness (μm)
350	1045	4	0.5 – 2.0	Borosilicate glass (D263)	200 X 1000
947	1558	-	0.1/0.2	Non-alkali glass	200 X 200
			0.2	Non-alkali glass and silicon	
4 – 6	355	-	-	Pyrex glass and silicon	500 X 500
-	1064	3000	-	PE film and black PE sheets	50 X 6000

Laser Transmission welding
Nanosecond Nd:YAG laser
Femtosecond fiber laser

PE: Polyethylene

Now if you look into the other non metals for in the form of the laser microwelding processes; here if you see that pulse duration normally we use the in femtosecond level and 350 femtosecond level 947 and even 4 to 6 femtosecond level pulse can be used for the processing of the non metals and probably in this case only the in mode of the laser transmission welding.

So, here the spot diameter is focused only on 4 micrometer. So, how precisely need to control when the using the a ultra short pulse laser or very femtosecond pulse laser speed is around 0.1 to 0.2 or maximum 2 millimeter per second and we use the different types of metal space the all are non materials; glass silicon or different types of metal similar combination of the dissimilar combination metals and thickness in terms of micrometer can be produce around 50 micrometers.

So, mostly the non metallic metals is processed in the micro scale application using the femtosecond pulse laser and in the mode of the laser transmission welding.

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Applications of laser microjoining **Dissimilar materials**

Laser condition				Object material	
Type	Average output Power (W)	Spot diameter (µm)	Speed (mm/s)	Materials	Weld dimensions (µm)
CW diode	2.2	800	~ 1.67	PI/Ti	200 – 300 (W)
	3.8		~ 21.67		
CW fiber	1.0	300	~ 1.67	PI/BSG coated with 0.2 mm thick Ti	-
CW fiber	1.0	200	~ 1.67	PI/Ti	-
				PI/BSG coated with 0.2 mm thick Ti	~ 330 (W)
CW fiber	2.2	300	2 ~ 16	PI/Ti	-
	3.8		10 ~ 33		-

PI: Polyamide
BSG: Borosilicate glass

Now, dissimilar material combination can also be welded in the microwelding applications maybe observed the typically continuous of diode laser, fiber laser normally used average power output is around 2.2 watt to minimum one watt and spot diameter in the 300 micrometer different speeds, but different types of material we observed that application of the laser in case of dissimilar combination of the materials.

So, polyamide and titanium this joining of the two materials to different types of materials glass and polyamide that combination and polyamide are titanium already we have seen that also polyamide and titanium that combination of the materials for the dissimilar join configuration; we found out the application in the in the microscale. So, these are the practical application of the laser microwelding processes observes in the literature and super have used what see.

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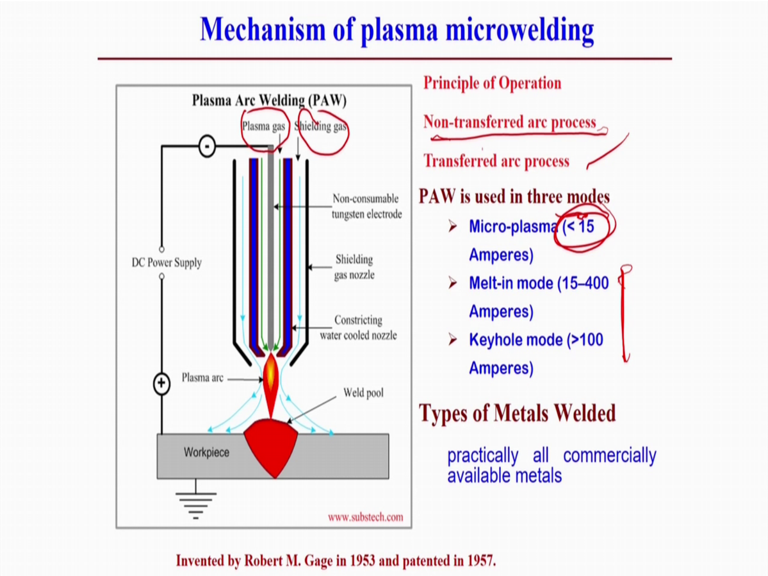

Now, we shift to the plasma microwelding processes or maybe using a micro plasma arc welding machine. So, plasma microwelding process the principle is little bit different from the laser; here if you see the plasma microwelding processes now only we have already idea that the plasma welding processes, but we say same machine can be used, but it should be capable to control for microwelding application less than 15 ampere current can be modulated using the plasma microwelding process.

So, principle of operation in terms of the non transferred arc or transferred arc process. So, non transferred arc means the plasma gas should be supplied that gas with the electrode that can create the arc, but there is a need of another shielding gas in plasma welding process. If you see the shielding gas and plasma gas two different gas is required for the for the creation of the arc and the shielding of the molted material.

You see, but we see the non transfer arc in the normal process and transfer arc will be when there is a there is a if you want to produce a layer of the surface on the on the workpiece material; in that case maybe you can use the fine powder along with the arc. So, that fine powder can be coaxially projected along with the arc on the surface the it creates a small layer of the surface. So, that type of arc is considered as the transferred arc process.

So, probably microwelding process we generally use the non transfer arc welding processes, but if you see for microwelding application using the plasma arc welding process the current should be less than 15 ampere; as compared to the other two modes melt in mode and the keyhole mode, where the cases the label of the current will be different in this case practically all types of material can be process using the plasma arc welding process.

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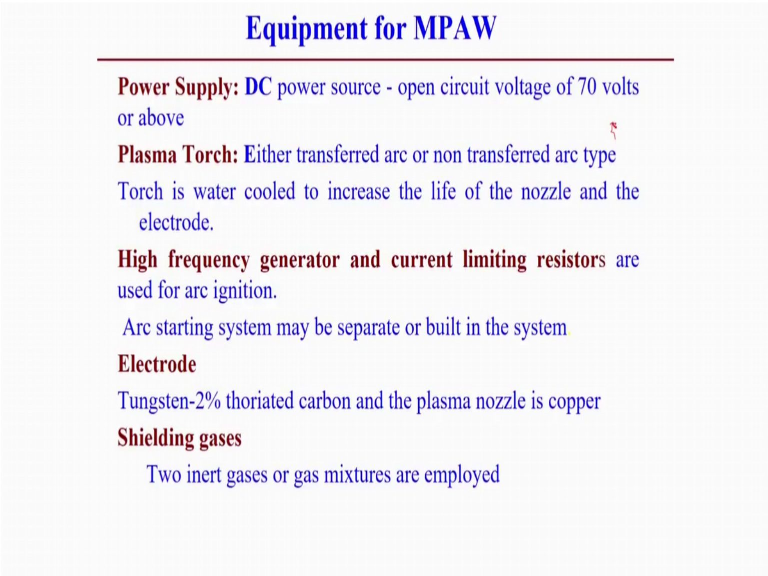

Now, what are the different equipments of the micro plasma arc welding process? So, definitely first is the power supply, DC power source where the open circuit voltage is around 70 volts or above a plasma torch.

So, torch either it can be transfer arc type or non transfer arc type and torch most of the cases find out the water cold to increase the life of the nozzle and the electrode; a high frequency generated can also be used for the arc ignition and maybe a set starter kind of things arcs starting system is normally found out in the any micro plasma arc welding machines and the electrode is a Tungsten's electrode is used of the micro plasma will be along with the copper nozzle.

And shielding gas we use the two inert gas or gas mixtures can be employed at the shielding purpose one another is the for the generation of the plasma arc. So, maybe same type of gas can be used for the generation of the plasma or as well as the shielding purpose.

The two inert gas is used shielding purpose can be used if we need some extra arrangement of the gas supply specific to joining of the titanium alloy. Because titanium alloy the extra shielding gas of the require to protect the material from the oxidation. So, this is specifically required for the titanium, but it may not be required for the other welding processes.

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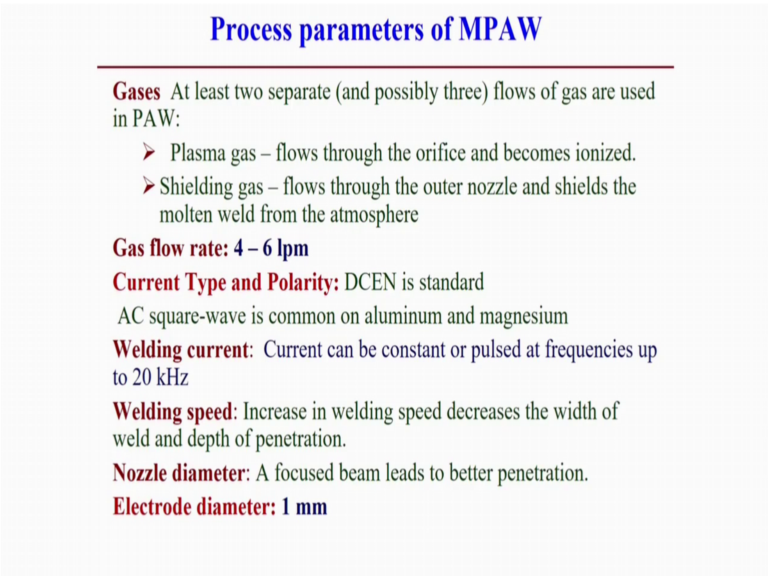

So, what are the process parameters? Specifically in micro plasma arc welding process; one is that at least two separate and possibly three flow of the gases are used in the plasma; plasma can shielding gas that we have already discussed gas flow rate is around 4 to 6 liter per minute. The current type and polarity probably use the DCEN direct current electrode negative in that form we use so, that in that form the maximum heat is generated on the workpiece and the certain possibilities of heat is generated on the electrode material.

So, that is why DCEN polarity can be used normally used, but in very specific for example, aluminium and magnesium or their alloy can be processed using the plasma arc welding process, but current points will be AC. So, that that during as application of the current some 50 percent heat is generated on the workpiece and 50 percent heat is generated on the electrodes are.

So, that actually they in one cycle; so, during the one cycle thus amount of the heat is generated on the one that actually acts as the cleaning action of the oxides layer in the in very specific to aluminum. Welding current is around frequency is 20 kilohertz can be used, welding speed depending upon the material because normally the when there is a increment of the welding speed there is a less deposition of the heat to the substrate metal.

So, it is a some relation between the welding speed and the heat input to the substrate material. So, the normally we use the for example, 0.5 millimeter thick of the titanium or still maybe 1 to 5 millimeter per second within that range you can use the welding to synthesis of micro plasma arc welding process.

So, electro diameter can be used as normally we use the one millimeter or definitely depends on upon the application or maybe sheet thickness or that what is the amount of the penetrations is required based on that electro diameter can be choosed can be chosen, but normally we use the 1 millimeter diameter of the electrode.

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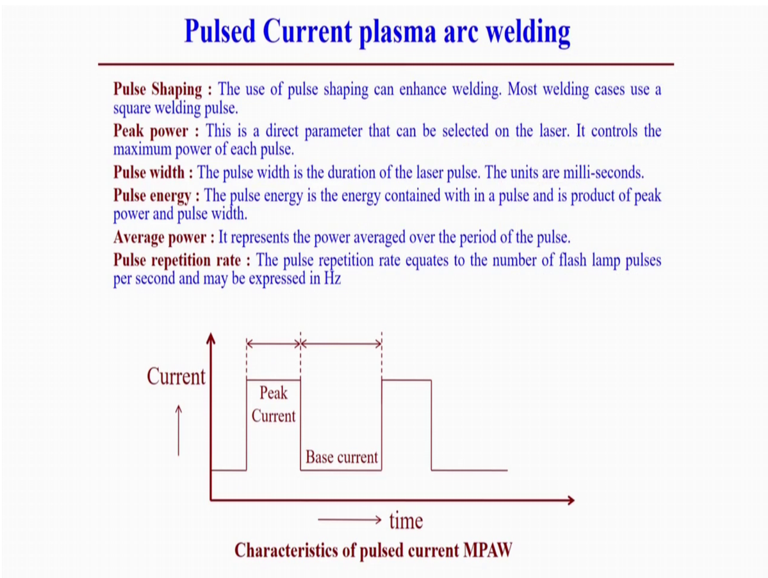

So, like laser welding process plasma current can also be make in the pulse form, but if the shape of the pulse is using the square shape of the pulse where the most of the welding cases we use, but which is very difficult to control of the shape of the a shape of the pulse like laser welding process in case of the plasma welding processes.

So, it is a it is a not much variation of the shape of the specifically not variation of the shape of the pulse is possible in case of the plasma micro plasma arc welding process. So, peak power pulse width all a like the laser welding process; we can use the normally pulse width in the terms of millisecond, but we can choose the pulse width, but at the same time peak power peak power or maybe peak current or base current; we can use it and accordingly we can estimate the what is the peak power in case of because power is in case of plasma arc welding is equivalent to the volt into ampere.

So, average power can also be estimated like laser welding processes also similarly pulse repetition rate that actually represents in terms of the hertz, but in this case the plasma arc welding processes probably two things one is a peak current and the base current base current may not be 0 some certain current value this will be used as compared to the peak current.

So, purpose of the using the pulses and even for the plasma microwelding processes that actually helps to join specific to the very thin sheet very thin sheet application. Basically the ramping of the power in this case helps to join even small smaller thickness of the material that is a purpose of the pulses and even in case of plasma microwelding process.

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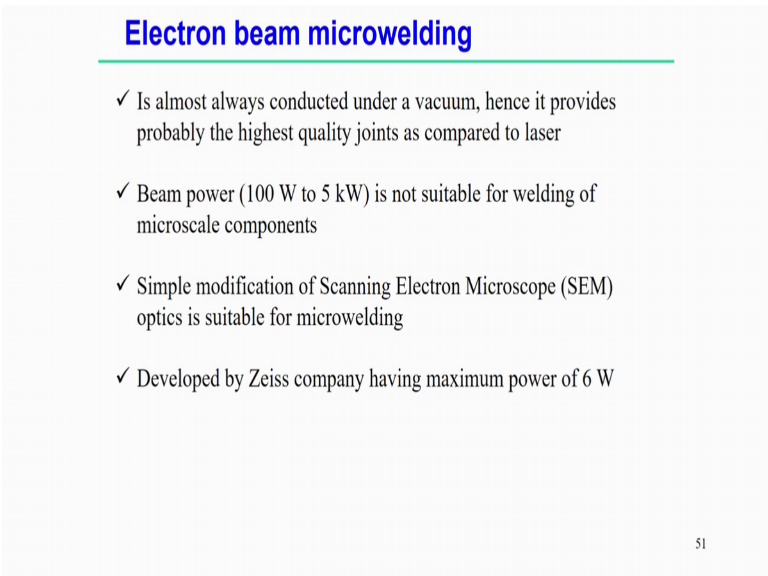

Now, we shift to that point that electron beam microwelding process. So, of course, we have we all we already learned that probably the electron beam or laser beam can be used when there is a requirement of the high depth of penetration. But in that case the huge power is normally electron beam produce the huge power and that power is concentrated over a narrow zone and that is responsible to create some high depth of penetration. But if we use the some other way the electron beam and it is in case of microwelding processes then it is possible to produce even for low depth of penetration.

So, what in most of the cases of course, it is almost welds are conducted almost in the vacuum. So, in that cases the join properties is very much attractive or maybe very good quality as compared the laser or some other welding processes; this is the first priority that is that in case of electron beam welding process. Second thing is that power beam normally 100 watt to 5 kilowatt is available in the market or for convention welding process, but that range of the power is not suitable for the microscale application.

But if we compare as a laser conventional when laser that sometimes very low power laser also suitable in case of the microwelding process; if we follow the proper pulsation of the laser power. But that is not the case of the electron beam welding process. So, in that case these charges also found out that simple modification of the scanning electron microscope; optics electron microscope and specific in optics, it is possible to produce that for micro welding applications.

So, this technology has been developed by the Zeiss company, but it is having the maximum power of 6 watt.

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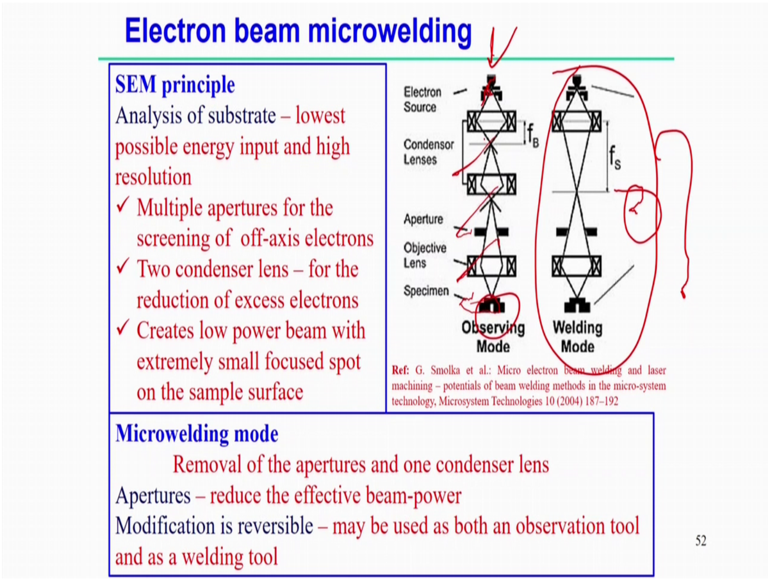

Now, look into that in which principle the SEM works basically the purpose of the scanning electron microscope of course, the here the source is the electron, but try to produce the lowest possible energy input, but with the high resolution that is a basic principle of the scanning electron microscope.

But if you see the scanning electron micro basic structure or their optical structure is like that electron source is there. And then condenser lens and aperture, objective lens and then we observe the observing specimen is there. So, that is the typical optics in case of the scanning electron microscope.

But here if you see that multiple apertures are used, but what is the purpose of apertures? This is basically apertures is used for the screening of the off axis electron electrons and here two condenser lens are used for the reduction of the excess electrons. And finally, creates the low power beam with the extremely small focus spot on the sample surface.

So, this is the basic principle of the a scanning electron microscope, but if you look into the modification of this scanning electron microscope in other way; simply in the if we try to make in the microwelding mode the removal of the apertures and the one condenser lens.

So, out of the two condenser lens probably or more the if it is possible to remove a all the condenser lens and apertures that actually makes suitable in for the microwelding applications. So, the microwelding applications the optics is like this here if you see the apertures actually reduces the effective beam power. So, this removal of the apertures probably effective beam power can be increased. Second modification is that that removal of the condenser lens probably the that not the access electrons are not removed in this case by using the by removing the condenser lens.

So, in this mode the same electron beam source can be used as a microwelding application so, but modification is reversible in the sense that say it can be used either scanning electron microscope or microwelding applications; so, that type of instrument is available in the market.

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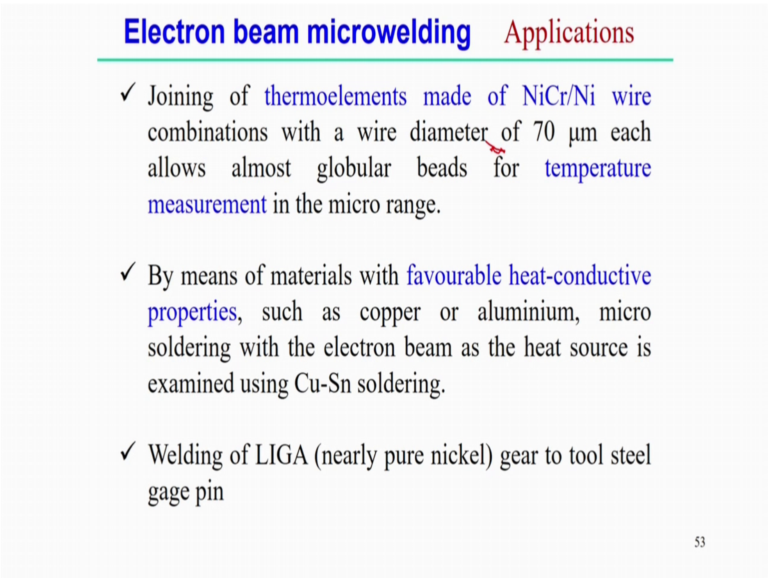

So, what are the typical application of the electron beam welding you found out that joining of the thermo elements basically made of nickel chromium or nickel wire typical dimension and basically that can be used for the temperature measurement this things and other application of this things ah; heat conduct the materials with the favorable heat conductive properties that can be processed using the micro beam welding process.

So, such as copper, aluminium micro sometimes micro source of the electron beam can be used the soldering application as well, but this can be used more is the welding of the LIGA nearly LIGA is the one type of material that is almost pure nickel that joining gear to the tool steels gage pin. So, in that typical application the electron beam welding can be used.

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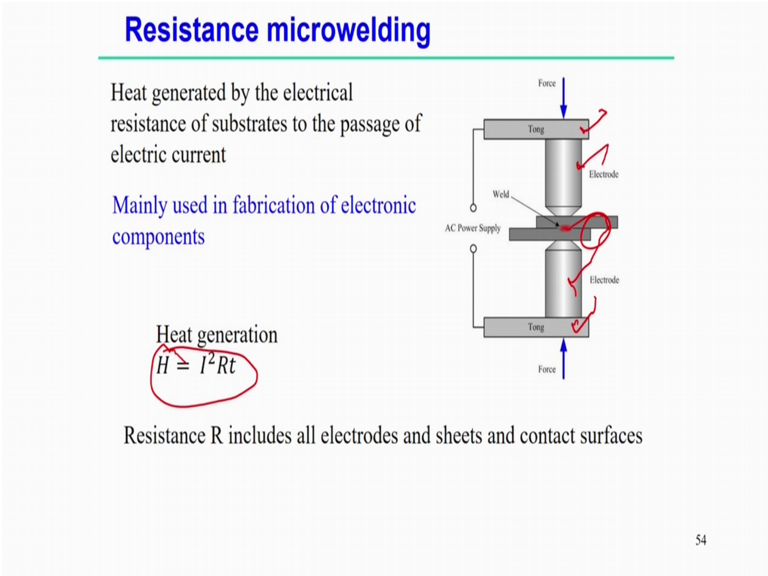

Now, if we look into the resistance microwelding; the heat is generated by the electrical resistance of substance to the spaces of the electric current. So, in this case the same plates which are now, conventional resistant welding it works on the conventional resistant welding processes, but that we know that welding the heat generation is the due to the resistance exist with the passage of the current.

So, resistance exist between in between several contracted contact surface as well as the within the bulk metal itself. So, if we consider all the resistance include and then heat is generated by using this formula H equal to I square Rt; I is the applied current, t is the time duration and R is the resistance, but R resistance should be considered all the resistance of the contacting surface of the circuit. You have to see the contractive surface is this from electrode and the workpiece material from and between this two between all this elements the; we need to calculate the r resistance and that is responsible.

But we will try to see how this resistance microwelding is different from the conventional microwelding is the different from the conventional welding process.

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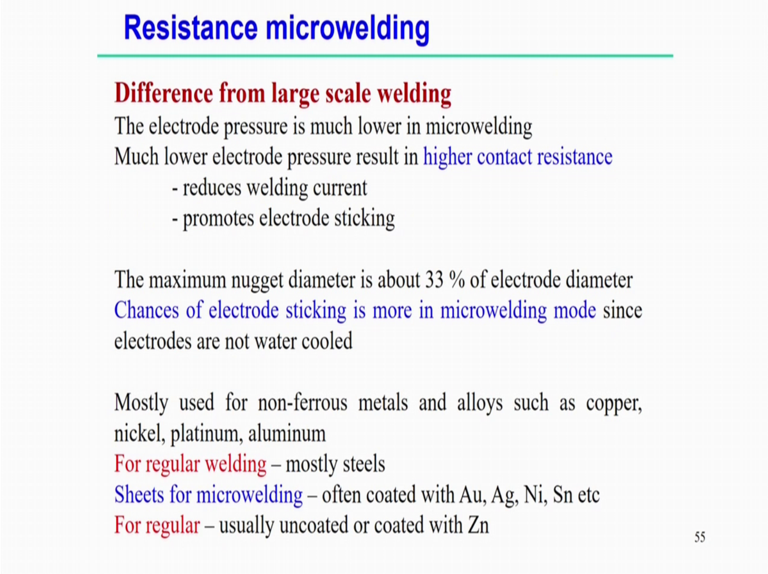

If you see the electrode pressure in this case is much lower in the micro welding processes definitely as compared to the conventional welding processes. So, because much lower electrode pressure basically results in the high contact resistance and when there is a high contact resistance also reduces the welding current and of course, the difficulty is the it promotes the electrodes sticking.

It is observed that maximum nugget diameter in case of resistance microwelding process is around 33 percent of the electrode diameter, but chances of the electrode sticking is more in case of the microwelding applications because specifically then microwelding applications the electrodes size is small.

So, there is no scope to cool using the water cooling process of the electrode and that normally in case of conventional resistance welding process water cooled is followed because the size of the electrode itself. So, size because of the size resistance; there is a chances of the sticking of the electrode is a main obstacles in case of a resistance microwelding process.

But in terms of application the most of the non ferrous metals and alloys are used or processed using the resistance microwelding process, but for regular welding regular microwelding processes we mostly steels are processed and a, but in case of microwelding mostly; we use the coated steel with a silver, gold and nickel etcetera, but for regular or; that means, conventional microwelding processes the usually processed or usually welded using the uncoated or coated with the zinc that type of metals is suitable in case of or mainly applied in case of conventional welding processes.

But after the welding processes of the different welding process of the metallic materials but, if we focus on the microwelding of the plastics.

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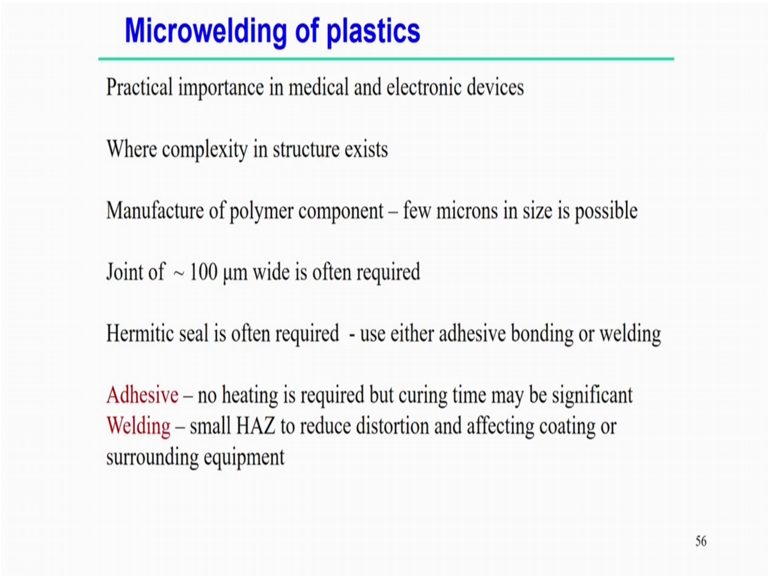

Here the practical importance is the microwelding of plastics is specific to medical devices and the electronics devices, where complexity in structure exist specifically in that case the microwelding is more suitable where the most complex structure is processed using a can be processed using the microwelding process using the different microwelding processes of plastics material.

So, then even it is used manufacture of polymer component even very few micron size is possible using this methodology joining of the 100 micrometer is wide is often sometimes required and sometime the sealing of the metals is required in case of micro in case of micro components.

So, that sealing of the materials using the plastic component is used is processed by the microwelding of the plastics. But of course, there is a alternate for the adhesive bonding or a adhesive joining processes, but in advantage of the adhesive process is the no heating is required, but sometimes the curing time maybe significant.

So, alternate is the welding process of course, in this case the small heat affected zone has been created, but different heat affect the coating or the surrounding equipment in a very in a specific device when there is a compact of the several components are there. So, in that case the if these are the two different advantages or disadvantages of the a microwelding the plastics.

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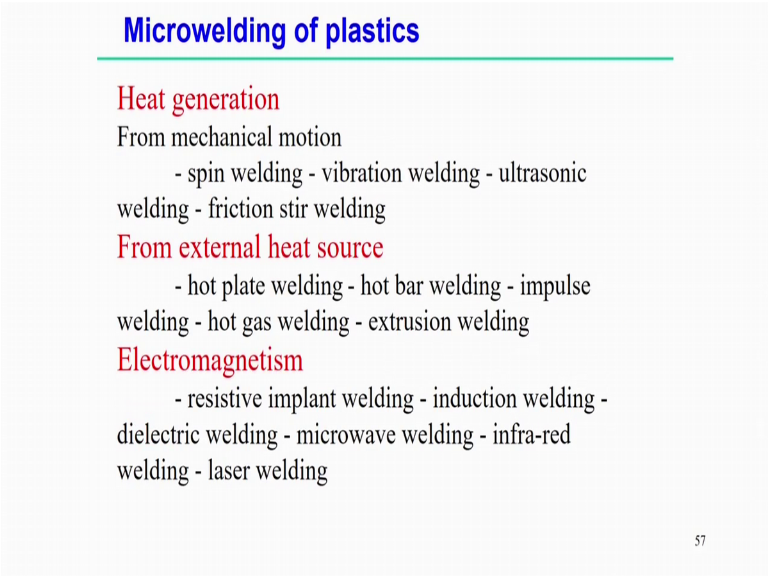

So, there is a separate module, but the discussion of the micro welding of the plastics materials. So, I am not repeating the same thing here again.

But in the trying to focus on the different types of processes that can be used in the microwelding applications, but main thing is that the during the microwelding applications in specific to plastic material here to see the heat generations it basically comes from the mechanical motion. So, based on that it can categorize or that was the several techniques exist. One is the spin welding, vibration welding, ultrasonic welding and friction stir welding; all these cases the heat is generated by the mechanical motion of the material.

So, second is that from external heat source; hot plate welding, hot bar welding, the impulse welding, a hot gas welding extrusion welding these are the typical welding processes. And where the heat source is externally applied and of course, electro magnetism that also is the drives the microwelding processes a plastics this will be the typical welding processes includes that implant welding, induction welding, dielectric welding, microwave welding, infrared welding and of course, the laser welding.

So, all this comes under the categorization of the electromagnet magnetism. So, the brief discussion of the different welding techniques for plastic; there is a separate model we will try to discuss that on that separate module.

Thank you for your kind attention.