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

Lecture - 21
Welding and Joining of Non-Metals Part I

Good morning everybody, after much discussion on welding and joining technologies for metallic materials. Today, we will try to focus on the welding and joining of non-metallic materials.

So, very few specific non-metals we have consider for example, the polymeric material glass and ceramic welding and may be biocompatible plastic metals that are considered for this module. And we will try to deep discussion on the different welding and joining technologies for this non-metallic material

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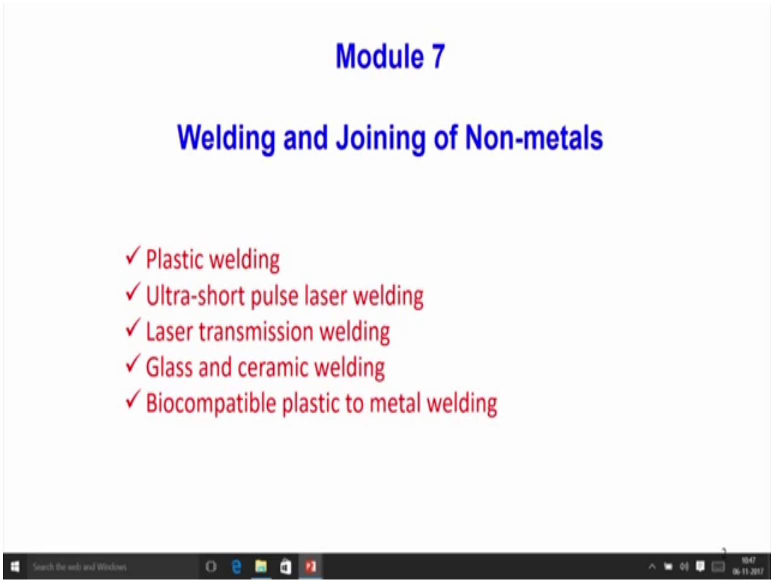

So, here you can see that the we divide the module in the several subcomponents like that first we try to look into that plastic welding of the polymeric materials; what are the different technology is available and what are the recent advancement for joining of the polymeric material we try to see that first.

And then we will discuss the ultrasonic pulse laser welding which is different from the conversional laser welding process. And the this ultrasonic pulse laser welding ah; so, far much application we can see specifically for a non-metallic materials; that means, specifically for a different kind of polymeric materials then we will see the what are the laser transmission welding process and what this how this technique is different from other welding processes and what are the principal of the laser transmission welding process?

Then we will look into the different welding methodologies for glass and ceramic specifically ceramic materials. And finally, we will see that welding or joining technologies different by compatible materials plastic materials along with the other metallic materials. So, there are several technologies available, but the in principle and this welding techniques for this non-metallic materials is little bit different from the welding process for metallic materials.

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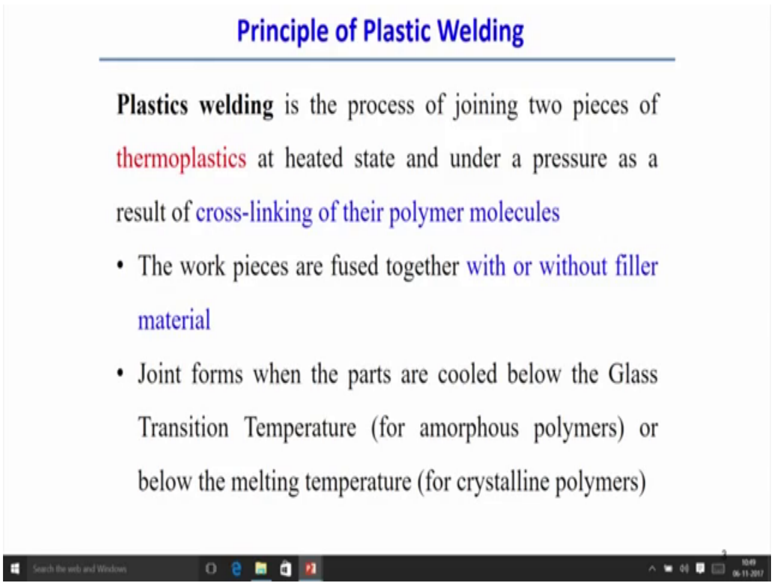

So, what is the principle of the plastic welding process first you see the plastic may be welding process the process of joining two pieces of the thermoplastic. So, basically specifically mention that it is a thermoplastic at heated state and then after sufficient heating the application of the pressure such that cross linking of the polymer molecules happens and then join between the two components of the plastic metal.

So, in principle it is same the convention welding process because here we need a source of heat. So, that source of heat maybe different and different difference as compared to the convention welding process is that how we can utilize the source of heat and how we can control this source of heat which may be applicable for the joining of the plastic materials.

So, plastic can also be join with or without the filler materials depending upon the applicability and the different components. But normally we can divide into two categories like that the welding or joining forms in case of the glass that parts for the amorphous polymers that we consider the as a reference for the last transition temperature.

So, that cooling should be done below the glass transition temperature for the amorphous polymers. And then after cooling figure then the joining of the two plastic components actually done or in case of crystalline polymers we considered as a reference for the melting temperature.

So, as by hitting its goes above the melting point temperature and then during the cooling phase it comes below to the melting point temperature. And then after the cooling figure the join between the two plastic component can be done. So, if you look into more details that welding techniques for polymeric material in principle that; from the figure if we see right hand side the in the two surfaces in come in contact, there is no heating, there is no application of the heating and then partial heating and the time t greater than 0 and finally, we reach the completed in after sufficient time.

So, in principle that interfaces physically come from with respect to each other such that intermolecular diffusion and chain entanglement actually occurs and that actually is responsible for forming of the welding or joining between the two polymeric material. So, healing of the interfaces is basically the due to the diffusion of the polymers chains across the interface.

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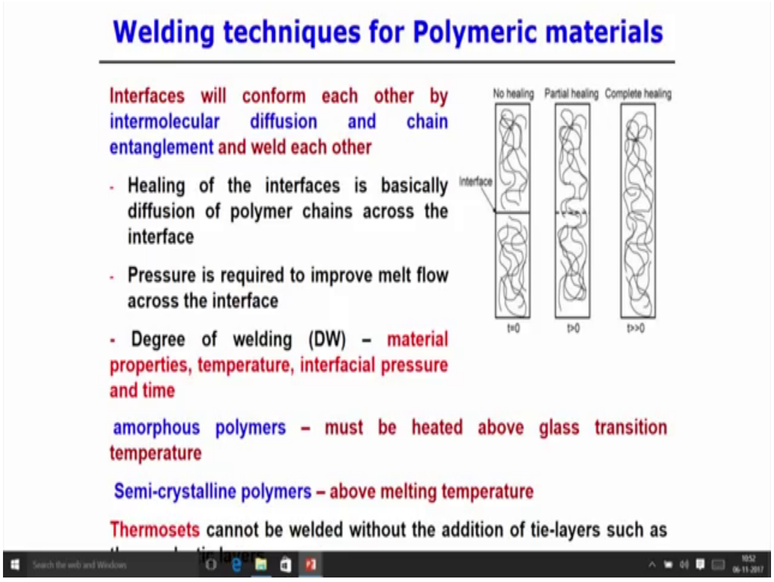

So, here one important point is that the diffusion of the at the interface of the polymeric chains happens an advantage in the point that in case of metallic material; we can find out that there is a there may be the possibility of oxide layers most of the cases we can and it is if you want with good diffusion bonding between the two surfaces in contact; then it definitely needs to remove the oxides layer, but that is not that problem is does not exist in case of the most of the polymeric materials.

So, in that case polymeric materials it is without any surface preparation also when the two plastic components into come in to the contact. And if we apply the proper heat and pressure condition then it is possible to join the polymeric materials. So, in that sense it is advantages as compared to the metallic material, but degree of welding in case of polymeric material; we can find out that it depends on the material properties temperature and interfacial pressure and time also all other complex function. And then with a proper choice of all these parameters we can expect a good bonding or good joining of the polymeric materials.

As I mention that amorphous polymers basically the must be heated above the glass transition temperature where semi-crystalline polymers are crystalline polymers the above the melting point temperature, but here one point need to mention that the thermosets cannot be welded without the addition of a tie-layers. So, in principle the welding of thermosets is different from the thermoplastics. So, thermosets polymers can be welded with the help of the is a tie-layer that is normally thermoplastic layer; we put it and then it is possible to join the thermosets polymers this is the actually the characteristic behaviour of the thermosets are different from the thermoplastic.

So, that is a in case of joining of the thermosets we need to consider this in principle that there is a application of the or intimidate layer of the thermoplastic is required to join the thermoset plastics.

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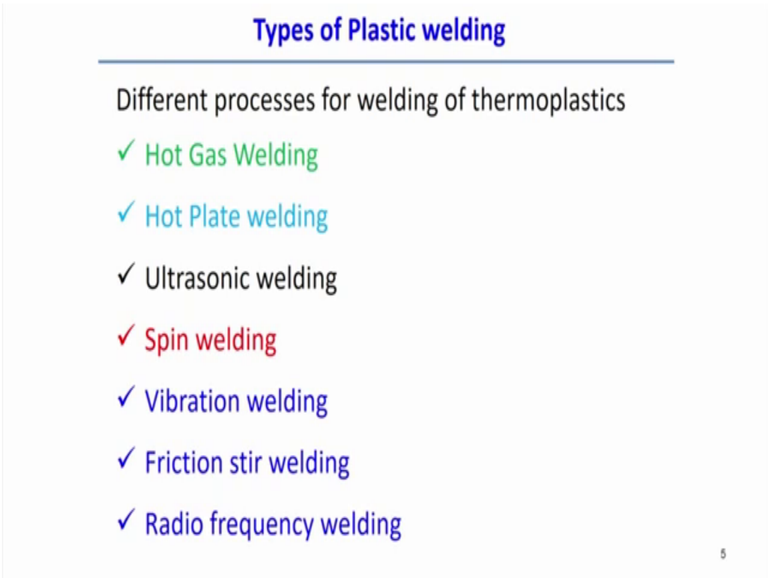

So, now we will we will try to look into the different types of the plastic welding. So, different processes for the welding of thermoplastics that are hot gas welding. So, this techniques actually already develop and that hotplate welding, ultrasonic welding, spin welding. So, here you can see the hot gas welding.

So, simply we can use the stream of the hot gas and that if we controlling such a way that it is responsible to fuse the to melt the contact of the interface. And then we can join the two plastic material component then similar to hotplate welding instead of directly using the hot gas in; here we can use the metallic plate and that metallic plate is basically control the amount of the heat and then it responsible to joining of the two components.

Then ultrasonic welding; so, ultrasound vibration if you create and that actually that ultrasonic vibration is basically creates in the very small localised area the frictional energy and that that localised area in a small part the frictional energy is basically melt heat the sample and that is then after that welding can also be done.

Similarly can spin welding spin welding is the similar kind of the friction welding and then vibration welding and there is a other another deviation division of the plastic welding is there vibration welding friction stir welding and the radio frequency welding.

So, if you see the vibration welding means we can use simply mechanical vibration and that is that is the in similar principle of ultrasonic welding we can join the two plastic components. But there is a minor difference between the ultrasonic welding and vibration welding as well. Friction stir welding and radio frequency welding these are the two recent developments of the joining of the plastic components.

So, friction stir welding we have enough discussion on this for the joining of the metallic metals which is worst establish process, but friction stir welding still it is a under development in specifically for joining of the plastic components. We will try to discuss that up to what level the joint can be achieved using the friction stir welding process.

Then radio frequency welding is specifically frequency welding we generally observe in case of plastic welding. So, all these welding possibly we try to discuss in details in the successive slides.

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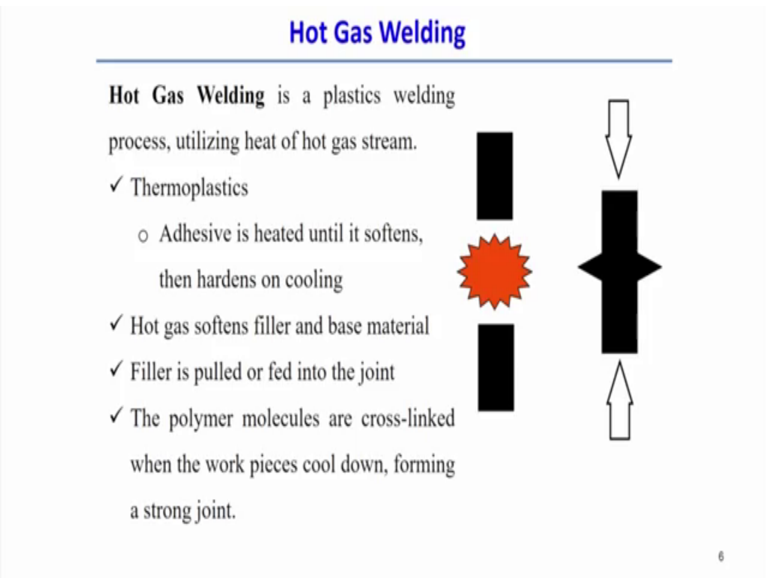

We can find out the hot gas welding; so, simply hot gas welding is a plastic welding process simply utilizing the heat of the hot gas stream. So, actually with the application of the hot gas stream there is a; we apply until and unless its soften the material and then after softening the material with application of the pressure then that material becomes harder and with the with the during the cooling phase. So, from the figure it is obvious that at the interface some using the hot gas stream, we can create the we can heat the samples and then after that we need to apply the pressure.

So, the job of these hot gas stream is that simply soften the filler material; if there is any use of the filler material as well as the soften the base material. Then filler material expose of actually filler when we use filler material filler material is actually cool or fed into the join. Then finally, the polymeric molecules are cross-linked and when they are when the work pieces basically cooled down. And finally, cooled and as a result it forms a strong join between the two plastic components.

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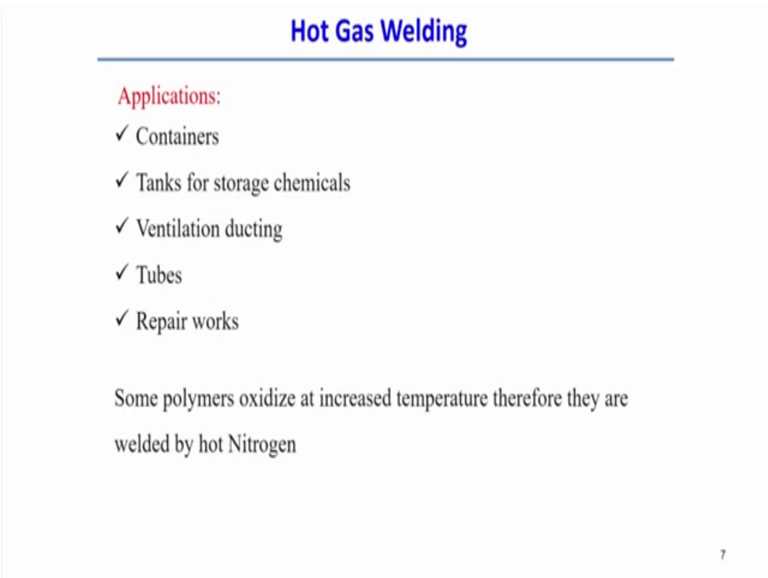

We can see the hot gas welding the several application of the hot gas welding and that producing the plastic containers producing the tanks for the storage chemicals. And here ventilation ducting tubes we can find repair works different type of repair works we can very easily use that for hot gas stream for joining of the plastic components.

But one important point is that if the a polymeric material having the tendency to oxidise at very high temperature; then instead of hot air we can use the stream of the what nitrogen because at the same time I did not actually protect this oxidation of the plastic polymeric materials.

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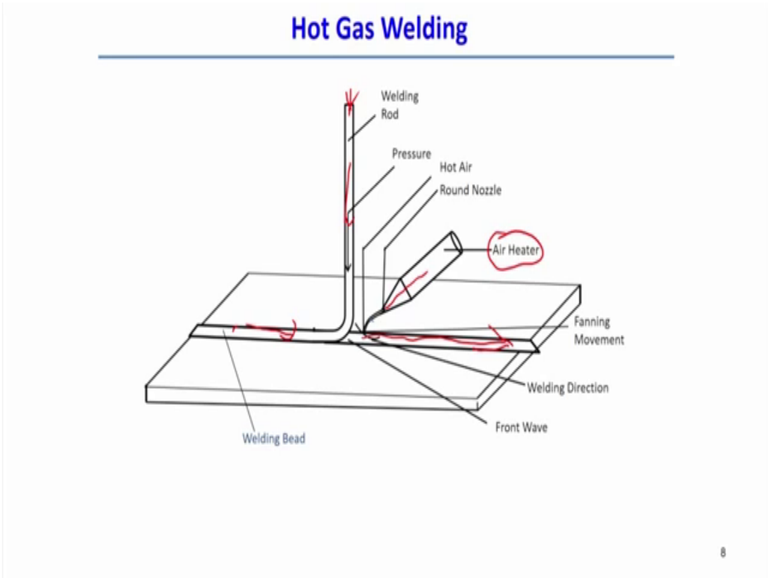

So, if you see that schematically that hot gas welding looks like this that there is a welding rod and the welding rod is basically paid directly at the interface between the two place and at the same time there is a application of the pressure and if we see continuous there is a forming of the well bid.

So, here we can see with the this is the welding rod and there is a continuous feeding of the welding rod at the at the same time here we can apply the pressure. And then there is a continuous form of the welding bid, but this to soften this welding rod there is a air heater we can use and the through the nozzle round nozzle the hot air.

Hot air pass passes through the interface and at the interface there is a this creation of the front wave simply the application of the hot gas stream is actually try to soften the material. And then finally, there is a continuous movement of along this direction that is the welding direction and it creates the weld joint between the two components. So, this is the techniques for the hot gas welding of plastic components.

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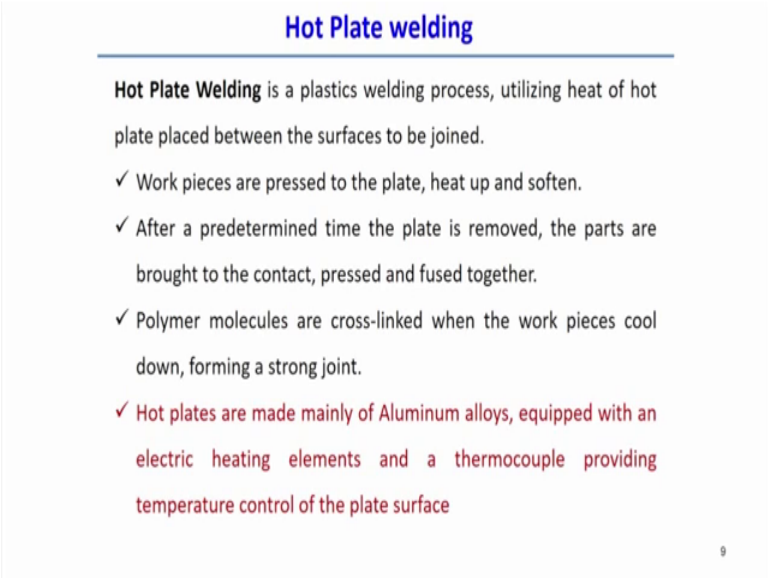

Now, next we will try to discuss the hotplate welding. So, in the hotplate welding also instead of the continuous hot air we can use as a hotplate to heat the plastic components and the this is this hotplate are placed between the surfaces to be joined. So, work pieces are placed actually work pieces are placed to the plate and then gradually heat off and then finally, it is soften the that plastic components.

So, after a predetermined time of the heating in the plate is removed after then parts are come in contact between two components and then place and finally, fuse together. So, polymeric molecules is with the same principle cross-linked with respect to the when the work piece cooled down and then finally, it forms the weld join.

So, here the only difference in the hot gas welding is the simply the instead of using the directly in a very very small focus area the hot gas stream here we can use the hotplate. So, hotplates, but hotplate is mainly used of the aluminium alloy and we know that aluminium alloy is having very good thermal conductivity and equipped with an electric heating.

So, electrical conductivity is also good for the aluminium alloy and then a thermocouple is in the that hotplate welding machine the thermocouple is also provided with this system. So, that we can control the temperature and this is the working principle of the hotplate welding.

Now, where we can find out that typical application of the hotplate welding that components of the domestic electric devices such as dishwasher, washing machine, vacuum cleaner several components it is possible to join using the hotplate welding process and then different pipes can also be we can that joining of the pipes can also be done using the hotplate welding process other automatic components for example, lights, fuel tanks, laser, bulbs, batteries here we can find out the application of the hotplate welding.

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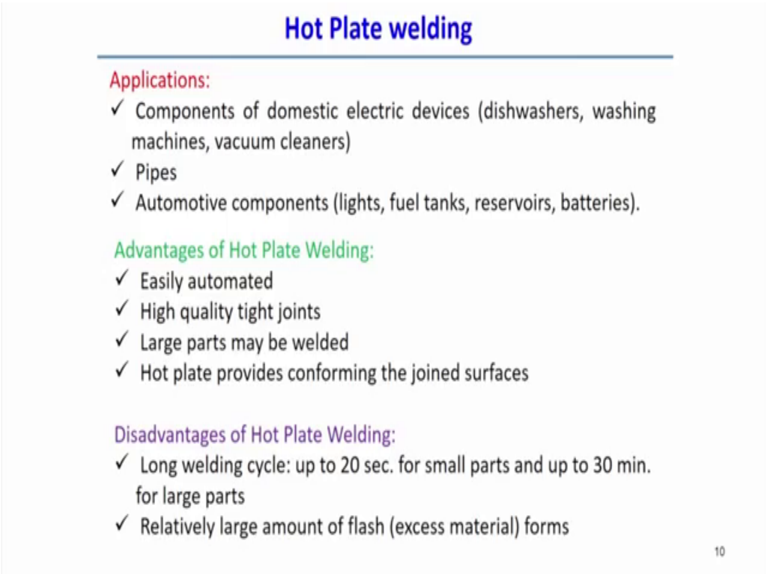

What if we see the advantages of the hotplate welding main advantage is that its easily automated and by that deciding the size of the hotplate looking into the component size. Then high quality tight joints can also be done and very large parts may be welded that is the one advantage as compared to the hot gas welding because hotplate welding depending of the size of the plate. So, a large area can be covered in case of this hotplate welding, but hotplate provides confirming the joining surface; that means, joining the two surfaces.

But the disadvantages of the hotplate welding that long welding cycle time; that means, the total welding time is relatively very high as compared to the hot gas welding processes. So normally welding cycle typically 20 seconds for small parts and up to 30 minute for the large part; so, there is a that that is the disadvantage is in the sense that there is a huge time welding time is required to in case of hotplate welding so; that means, rate of production may not be very good in case of this welding techniques.

And other disadvantage is that relatively large amount of the flash; that means, excessive materials can be forms in this welding process. So, we surface aesthetic point of view this hotplate welding is not good as compared to the other plastic welding processes; next we will try to discuss on the ultrasonic welding process.

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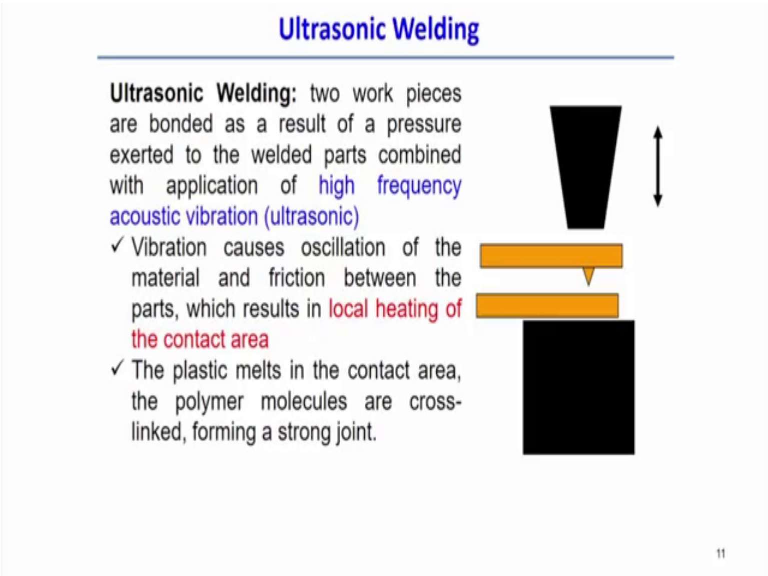

So, we did principle of the ultrasonic welding process we have already discussed, but here we can see the two work pieces are actually bonded as a result of the pressure. So, there is a application of the pressure, but parts with the along with the application of the high-frequency acoustic fiber. So, that is the principle of the ultrasonic.

So, high-frequency acoustic fiber acoustic vibration causes actually oscillation of the material and friction between the parts which is basically takes the situation of the local heating of the contact area. So, normally this high-frequency acoustic vibration creates the frictional heating its very small confined area.

So, therefore, the plastic melts in the contact area and then the polymer molecules are cross-linked and finally, form strong joint. So, in the in the figure you can see the workpiece material we can even put here all this is the vibrating element and creating the vibrating and the local area ; we can create the in the that local area we can generate the frictional heat and then I can be joined this thing.

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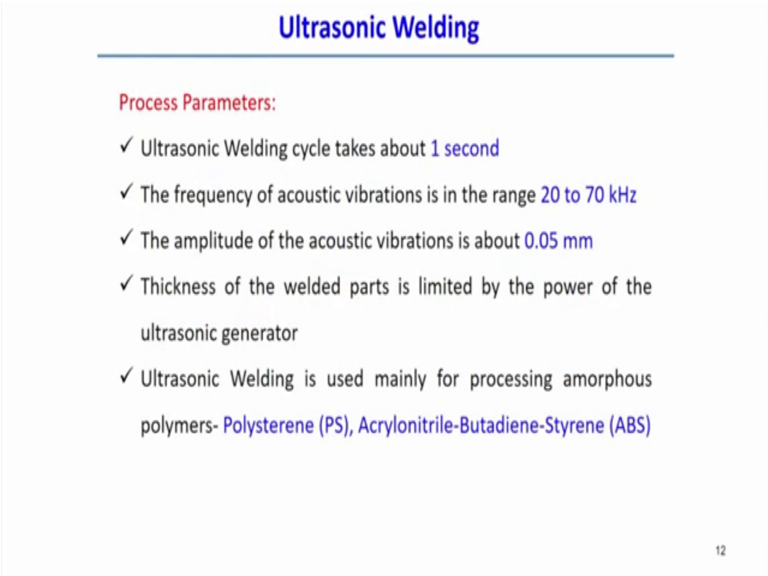

Let us see what are the process parameters in case of ultrasonic welding process; So, if you see the typical process parameter ultrasonic welding cycle is takes about 1 second; that means, a very small time as compared to the other welding processes; the frequency of acoustic vibration range from 20 kilohertz to 70 kilohertz. So, a high frequency vibration acoustic vibration is created in this process and the amplitude of the acoustic vibration is very small only 0.05 millimeter or we can say the 50 micrometer only.

So, in that range the amplitude of the acoustic vibration. So, that that is why the thickness; that means, affective zone by the very localised frictional energy heat energy is the very small it is very localised So, therefore, thickness of the plate welded using by this power is normally small, but it is decided by the power of the ultrasonic generator.

So, therefore, ultrasonic welding process is mainly used for the processing of the amorphous material polymers for example, the polyester PS and ABS; So, this kind of polymeric material normally used by using the ultrasonic welding processes. So, apart from this material we can see the there are several other application area using the ultrasonic welding process such as medical equipment.

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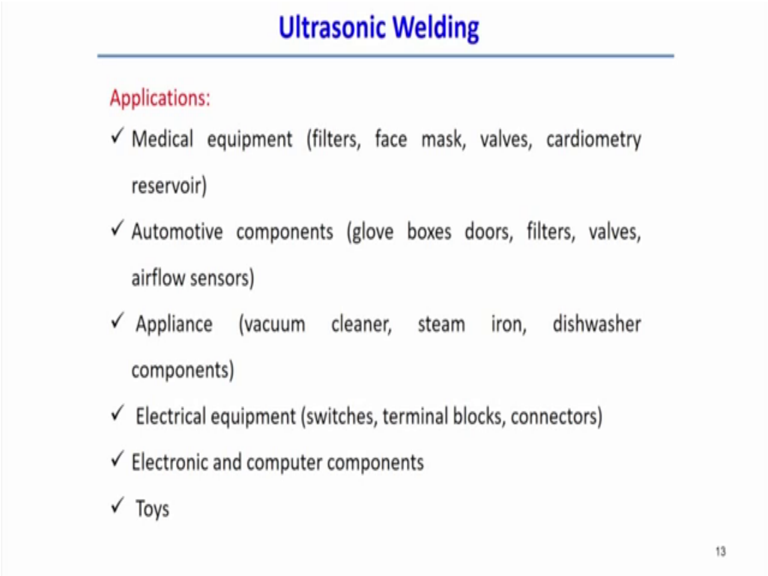

Like filters, face mask, valves, cardiometry reservoirs. So, all this typical medical equipment we can find out the ultrasonic welding process.

Then automatic components glove box doors filters valves. So, these are the automatic automotive components can also be welded using the ultrasonic welding process. And we can see the any other appliance devices; that means, vacuum cleaner, stream iron, dishwasher components can also be done using the ultrasonic welding process. So, electrical equipment switch terminal blocks connectors all can be done that using the ultrasonic welding processes.

So, even for toys also we can find out the application of the ultrasonic welding process.

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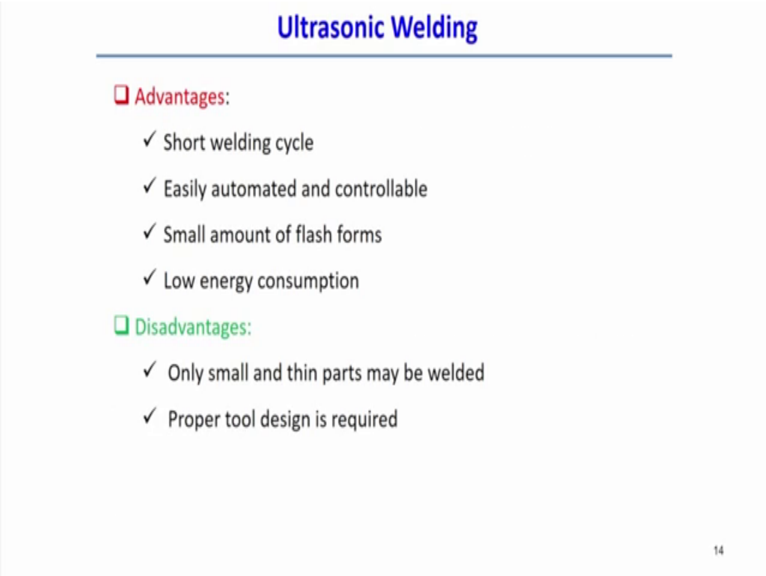

So definitely the advantage having certain advantage with a similar application area of ultrasonic welding process mainly is the short welding cycle time is short cycle time is very short. And of course, this machines can also be easily automated and can also be controlled control. So, therefore, when there is a good controlling of this instrument then it is easily can be focused in a very small component also joining of a very small components very small thickness.

So, another advantage is the small amount of the flash can form. So, there may after welding there is a less amount of the material flash is required to remove. So, the small amount of flash for machine is the another added advantage and low energy consumption as compared to the other hot gas or maybe we can say the hotplate welding processes.

But only disadvantage in that in the sense that small components can parts can be welded. So, it is a very big components cannot cover in the very when there is a requirement of the very big components to be welded and of definitely proper tool design is also required. So, that in this case is the tool design is more significant component as compared to the other welding processes; so, that is the advantage.

So, therefore, in overall we can say that ultrasonic welding is a very promising technology for joining of the plastic components and it is a very thin say thin components can be join more easily and rate of production is also very high as compared to the other hot gas or hotplate welding. So, far we have studied.

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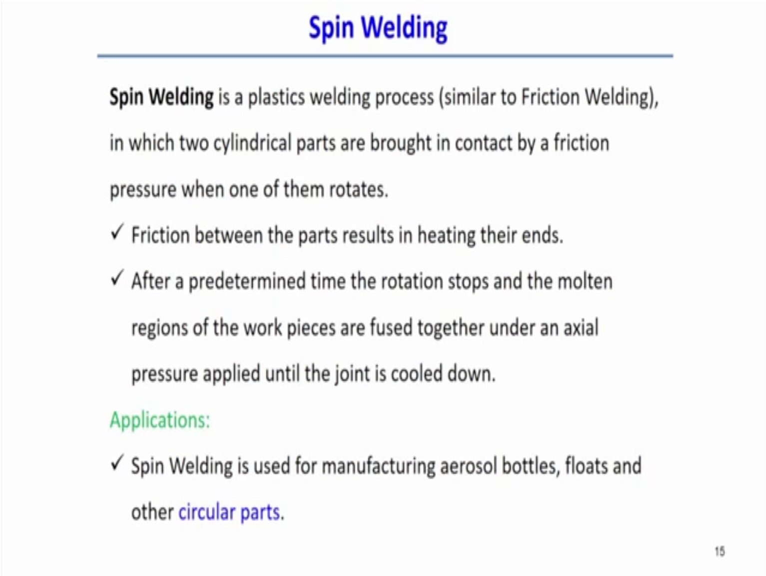

Now, another welding processes that is spin welding process; spin welding process it is a plastic process it is a similar principle to friction welding processes in which two cylindrical object parts can be brought into contact. And they can be joined by the friction pressure and definitely one of them should protect this having; that means, some relative rotational velocity between the components.

And then friction between the parts is a as a results in for the generating of the heat and after predetermined time the rotation stops and then molten regions of the work place actually fused together by application of axial pressure until the joints is cool down. So, we can keep on holding the axial pressure till the joints cool down to the room temperature.

So, typical application is used for the manufacturing of the aerosol, bottles, floats and other circular components we can by using the spin.

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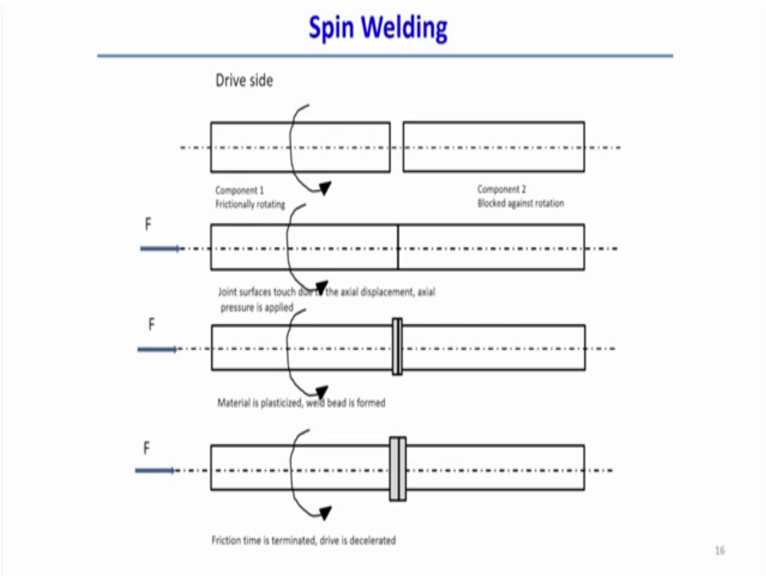

Welding process, we can see that how it works spin welding process. So, drive two components one drives starts rotating component the frictional rotating and component blocked again rotation; that means, keep at stationary.

So, then after rotating start rotating and then keep in contact the interface between the two components; And then finally, mutually plasticised and weld bid is form with the application of the axial pressure and at the first is rotation is blocked; that means, we can keep on we can block the rotational speed.

And then keep on holding the axial force until and unless is cool down to the room temperature. So, we can find out the flash form on the at the joint interface. So, it is a kind of similar kind of technology that we can find out in case of conventional welding process that is the friction welding processes.

So, this is one this is the principle of the spin welding process.

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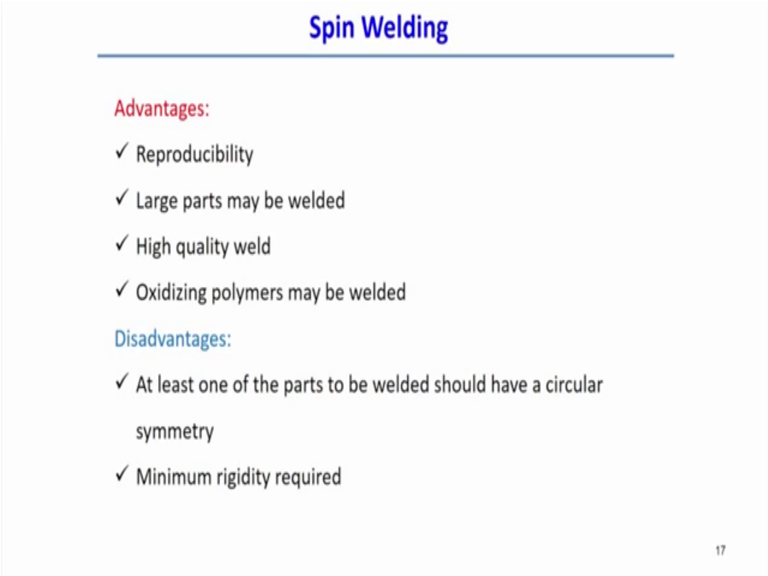

But the main advantage of this process is the reproducibility; that means, reproducibility with the similar welding conditions and large parts can also be welded and high quality weld can be achieved and oxidising polymers may also be welded because oxidising polymers if it is forms the oxidise layer it can be removed in the form of flash from the outside of this joint interface. So, that is why it is advantages in that sense.

But main disadvantage; that means, we can say the limitation of this process is that at least one parts to be is the cylindrical symmetry circular symmetry. So, that is should be welded joint and minimum rigidity required so; that means, when you circular part is supposed to join that the rigidity is of this component is the one constant for this kind of spin welding process we can say the friction welding process.

So, we will try to discuss in details on the friction welding process later on also.

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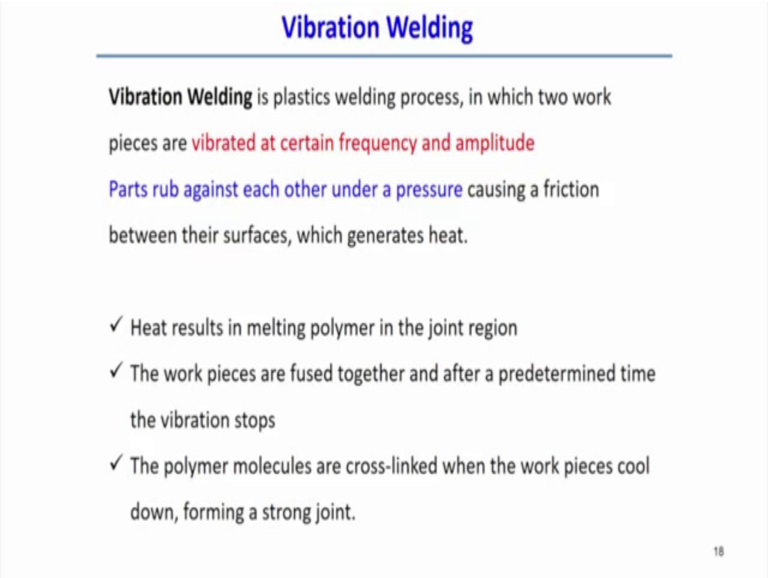

Next we will try to look into that another welding process that is called vibration welding; we can keep a separate name the vibration welding process as compared to the ultrasonic welding process because in this vibration welding process we can use the simple mechanical vibration.

So, vibration welding is a process in the plastics welding process in which two work pieces are vibrated with a certain frequency and amplitude. And then in this case the parts actually rubs against each other under the application of a pressure and that with that situation it is a causes the friction between the surfaces and that friction that friction is responsible to generate the heat at the interface.

So, therefore, heat results in the melting polymer in the joint region and the two work piece actually fused together after a predetermined time and the when with fused together joining with the rest of the vibration. And then polymeric materials are cross-linked and the work pieces cross linked after the cooling down of the work pieces and finally, it forms the strong joint between the two components.

So, therefore, we can see that in vibration welding process that say different from the ultrasonic welding process in terms of the amplitude of the vibration and frequency level also we can see that typical process parameters in the vibration welding process that here the vibration welding cycle is very short even in vibration welding cycle is very short.

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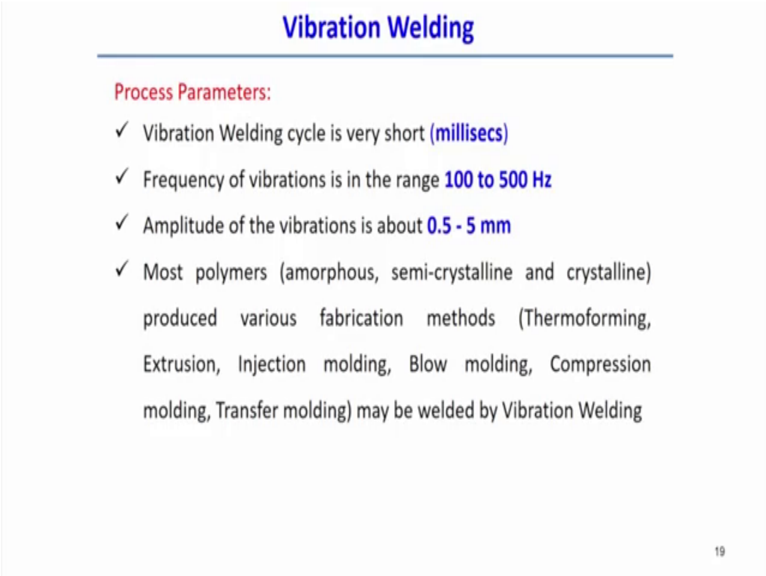

That means when in millisecond also the frequency of vibration is in the range of 100 to 500 hertz, but in case of ultrasonic welding process the frequency of the vibration was in the in the order of the kilohertz.

So, in that sense the frequency level are different in these two cases and amplitude of the vibration is a wide variation is possible 0.5 to 5 millimetre, but in case of ultrasonic welding process the amplitude of the vibration was very small even it was confined to only 0.05 millimetre only 50 micrometer, but here we can range amplitude of the vibration from 500 micrometer to 5000 micrometer. So, in that sense it is different from the ultrasonic welding process.

So, here also we can see the most polymers for example, amorphous, semi-crystalline and crystalline produced various fabrication methods; basically the thermoforming extrusion, injection moulding, blow moulding, compression moulding, transfer moulding that type of material can be welded using the vibration welding process.

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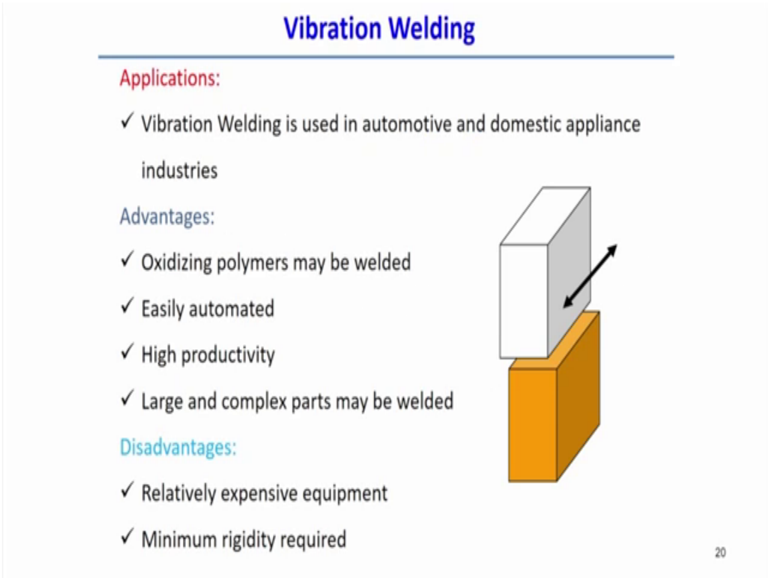

Here you can see the application of the vibration welding process is used in the automotive and domestic applications. So, advantage we can see the oxidised polymer can be welded that was also in case of friction welding or we can say spin welding; also we can find out that oxidising polymers can also be welded. Easily automated in this case very high productivity because cycle time is less and the large and complex parts can also be welded using this kind of welding process.

But disadvantage of this thing the unit produce the vibration that relatively expensive equipment. And of course, some minimum rigidity is also another requirement I can say that it is a another limitation of all this process.

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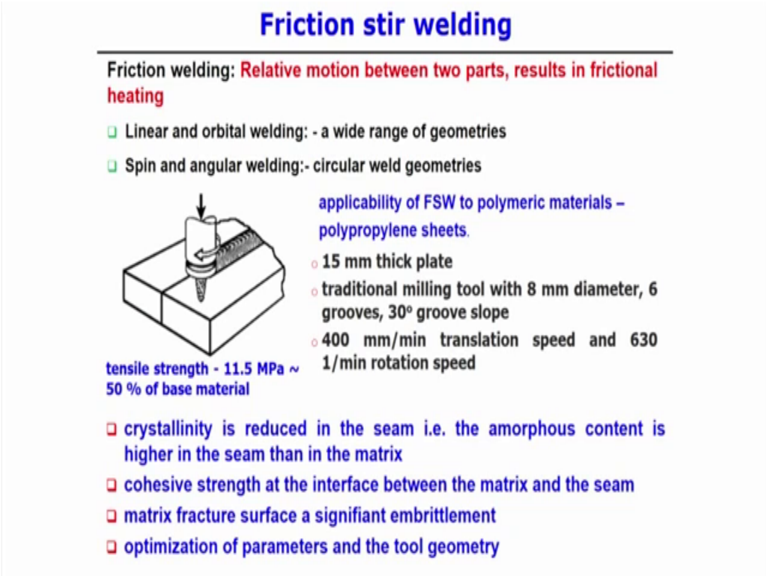

So, there is a new development also the conventional friction welding process we can find out in metallic material that can also be applicable in case of joining applicable or people have try to apply the friction stir welding process in case of plastic or polymeric material.

Here you can see the typical characteristic of the friction stir welding process, but before that friction welding we already discussed that definitely friction welding the relative motion between the two parts are required a results in the frictional heating. But apart from frictional heating it with a stirring action can also be add then we can see it is a friction stir welding process.

So, in case of linear and orbital welding process; a wide range of geometrics can also be welded. But in case of spin and angular welding process we can find out the circular weld geometrics is the best suitable geometric configuration that can be welded in case in the by the principle of the friction welding process, but friction stir welding process for polymeric material, we can see that with application of polypropylene sheets here; we can see the two plastic sheets in contact and in between we can use some tool and the tool rotational that generates heats and that at the same time there is a linear moment of the rotating tool; that means, along the welding direction so, this is the principle of the friction stir welding process.

But using this process it is it was tried to that polypropylene sheets for joining of the two materials. So, 15 millimetre thick plate have tried the using by simply by converting that additional welding process with 8 millimetre diameter and 6 grooves and 30 degree groove slope groove slope basically.

So, here we can use the tool; tool is having let us say kind of threaded tool. So, that threaded tool is used for the application of the polymeric materials and under the head of friction stir welding process. So, here the translation speed was 400 millimetre per minutes and the rotational speed was 630. So, using this friction stir welding process, but although it is a promising technology for the joining of the even for non-metallic materials plastic materials, but it was not very much successful because only 50 percent of the base material then was achieved by this welding techniques.

But what was the if you look into the typical characteristic or typical characterisation of the weld join we can see the crystallinity is basically reduced in the seam definitely there is a stirring of the material in the same; that means, amorphous content is more higher in the seam then the that with respect to the matrix material so; that means, at the exactly at the seam join the crystallinity is reduced. So, that maybe the one reason that we are getting the very small amount of the joint strength as compared to the base material.

Then cohesive strength at the interface between the matrix and the seam this is the another characteristic behaviour we can find out that at the interface between the matrix between the matrix and the seam we can find out the cohesive strength, but matrix fracture surface the then we can find out the fracture surface matrix fracture surface; we can find out the significant embrittlement.

And then these are the typical characteristic behaviour we fin can find out for the friction stir welding of polymeric material, but definitely to achieve a good weld joints there is a need of optimisation of the parameters and of course, optimisation of the tool geometry sequence. But further investigation on this process is required in specifically in the for polymeric material there is another new welding techniques.

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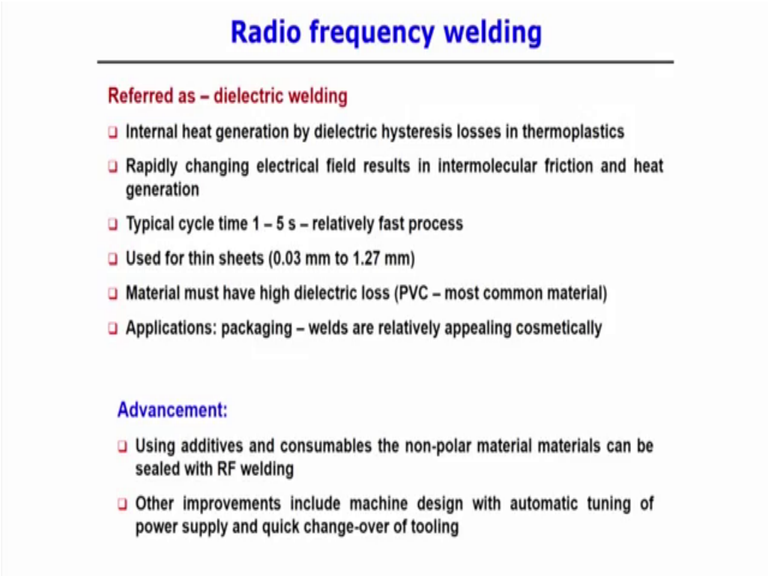

We can observe in case of joining of the plastic material that is radio frequency welding. So, sometimes also it is called as dielectric welding.

So, here internal heat is actually generated by the dielectric hysteresis losses in the thermoplastics. So, there is a rapidly changing of the electrical field that actually results in the intermolecular friction and heat generation. Therefore, we can find out the heater molecular friction and heat generation that that is due to the such a rapidly changing of the electrical field. So, in that principle we can find we can the radio-frequency welding technique has been developed in case of the plastic material.

So, here you can find the typical cycle time is 1 to 5 seconds therefore, we can say that relatively fast process as compared to the other existing process and then used for the very thin sheet 0.03 millimetre. But at the at the maximum 1.27 millimetre sheet can also be done using this techniques and the material must have high dielectric losses then only this process can also be applicable.

For example most of the PVC that that material most common material this generally join by the radio frequency welding process; So, application we can find out the packaging area welds are relatively appealing cosmetically; that means, the cosmetic aesthetic appearance of the weld joint is very good in this case. So, therefore, we can find out the tremendous mainly the packaging industry you can find out the application of this kind of joining process.

So, this aesthetic aspect is very good in the radio frequency welding process and other reason is that is it can be well control process. And this process remotely use and the can also be remotely use therefore, in that sense the packaging industry we can find out the very good application for the radio frequency welding polymeric materials.

But advancement point of view we can find out that this there is a advancement also happens using the additives and consumable the non-polar materials can be used can be seen using the; that means, in case of the using the additives and the consumable non-polar material using these the this radio frequency welding can also be done.

So, other improved; that means, machine design with the automatic tuning of the power supply quick changeover of the tuning; that means, there is a advancement in the development of the radio frequency welding machines for in case of joining of the plastic materials also develop nowadays.

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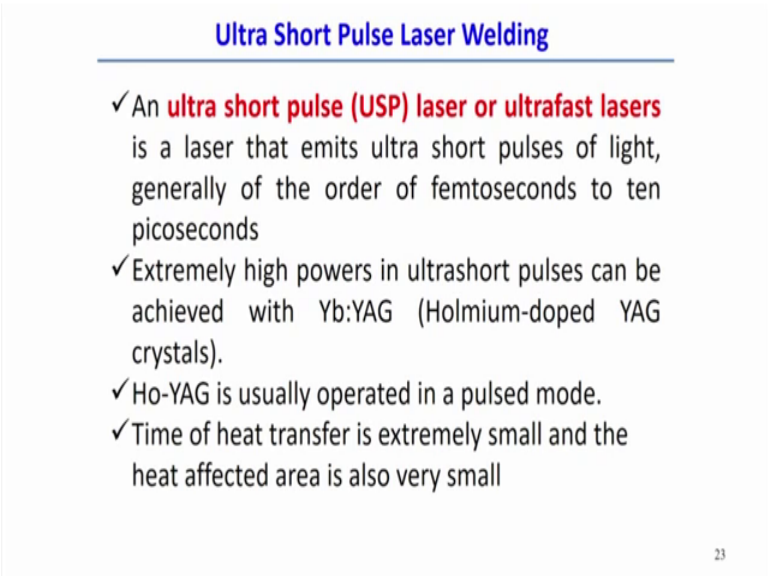

So, after this different welding of the plastic material process we can see that there is a another welding techniques that is called ultra short pulse laser welding techniques.

So, this welding techniques is completely different from the conventional laser welding process there are also pulse the in the only difference is the ultra short pulse laser welding that in terms of the pulse duration. And in principle there is a some mechanism of the heat generation are different as compared to the nanosecond or we can say that microsecond or millisecond pulse laser.

So, here you can see the ultra short pulse laser or sometimes it is called ultrafast laser is a laser that actually creates the pulse over the duration of the femtosecond to the picosecond level. So, therefore, since the that pulse duration is very small normally we can create the very high power and low amount of the pulse energy.

So, in principle the ultra short pulse laser is simply apply the and pulse energy within the very short duration of the time. So, that time that short duration the duration of the pulse in ultra short pulse laser process is basically comparing is the comparable as compared to the relaxation time within the metallic material or in case of other non-metallic materials also.

So, extremely high power in ultra short pulse can be achieved using the allonym duct YAG laser crystals. So, therefore, Ho-YAG laser is usually operated in case of pulse mode also, but even there is a development now also development of the ultra short pulse fiber laser also. So, that it creates that very small duration of the pulse.

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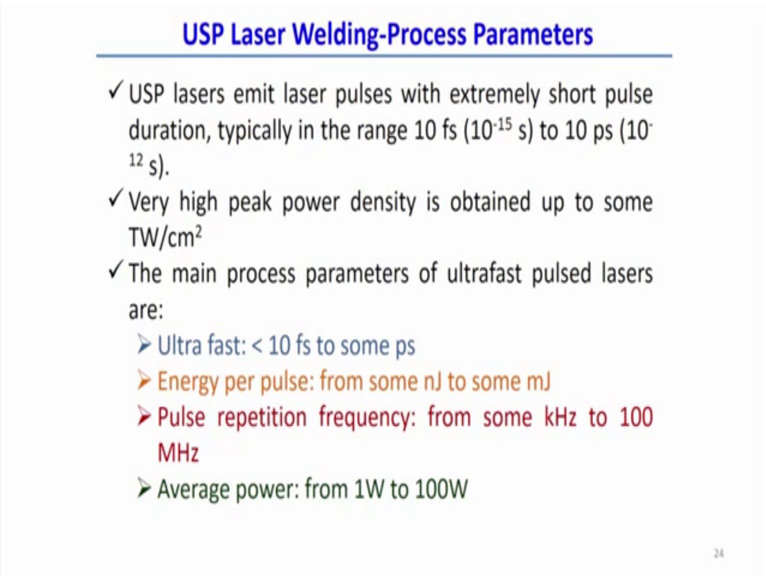

So, definitely the ultra short pulse laser emit laser pulse extremely short pulse typical in the range of 10 femtosecond or 100 femtosecond 10 may be at minimum 10 femtosecond. So, 1 femtosecond is equivalent to 10 to the power minus 515 second and the range between picosecond also picosecond means 10 to the power minus 12 second.

So, therefore, since duration is very high the very high peak power the power density peak power density is obtained is also very high as compared to the conventional laser. But the main process parameter for ultra short pulse laser are the ultra the less than femtosecond laser pulses or may be or the order of the femtosecond pulse laser.

So, energy pulse from the nano joule to micro joule that range of the pulse energy and pulse repetition rate can vary as much as kilohertz to the 100 megahertz within that range. So, there is wide applicability of this ultra short pulse laser nowadays is observed in case of metallic or non-metallic materials.

So, average power here you can find out that it varies from 1 watt to 100 watts. So, average power is quite low as compared to the other high power or maybe a conventional laser processes. But the main significant point in ultra short pulse laser is that very high peak power very high peak power and application of the pulse energy over a short over a femtosecond duration of the point.

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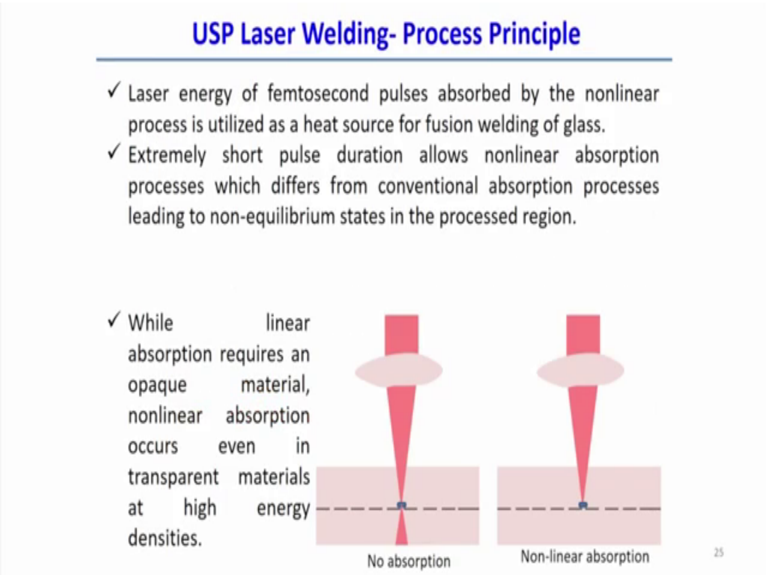

So, definitely there is some characteristic difference with the application of the ultra short pulse laser which cannot be explained by the or maybe which cannot be applicable for the conventional laser welding processes.

So, since laser energy now we will try to discuss this ultra short pulse laser welding process in the with the perspective of the application in non-metallic material. So, laser energy of femtosecond pulses actually absorbed by the non-linear processes utilized as fusion welding of the glass.

So, normally we can find out the huge application of the ultra short pulse laser for the joining of the glass. So, extremely short pulse duration basically allows the non-linear absorption of the energy by the material which different from the conventional absorption process leading to the non-equilibrium states in the process region.

If you see the figure the representative figure here you can see the application of the ultra short pulse with the application of the conventional laser at the interface there is no absorption and the all energy has transmitted through this material. And if there is a at the interface there is a minimum amount of the absorption or there is no absorption and if we use the glass material and of course, but if you if you use the ultra short pulse laser.

So, ultra short pulse laser says that there is a non-linear absorption at the interface because of the non-equilibrium thermal non non-equilibriums actually exist with the application of the ultra short pulse laser. So; that means, application of the pulse laser is; so, fast that the heat energy is absorbed at the interface that, but similar material cannot absorb the laser energy if we use the nanosecond or microsecond or millisecond laser pulse laser.

So, therefore when the linear absorption requires of a material, but non-linear absorptions even in the transparent material at the high energy densities can also occur at the interface.

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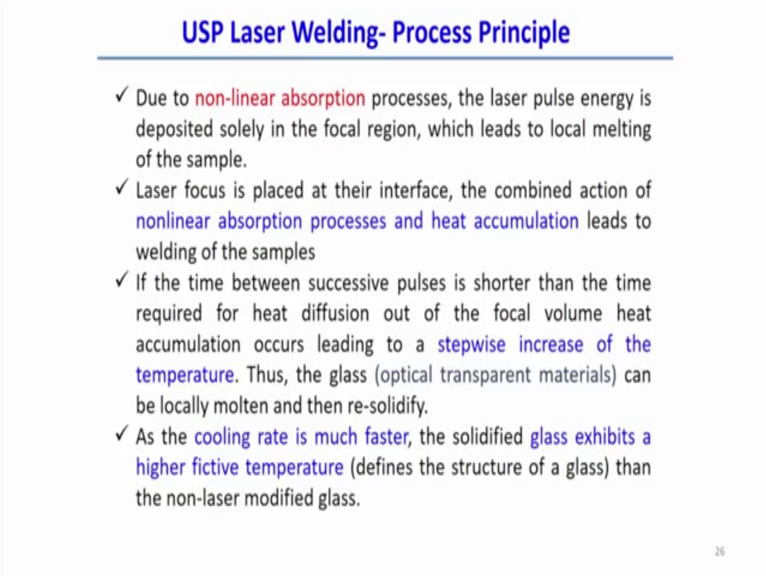

In if we see the processing principle of the ultra short pulse laser is that non-linear absorption process is absorbed the laser pulse energy is deposited only within the focal region which actually leads to the very localized melting of the sample.

So, another advantage is that with the application of the ultra short pulse laser. So, that heat affected zone on the surface is very small which is not compatible as compared to the conventional laser welding processes. So, laser focus is placed at the interface and then the combined action of the non-linear absorption process and heat accumulation occurs within that period that actually leads the welding of the sample that is why this process is mostly can be mostly we can find out in case of glass.

So, if the time between the successive pulse is shorter than the time required for the heat diffusion that actually happens in the in case of ultra short pulse laser application. So, therefore, they just stepwise increase of the temperature. So, temperature may not be the application of the pulse laser there may not be continuous equipment of the temperature. So, temperature actually increases and the stepwise. So, so the glass; that means, optical transparent material can be locally molten and re-solidification with the application of the ultra short pulse laser.

But at the same time the cooling rate is also very very fast in this case. So, therefore, the solidified glass exhibits the higher fictive temperature. So, that defines the that actually defines by the indication of the structure of the glass. So, that is comparable as compared to the non-laser modified glass because that in the ultra short pulse laser also there is a high rate of cooling we can absorb.

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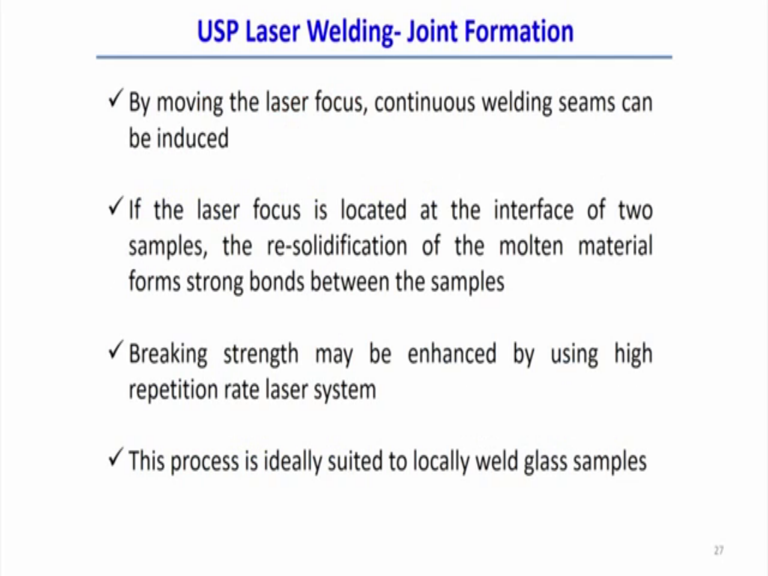

Joint formation is the similar to conventional processes simply by moving the laser continuous welding seam can be induced, but the if the laser focus is the at the interface of the sample re-solidification occurs of the molten material and that actually case the strong bond, but in cases that baking state definitely the mechanical properties can also be improved or mode of material joining can be can be decided by the repetition rate of the applied ultra short pulse laser for.

If we see the general the very low repetition rate in case of ultra short pulse laser and low repetition rate at the same time the high pulse energy is more suitable for the material abolition process.

So, simply vaporise the metal very quickly, but in other way that high repetition rate, but low pulse energy is mainly suitable for the joining of the welding mode of the material. So, therefore,, but this is more suited for the joining of the glass using the ultra short pulse.

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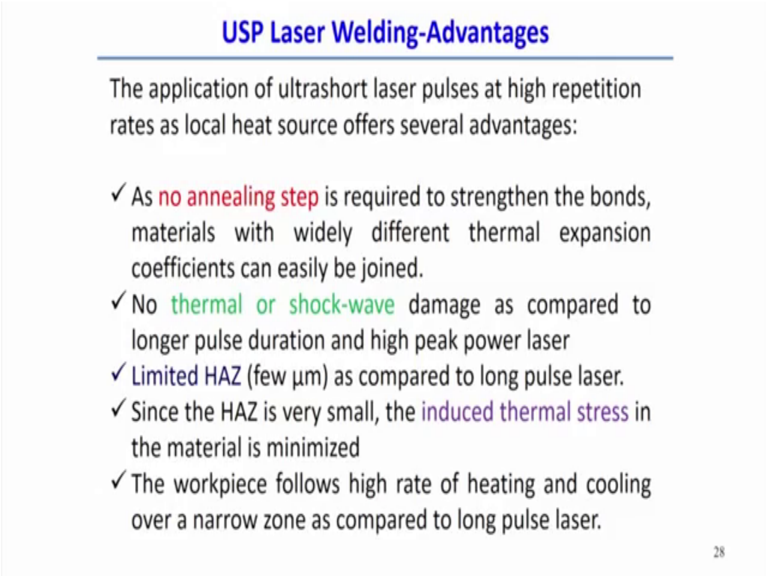

Laser mainly having the two advantage because there is a one advantage is there that even for the transparent glass is joined by the non-linear absorption by the application of ultra short pulse laser and that heat affected zone is localised and melting can be localized in a very small zone. So; that means, overall heat affected zone is very small as compared to the other welding process or we can say it is a very controlled heat affected zone can be produced by the application of the ultra short pulse laser.

So, apart from that the no annealing step is required to strengthen the bonds materials with the widely different thermal expansion. And coefficients can be easily joined in case of; that means, the using the ultra short pulse laser also there is a advantageous by joining of the dissimilar combination of the metals which cannot be produced as by using the simply a conventional welding process; that means, it is a medium or short short range of the pulse lasers.

No thermal or shock wave damage can be observed as compared to the long pulse laser duration and the high peak power. Actually the thermal or shock wave damage mostly decided by the pulse frequency here; limited heat affected zone definitely we have already told that limited heat affected zone can be produced using this long pulse laser therefore, since limited heat affected zone is produced. Therefore, thermal induced stress also very less in this minimised this type of material.

The workpiece follows the very high rate of heating and cooling over a narrow zone as compared to the long pulse laser that is also another advantage of this joining of the ultra short pulse laser. So, we can find out the typical application and limitation of the ultra short pulse laser welding process. So, materials using different type of the glass.; so, far you have observed by the application of the ultra short pulse laser. Fused silica borosilicate glass and ultralow expansion glass that is are the typical materials mainly used for the ultra short welding process.

What limitation is that development of suitable delivery system; that means, jigs design of the jigs and friction and focusing; that means, focusing of the laser and various defined zone is the that is the main limitation of this process and definitely cost is another important criteria for the wide application of the this welding process.

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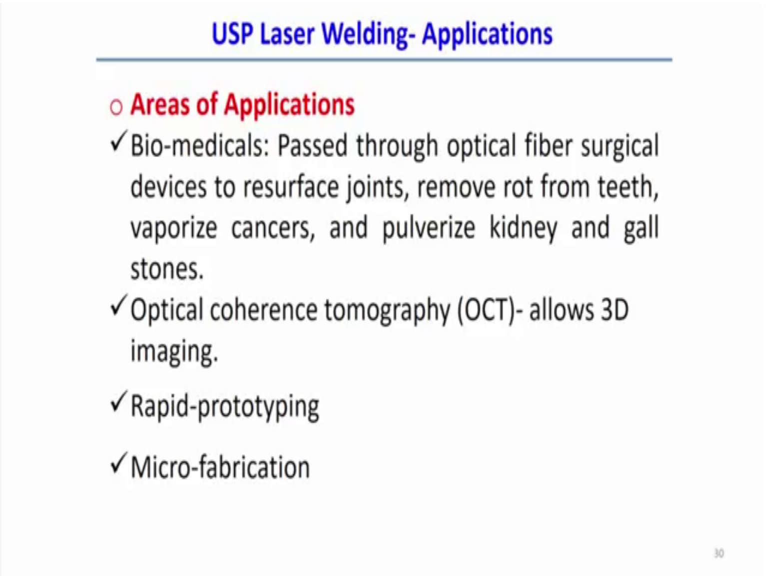

So, we can areas of application we can find out using the ultra short pulse laser that is the biometry bio-medicals we can passed through the optical biomedical we can find out the.

So, many medical devices can be welded using the ultra short pulse laser even for 3D imaging process; also we can find out the ultra short pulse, we can find this application of the ultra short pulse laser ultra short pulse laser typical it is very much suitable for the micro-fabrication and rapid prototyping is the another application area of the joining of the ultra short pulse laser.