Mathematical Modeling of Manufacturing Processes

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Lecture – 37
Processing and Shaping of Non-Metals and Bio-Materials

Hello everybody now I will look into that we just come to the last module of this course that is processing of the non-metallic material.

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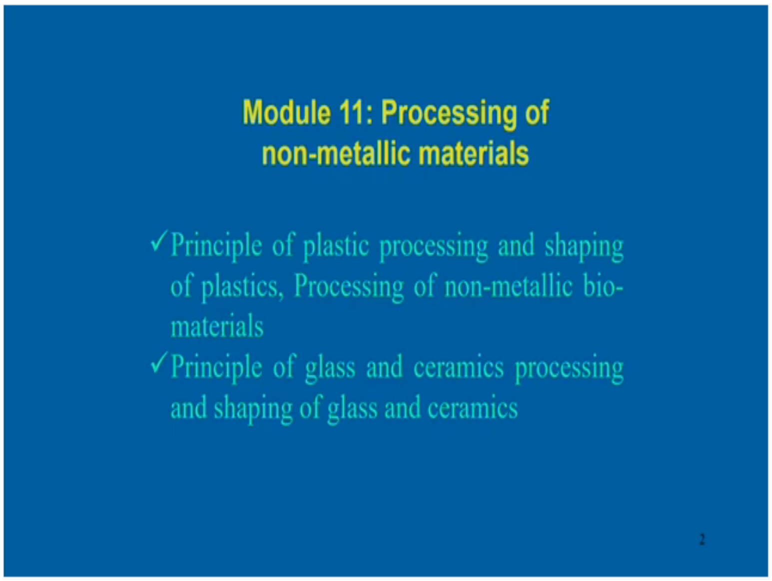

So we have discussed so far the different manufacturing processes and they are mathematical modeling approach which is mainly associated with the metallic materials. Now we will try to look into that what we can process the non-metallic material. So there are so many non-metallic materials and of course that there is a vast area, these non-metallic materials.

But this module we have we tried to focus on the non-metallic materials on only for the different kind of the plastic, ceramics and glasses, what we can process or maybe different manufacturing processes mainly the joining process and the machining process associated with this non-metallic material. And a discussion on this different basic understanding of the processing of the non-metallic material and overall understanding of the different manufacturing processes basically associated with this non-metallic materials.

So first we coverage will be the principle of the plastic processing and then shaping of the plastics different plastic processing of the non-metallic bio-materials also. So biomaterial or sometimes we try to look into the dissimilar combination of the materials but we can integrate the dissimilar combination of the materials which is open find the practical application in case of a bio-material industry.

And then we will try to look principle of the glass and ceramic processing mainly the machining and the welding process and the shaping of the glass and the ceramics. So this is the overall view of this module.

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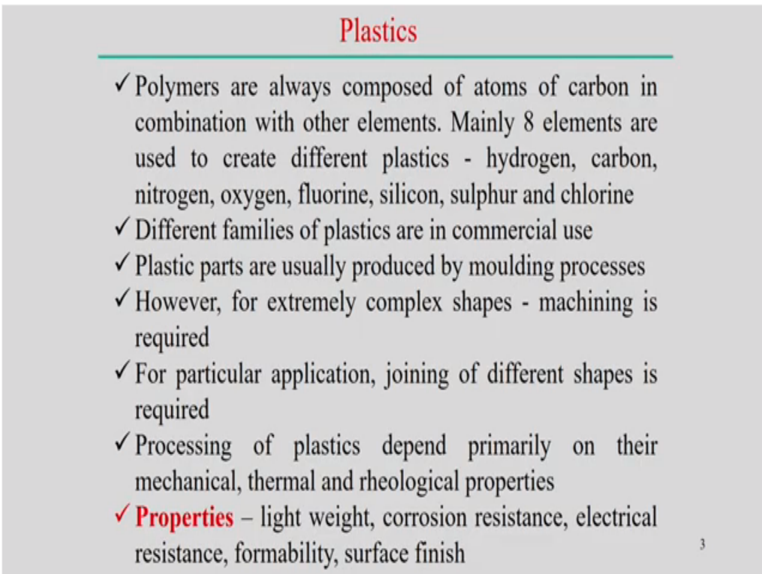

Now start with the plastics. So definitely polymers are always process composed of the atoms of the carbon atom mainly in combination with the other elements. So there are so many elements can be combined. Different types of the polymers can be processed. But in engineering application mostly 8 elements are used to form the different kind of the plastics. So these 8 elements are hydrogen, carbon, nitrogen, oxygen, fluorine, silicon, sulphur and chlorine.

So all these kinds of 8 elements there form the different kind of plastic which normally found in general application in the application in engineering application we can find out. So of course all this elements they produce the different families of the plastics and which are in actually commercial use. Structure, actually plastic try to forming the mer and then we did several mer join it and create the polymer.

So different polymer having the different kind of structures so that is not the here the scope of analysis. But with general plastic parts are usually produced normally by the molding processes. But when there is a extreme complex shapes so then put may be necessary to machining is maybe required and for a particular application, it is also necessary to joining of the 2 different plastic components or it may be necessary to joining the plastic component to other and metallic component.

So different manufacturing process is important here. But processing of the plastic primarily depends on their mechanical thermal and the mostly the rheological properties. So that different manufacturing technology has been deployed based on their properties which is actually different from that metallic material. Properties in general of the plastics is basically light weight, corrosion resistance that advantage, electrical resistance, formability, surface finish and of course some reduction in the weight also it is possible as compared to the metallic material.

So that is why there is a several application of the plastic and normally we find out in the engineering field.

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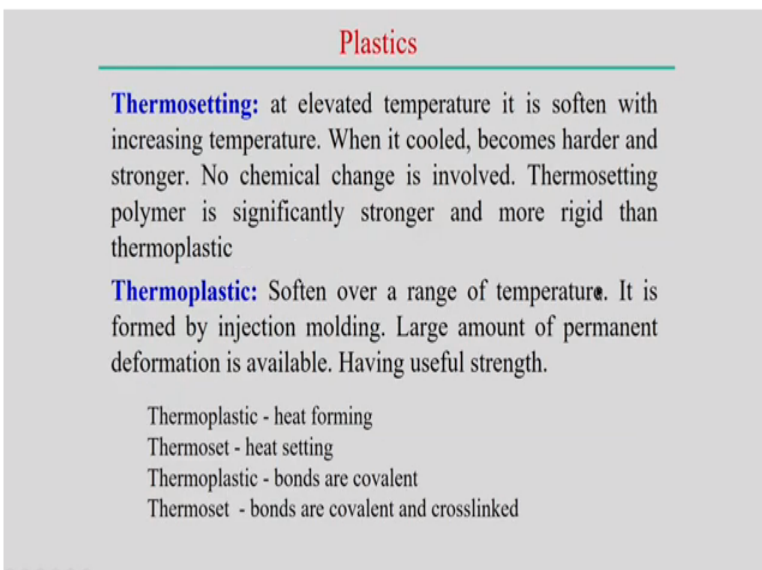

But normally plastic can be grouped into these 2 types of the plastic we normally handles, 1 is the thermosetting plastic another is the thermoplastic. Thermosetting plastic means it creates that pipe particular shape with the application of the heat that is called setting of the shape and with the application of that why it is called thermosetting plastic. And here it elevated temperature it becomes softer at here with increasing temperature.

But when it is cools becomes harder and takes a particular shape. No chemical changing involved. And thermosetting plastic is basically significantly very stronger and more rigid as compared to the thermoplastic. But on the other hand thermoplastic is actually become soften over a wide range of temperature and it is formed by the injection molding and large amount of permanent deformation is possible in case of thermoplastic.

So based on that thermosetting plastic and the thermoplastic, they having different kind of the application. But of course thermoplastic having some useful strength. But this strength is the maybe less as compared to the thermosetting plastic. In general thermoplastic is basically heat forming then which takes the form, it form is by application of the heat and thermoset heat setting. It absorb the heat and accordingly it can take the shape.

So thermoplastic in general it is called bonds is basically covalently bonded, but thermoset bonds are covalent as well as it creates the crosslink in the structure of this plastic. So that is why this is the difference between the thermosetting and the thermoplastic materials.

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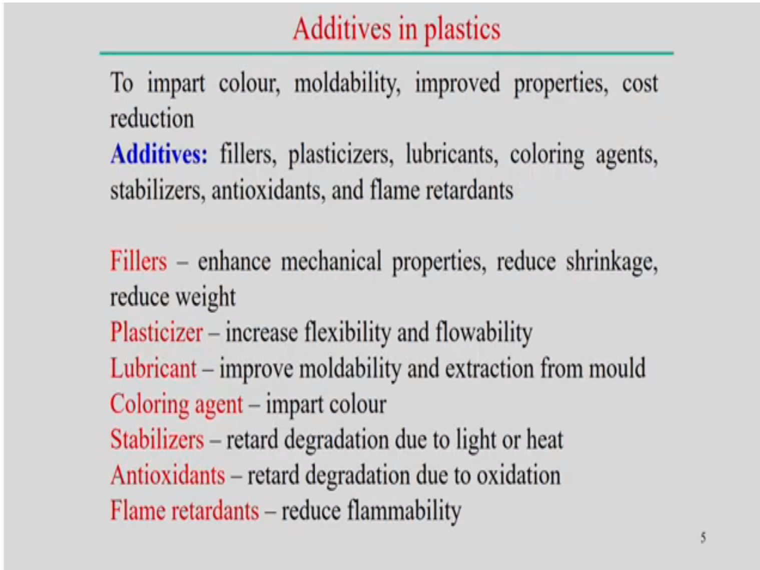

Now sometimes in the plastic also it is necessary to add some kind of additives to impart certain kind of properties or to impart color also like properties means moldability. We can enhance the moldability using some certain additives. We can improve certain properties with the additives and some of course most of the cases that cost reduction is also one other aspect such that we can add some additive to the plastic to change their to modify their properties.

But additives in general which added in plastic that is in the filler and categories like the plasticizers, lubricants can also be added, coloring agents can also be added, stabilizer, antioxidants and flame retardants that all can be added as a additives to the plastic. So filler materials here we can see the enhance mechanical properties that is the main purpose of using the filler materials.

It also reduce the shrinkage, reduce the weight also. Then plasticizers are increased flexibility and flowability. That is the main purpose of using the plasticizer with the addition to the plastics and coloring agent, definitely if we use some kind of colouring agent to bring certain color in the plastic making attractive. Then stabilizer here the stabilizer means that retard the degradation that means resistance it creates some kind of resistance to the light and heat.

And antioxidants that it avoid the degradation due to the oxidation. If we use antioxidants to the plastic components as an additive then it removes the rate of oxidation, it reduce the rates of oxidation for this particular component and flame retardants is sometimes the reduce the flammability of this particular plastic we can use the flame retardants. So these are the different additives can be added up to certain extent for the plastic components to impart the or to change their properties to improve their properties up to certain extent.

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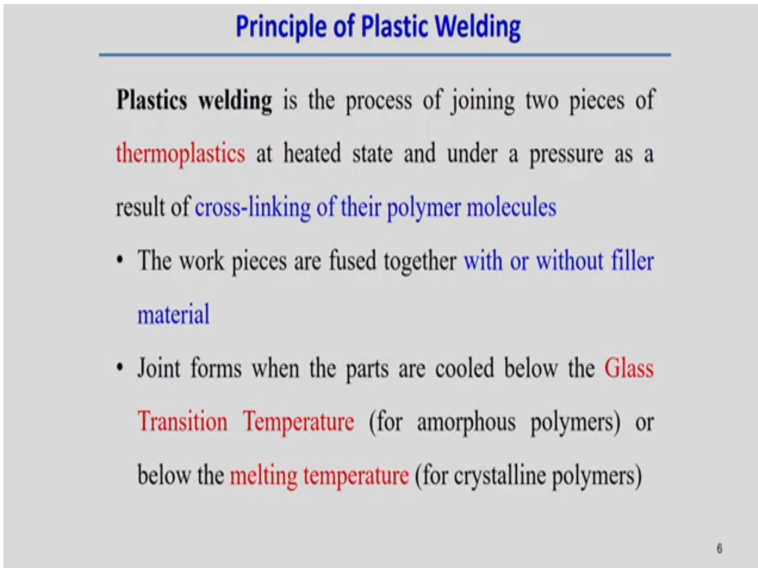

Now this is overall about the structure and the properties of the different kind of the plastics. Now we will try to look into the manufacturability of these plastic components. One is such manufacture processes is the welding or joining of the plastic components. So what we can join the plastic components? Of course in principle that we need to apply some kind of the heat at the interface and then interface can be joined with the application of the pressure.

So plastic welding is the process of the joining 2 pieces of the thermoplastics normally that joining plastics means we understand the joining of the thermoplastics at the elevated temperature or some certain temperature under pressure and the result is a cross-linking of the polymer molecules crosslink with respect to each other and they join together. Of course, these temperature is here in this cases which is not comparable with respect to the metallic material.

So this case is normally temperature in this low as compared to the metallic material. So then once the heat the surface brings together fuse together with or without any kind of filler metal is possible to join the 2 plastic components. But this in principle when joint forms the parts are cooled below the glass transition temperature and the for amorphous polymers one kind of polymer or melting temperature for the crystalline polymers.

So when the crystalline forms in the amorphous structure in this case polymer form in that case is the glass transition temperature is important here. But when you look into the crystalline structure, polymer structure, then melting temperature is important. So once melt it join it then after that they allowed to cool to room temperature. Then we can get the joining of these 2 plastic components. So there are different technologies also developed in plastic welding of the thermoplastics that these are the listed are the different processes.

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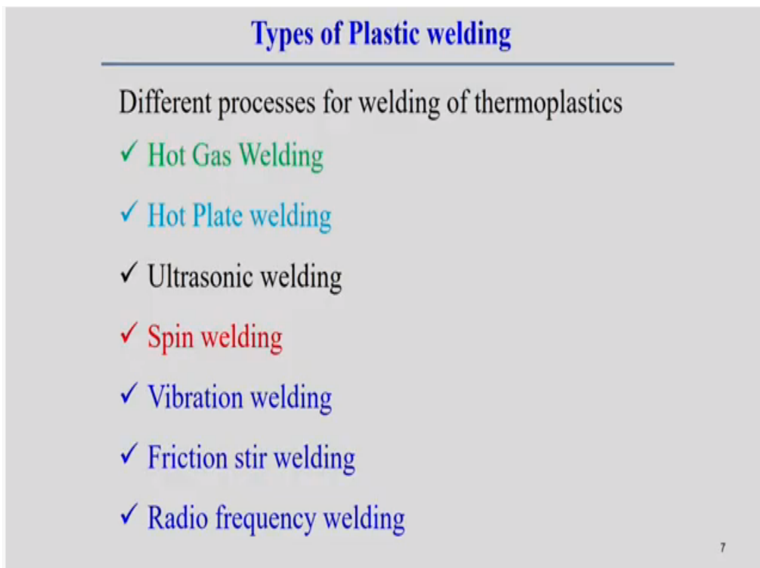

One is the hot gas welding, hot plate welding, ultrasonic welding, spin welding, vibration welding, friction stir welding, even for radio frequency welding. These are the developed technology for the joining of the plastic components.

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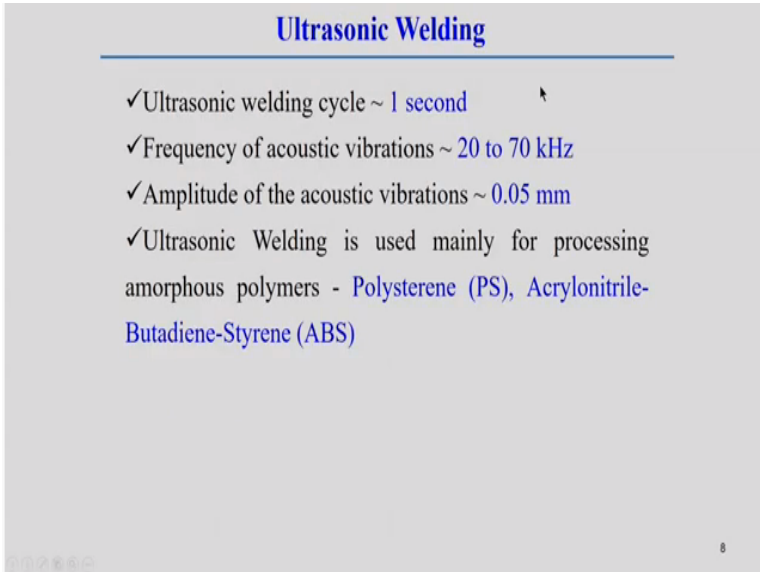

Now few of them we tried to look back this few of the processes. One is the ultrasonic welding processes. So definitely ultrasonic welding processes very localized process heat the vibration is created, vibrating tool is used and this vibration is basically confined into very small zone and here in that zone plastic deformation normally happens in these cases on this small heat is generated and that localized area the 2 plastic components can be done using the ultrasonic welding process.

But in this case ultrasonic welding cycle is normally 1 second and frequency of the acoustic vibration is around 20 to 70 kilohertz kind of vibration can be used. But amplitude of the acoustic vibration is around 0.05 millimetre. Ultrasonic welding is mainly processing amorphous polymers. So that can the polysterene PS and the ABS. This kind of polymer normally handles by this ultrasonic welding process.

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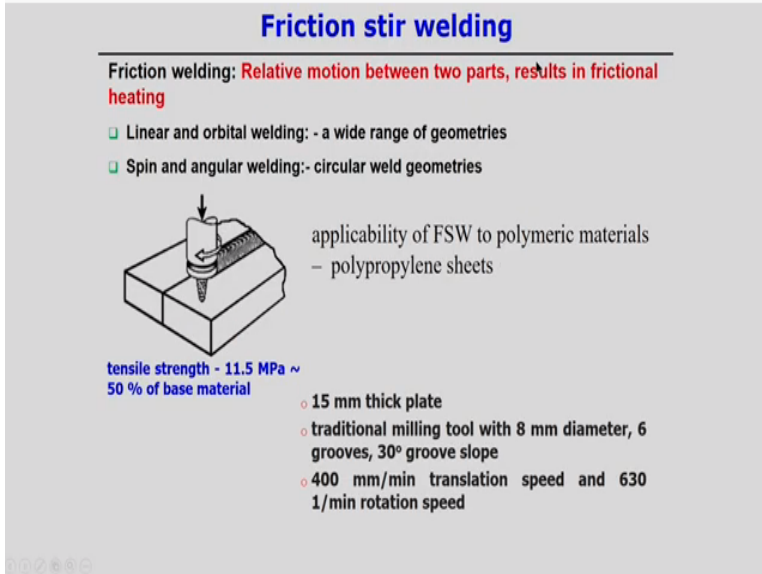

Even friction stir welding process has been developed for joining of the plastic components. So in these cases in friction welding the relative motion between the 2 parts results in the frictional heating and when along with the frictional heating there will be the stirring action. Then it is called the frictional stir welding. So linear and the orbital welding wide range of geometries can we developed by friction welding process and spin and angular welding also circular weld geometries can also be used in this fictional welding process.

But development also happens in case of friction stir welding. Because friction stir welding is possible to join polymeric materials that polypropylene sheets. Here we can see the polypropylene sheets can be joined using the friction stir welding process. So in this cases the tensile strength is achieved around 11.5 megapascal which is around 50% of the best material. But this technology is not very well established technology still research is going on for joining of the plastic components using the friction stir welding process to achieve a very good weld range strength.

So it is possible to even friction stir welding process development happens of joining around 15 millimetre thick sheet plate and the machine has been developed using simply traditional milling machine with the 8 millimetre diameter 6 grooves and 3 groove slope. Based on that the kind of the screw kind of things has been developed and as a tool and can be used as a friction stir welding process for joining plastic components.

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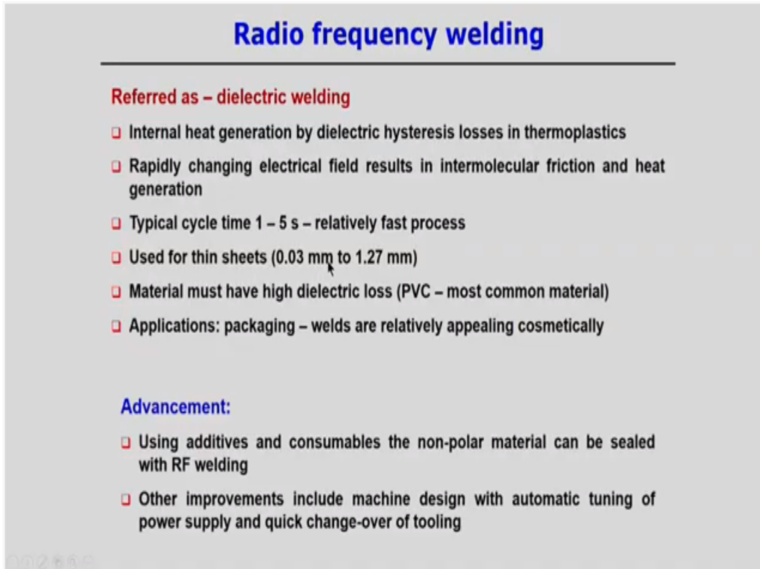

Even radiofrequency welding also has been developed for joining the plastic components. So radiofrequency welding can also be refer to as the dielectric welding process. In these cases the internal heat degeneration is happened by dielectric hysteresis losses in the thermoplastics. So if there is a rapidly change in the electric field that actually results in the intermolecular friction and that creates some kind of the heat generation inside this component.

In this cases typical cycle time is 1 to 5 seconds and it is relatively fast process and when thin sheet around 0.03 millimetre to 1.27 millimetre thickness can be joined by radiofrequency welding process. But material must have high electric loss to make this process successful. So in this cases mostly used material for radiofrequency welding is the PVC material. This actually it is a very clean process radiofrequency welding process and now that is why it is used for the packaging application of the packaging.

Welds are relatively appealing cosmetically. So in this cases we can get very good application of this dielectric or we can say the radiofrequency welding in the case of packaging system. Advancement also happens in this radiofrequency welding process. So if we using additives and the consumables the non-polar material can be sealed with the radiofrequency welding process. Even other improvements including the machine design with automatic tuning of the power supply and then quick change-over of tooling.

In that cases with advancements of this that these radiofrequency welding can be more automated and then it can be used in the automated system. So this kind of development also happens in case of radiofrequency welding process.

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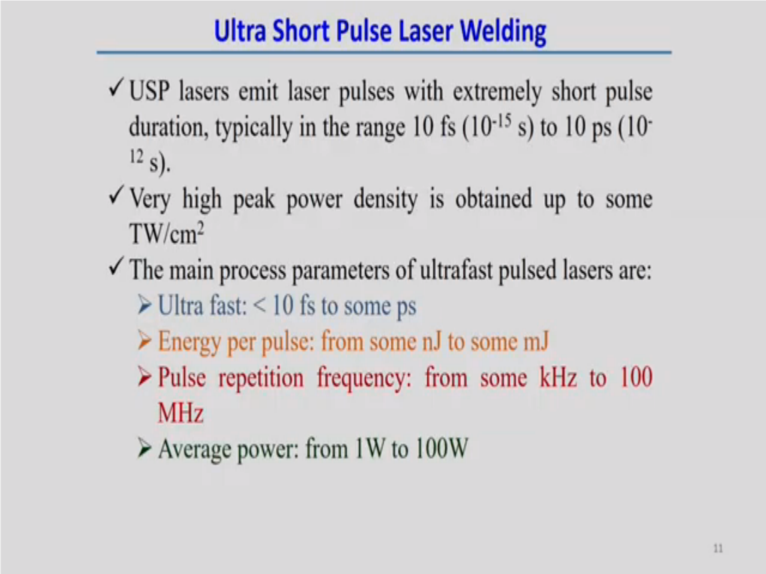

Now one of the most important welding process for plastic which is called ultra-short pulse laser welding process. So definitely ultra-short pulse laser welding processes it emits the laser pulses with extremely short pulse typically in the range of 10 femtosecond to around 10 picosecond. In that range the ultra-short pulse laser welding process has been developed. So within that range because within this short range the pulse energy has been really.

So peak pulse becomes very high within short period of time and if peak part is very high and the power density also very high in this process and that power density means the laser power normally releases but it is very small with the range of picosecond not femtosecond. So that is why this process is very much advantageous and this process normally used in case of transparent polymer and of course in transparent polymer.

If you want to join without using any kind of absorbing layer, the transparent polymers can also be joined using ultra-short pulse laser processes. So the main process parameters ultrafast pulse laser if the pulse duration is less than 10 femtosecond to some picosecond then we can say it is a ultra-short pulse laser. So energy per pulse normally where is from nanojoule to microjoule.

Pulse repetition, pulse frequency it is also varies from some kilohertz to 10 megahertz actually if pulse frequencies towards the higher side that means if say around 100 megahertz that can be more suitable for the joining or welding of the 2 components. But pulse frequency towards the lower side in that cases probably it is more suitable for evaluation process. And in this case the average power normally varies from 1 watt to 100 watt.

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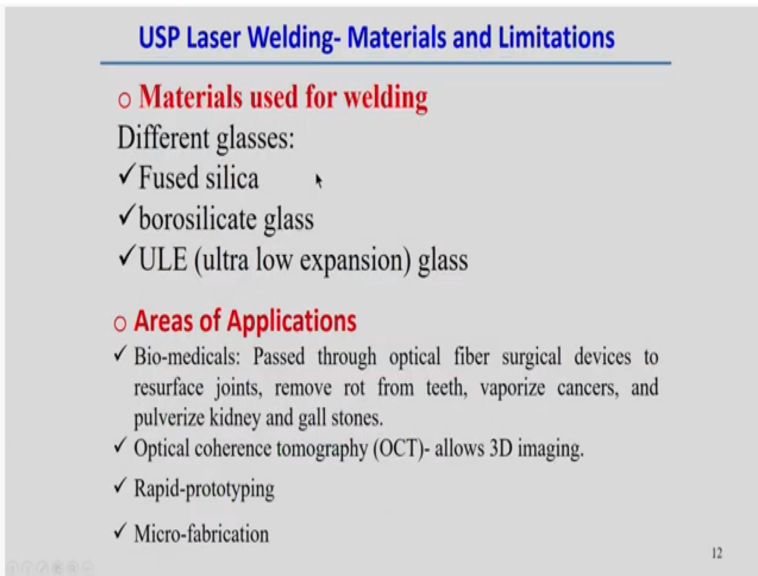

So we can see the ultrashort pulse laser welding process materials and limitations here we can say the different glasses, fused silica, borosilicate glass and ultra-low expansion glass. All this kind of materials can be joined together using the ultrashort pulse laser welding processes which is actually difficult for joining of this component using conventional laser welding processes. Where the pulse duration is the order of millisecond or microsecond.

Different areas of application we can find out this welding ultra-short pulse laser welding in the following application even bio-medicals that passed through the optical fibre surgical devices to resurface joints, remove the rot from the teeth, vaporize cancers and the pulverized kidney and gall stones. There we can find out the application of this ultrashort pulse laser. Even optical coherence thermography in these cases allows the 3D imaging where we can find out the ultra-short pulse laser system.

Rapid prototyping we can use it in a microfabrication even more suitable in case of microfabrication the ultrashort pulse system. So there we can finding out that all this application this thing.

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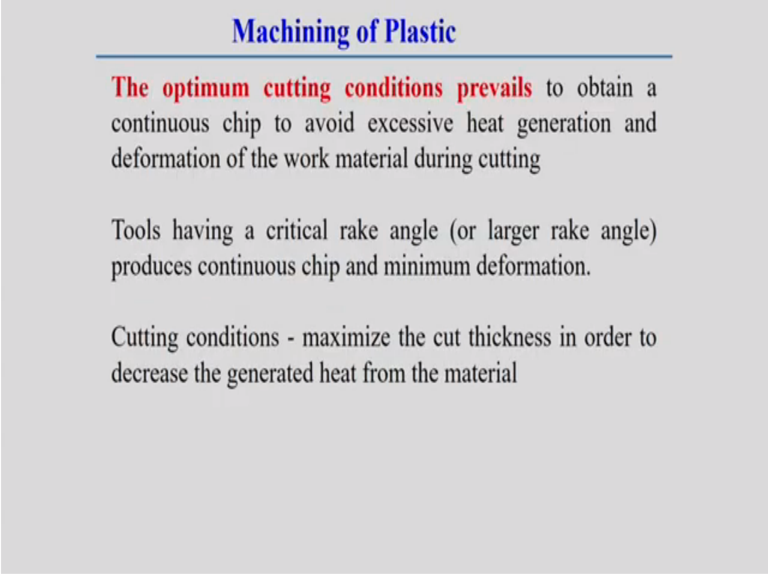

So apart from the joining or welding of the plastic components there is a development in the machining of the plastic components also happen. But of course if we try to look into the machining of an plastic components always even for conventional metallic material also try to finding of the optimum cutting situation. Such that it try to produce the continuous chip and avoid the excessive heat generation and deformation of the workpiece material during the cutting process.

So that also objective when we try to develop some kind of the machining process of a plastic components. But in general tools having the critical rake angle that is also important. It is having some influence for the type of chip whether it is continuous discontinuous chip or larger rake angle is helps to produce kind of continuous ship and with minimum deformation and even cutting conditions means as choose in such a manner that it will try to maximize the cut thickness in order to decrease the generated heat from the material.

So in that cases if the thickness becomes very high in particular plastic. Then it is possible to reduce the heat generation during the cutting. Because if there is a heat generation and that if it is possible to absorb this amount of the thermal strain produced by the heat generation and then it is there may not be any crack but if material is towards more brittle. So small thermal strain generated by the heat generation may not be absorbed by this material.

So in that cases if most of the cases it try to produce some kind of crack. So that is one serious problem of machining in the not in machining in general the processing of the plastic components.

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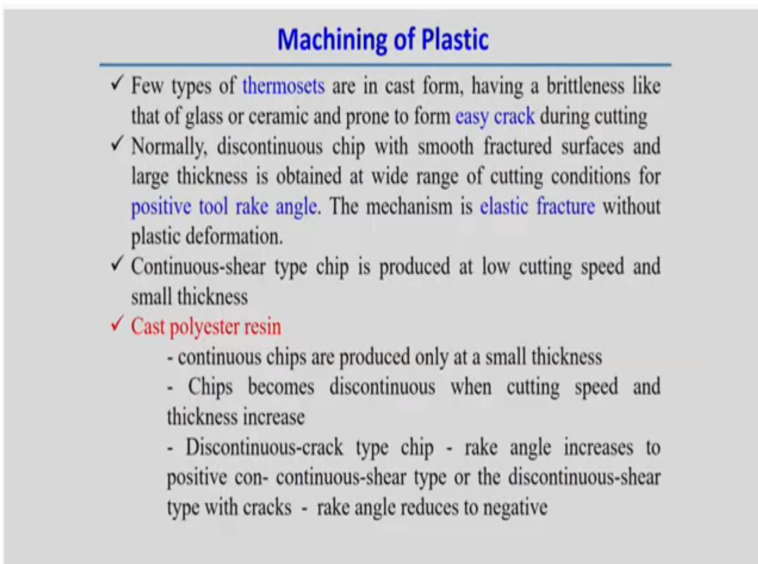

So if you look into the particular the machining of the plastic components here few types of the thermosets which are in cast form and that is thermosets is basically mostly at brittle in nature. So like glass and ceramic, they can easily form the crack formation. So that very carefully choosing the process parameters to get a successful machine of a plastic component. Normally discontinuous chips with smooth fractured surfaces and large thickness is obtained at a wide range of the cutting parameters or cutting condition we can see.

But in these cases the discontinuous chip with smooth fracture surfaces that is the one of the parameter is that large amount of rake angle is required in this cases and that sorry that is not only large that is positive rake angle is normally used. Such that the mechanism is the elastic fracture and without much plastic deformation happens in case of thermosetting plastics and of course continuous shear type chip also produced but that can be produced at a very low cutting speed and very small thickness in specifically when we try to handle the thermosetting plastics.

Example, the cast polyester resins it is a continuous in this particular plastic component continuous chips are produced only at small thickness. Chips become discontinuous when the cutting speed and the thickness cut thickness is actually increases. In these cases we can produce the chips becomes discontinuous. And of course if we see the discontinuous-crack type chip can also be produced.

In this case rake angle increases to the positive continuous positive value actually rake angle increases to the positive value and continuous shear type or other discontinuous shear type cracks is possible. In these cases rake angle reduces to the negative value. So looking into the different by modulating the different choosing the different kind of the rake angle along in the other process parameter is it possible to control continuous chip or discontinuous chip.

But at the same time that is more important to control the formation of the crack on the machine surface. So priority should be given to the choosing the parameter in researchers. So that we can avoid any kind of the crack formation on the surface. Then we try to look into the what type of chips it can be produced, continuous or discontinuous chip.

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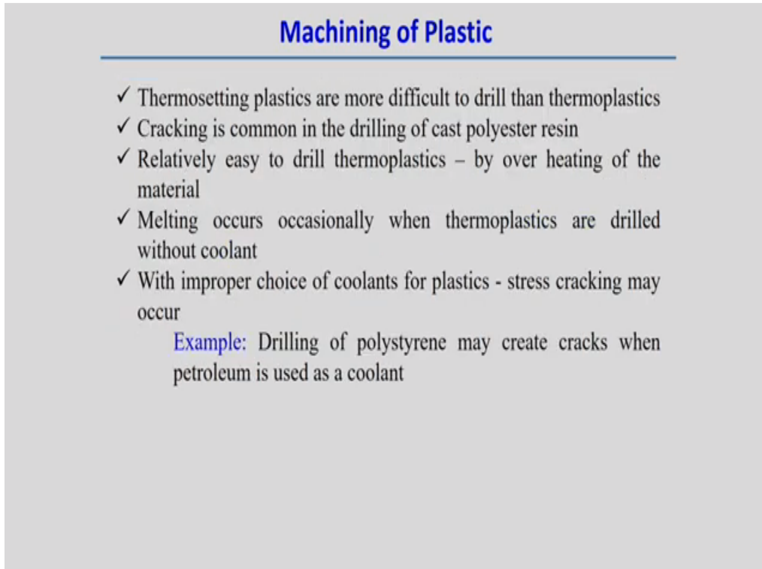

Thermosetting plastics are more difficult to drill than the thermoplastic also because crack is in general is the common during the drilling process of cast volume or resins. And of course in that sense the relatively easy to drill thermoplastic because by over-heating of the material within plastically deform the material up to certain extent. By melting occurs during the handling of the plastic machining with the plastic processes also occasionally melting may occurs.

When thermoplastics are drilled without coolant. So therefore coolant is having some improper choice of the coolant is important for the plastics because stress cracking may occur with the improper choice of the coolant during handling of the drilling of the plastic component. Example drilling of the polystyrene may create some kind of the cracks when petroleum is used as a coolant. So therefore a prepared choice of the coolant may be helpful in the drilling process to occur some kind of the crack generation during this plastic machining of the plastic component.

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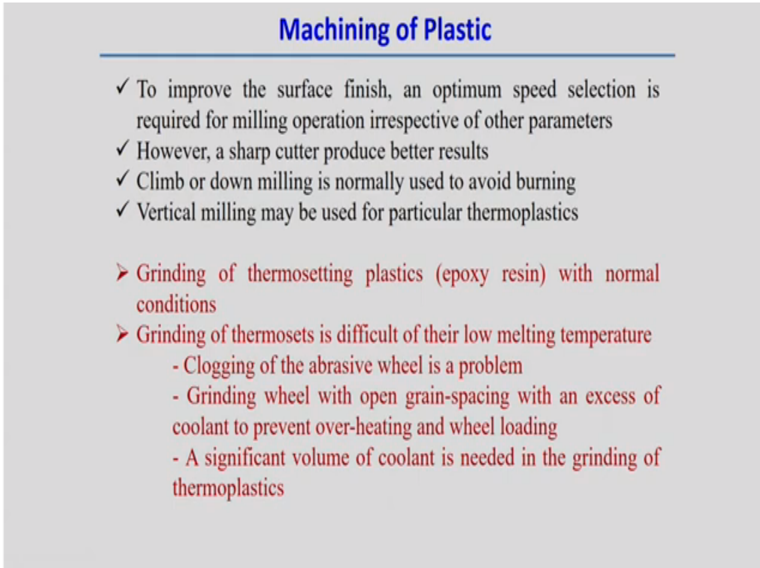

Even if we want to improve the surface finish of a plastic component even optimum speed selection is more important and relatively flexible by choosing the other parameters in these cases sharp cutter may help to produce the better results. So climbing or down milling is normally used to avoid the burning of a during the measuring of the plastic component, but vertical milling can be applicable in particular thermoplastics..

But of handing all this plastic components it is necessary to choose or to find out what is the range of the process parameters when you are handling this or try to do the milling process of the plastic components. If we look into the grinding of the other thermo setting plastics for example, epoxy resins. With normal condition it is possible to produce good surface finish, but grinding up the thermosets is difficult because their low melting temperature.

So that difficulty is in the sense the clogging of the abrasive wheel is a serious problem handling with the or grinding of the thermosets plastics. Therefore, grinding wheel with open grain spacing, with an excess of the coolant to prevent the overheating and the wheel loading is often possible and sometimes there is significant volume of the coolant is required needed for the grinding of the thermoplastics.

So therefore when you are handling grinding of the thermo setting plastics, so thermo setting plastic is well set, flexible to design the parameter to and that moves axil over the range of the parameters, but we have to be very careful when grinding of the thermosets. So in these cases, the cooler coolant having certain role and that to get the crack free grind surface.

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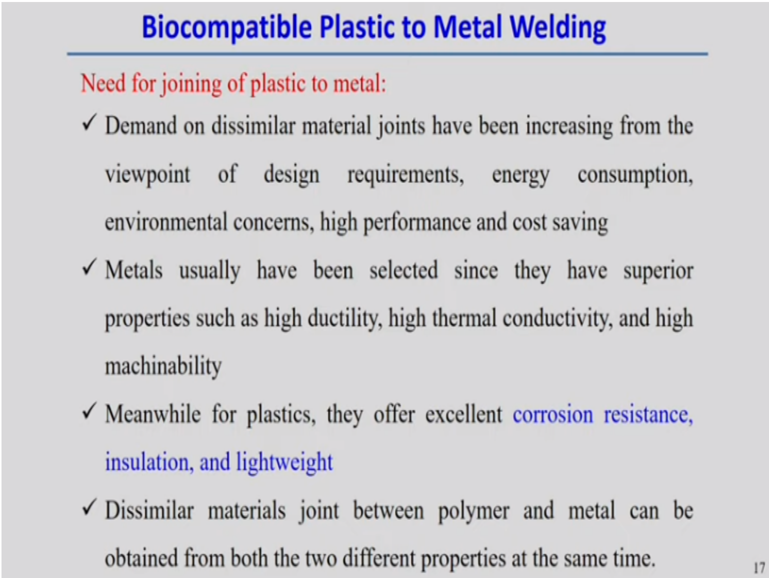

Now apart from the thermo setting, measuring of the different plastic components it is there is an application of this bio compatible plastic. So here we tried to look into that, the only particular angle that joining of the biocompatible plastic to the metal holding. Here we will be able to know what are the different materials, components we normally use in the biomedical applications. So need for the joining of the plastic to a metal.

If we look into that though, dissimilar metal joints have been used for increasing from the viewpoint of design requirements, energy consumption, environmental concern and particular there is a requirement based on that. So the joining of the dissimilar materials is important. Metals usually have been selected based on their properties of course ductility, high thermal conductivity and high machinability.

But of course the it are those parameter which is by competitive biocompatibility is another parameter. Based on that, we can choose the combination of the material for dissimilar joining. Meanwhile plastic which are excellent corrosion resistance, insulation and lightweight. It is sometimes suitable for the biomedical application. So therefore dissimilar materials joining between polymer and metal can be used open to different properties at the same time.

But there are several challenges for joining of the dissimilar communities of the materials or dissimilar plastic components only.

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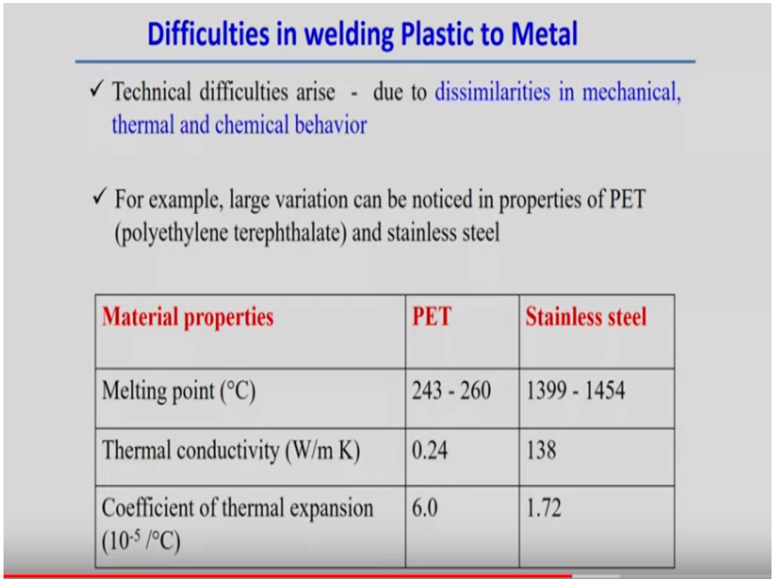

We can see that technical difficulties arises due to the dissimilarities in mechanical, thermal and electrical or chemical behaviour. This brings the difficulties in joining of the 2 different components. For example, large variation can be noticed in the properties of the polythene terephthalate PET basically and stainless steel. So in this case, if you look into the mechanical properties, material properties of PET and stainless steel.

You can see there is a huge range that melting temperature there is huge differences. Thermal conductivity there is huge differences. Coefficient of thermal expansion is almost 5 times with respect to PET as compared to the stainless steel. So therefore this huge difference in the material properties actually brings the difficulties of joining these 2 dissimilar combination that means combination in the sense the one metallic component with the plastic components.

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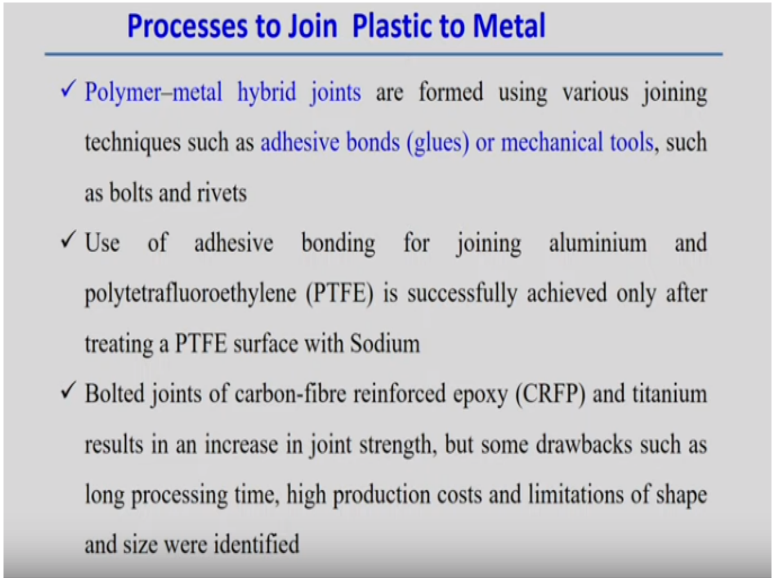

But processes to join in the plastic and metal. If we look into that polymers metal hybrid joins are formed using the various joining techniques. For example, adhesive bonds is one of the reliable technique on or mechanical tools such as bolts and rivets. Simply bolting and riveting can be used for the joining of this plastic to metals and but use of the adhesive bonding for joining of the aluminium and PTFE.

That one type of the plastic component is successfully achieved only after treating PTFE surface with the sodium. So therefore surface preparation of this particular process is important to get a successful joint. Bolted joint for carbon fibre reinforced epoxy and titanium, can be result in the joints strength but some drawbacks such as long processing time, high production cost and the limitation on the shape and size were identified.

So therefore having the different type of the plastic components, a combination of the plastic and metallic material can be joined and that can be used in the bio components or in biomedical industry.

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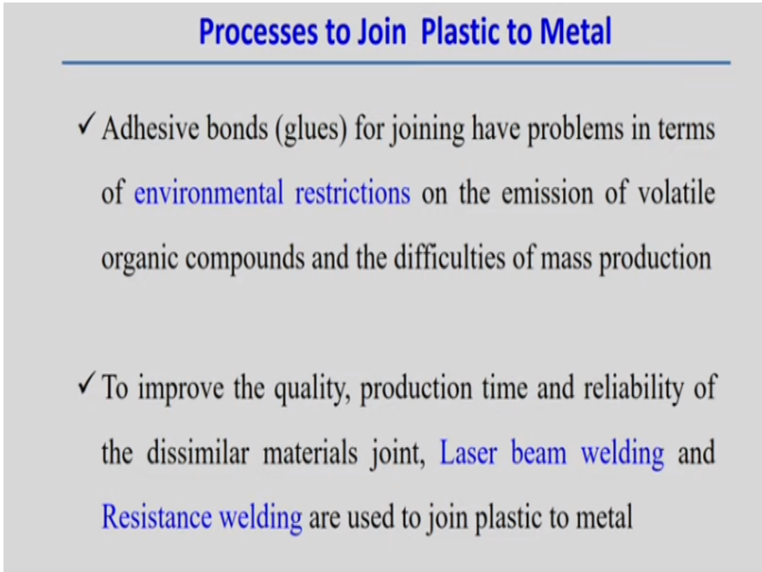

Adhesive bonds maybe glue can be used for joining of the having problem in terms of the environment restrictions. So this is the one difficulties even if we joined you can use simply adhesives and sometimes it is use it to some kind of volatile organic compounds and sometimes typical to make an automated system for the mass production. So therefore to improve the quality of production time and the reliability of the dissimilar materials joint.

So laser can be once again can be used here also and resistance only can also be used to join metal to the plastic. So in these cases the both are act as the source of the heat and that means the laser as well as the resistance welding process.

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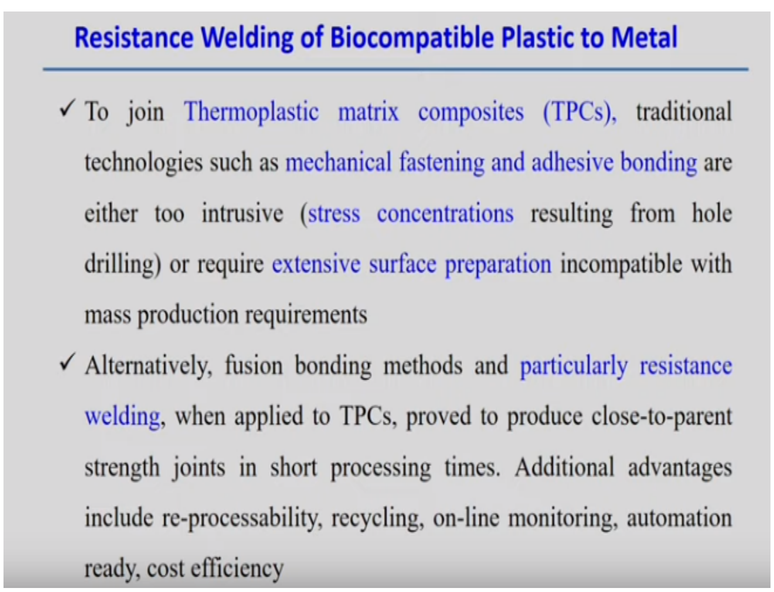

Now if we look into the resistance welding of bio compatible plastic to metal in this case is the thermo plastic matrix composites traditional technologies, mechanical fastening and adhesive bonding normally used. But they are either too intrusive when you stress concentration resulting from the hole drilling or required extensive surface preparation incompatible with mass production requirements.

So that can be the one serious problem other is the fusion bonding methods can be used particularly resistant welding when applied to TPCs proved to produce close to parent strength joint very good joint strength is possible if you use the fusion other than application of the different kind of the mechanical fastening or adhesive bonding technologies in this case. Of course fusion welding will go through a short processing time or additional advantage is that re-processability, recycling is possible online monitoring, automation and sometimes it becomes cost effective also.

All these kind of advantage benefits is possible when you try to join and the fusion follow some kind of the fusion welding process or bonding process.

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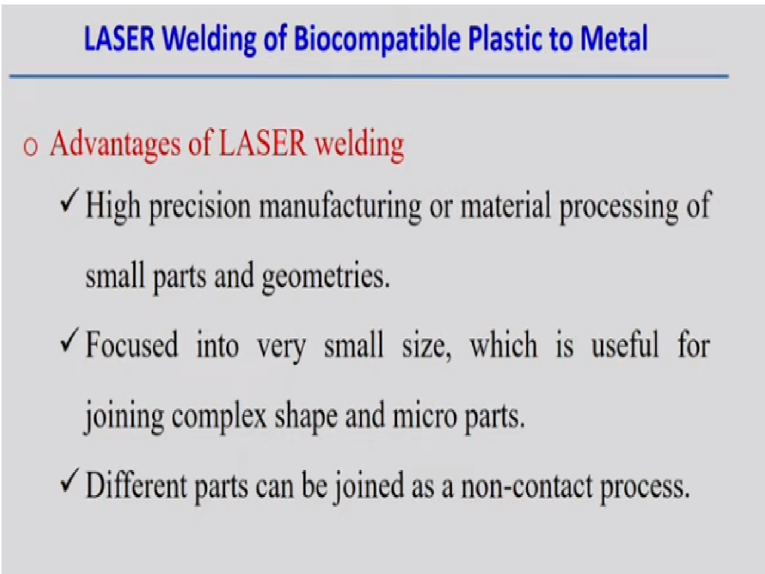

Now advantages of the laser welding process. We know that high precision manufacturing material processing small parts and geometries can be handled and that this as small part depends on the what is the focused diameter of the laser which is much low as compared with the ARC welding system .So therefore fused into the very small zone which is very useful joining complex shape and micro parts because here the limited heat affected zone and different parts can be joined as a non-contact process.

So it is not necessary to follow some kind of particular properties to follow up for these things. Workpiece material and not necessary in these cases because we are using the laser source here in this case.

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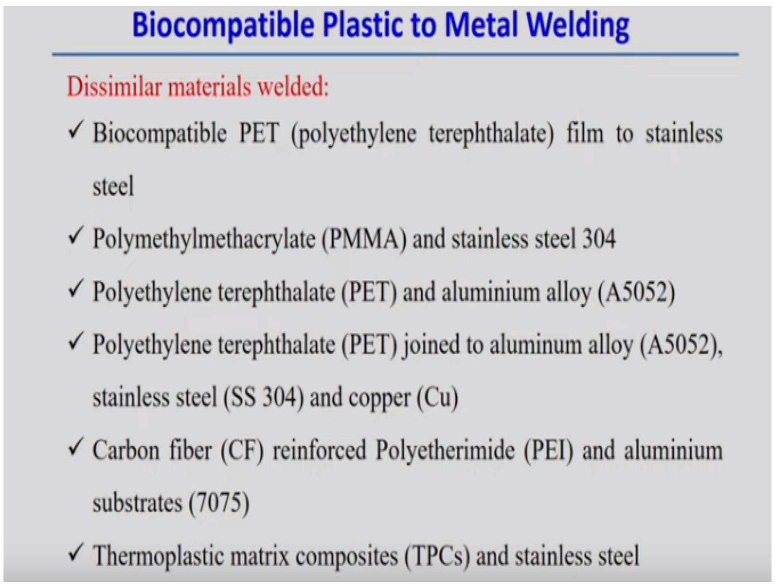

Dissimilar materials combination can be used in the practical application of the different biocompatible plastic to metal welding process. For example, biocompatible PET film to stainless steel. PMMA and stainless steel 304, PET and aluminium alloy this combination can be used. We have seen PET and aluminium at different grade aluminium alloy can be used here. Then stainless steel joined to aluminium alloy and stainless steel and copper also then carbon fibre to PEI reinforced and aluminium substrate also different grade aluminium alloy also.

Then thermo plastic matrix composites and stainless steel all these different kinds of the combinations of the non-metallic material as well as the metallic material we can find out the application in the bio compatible in the biomedical industry.

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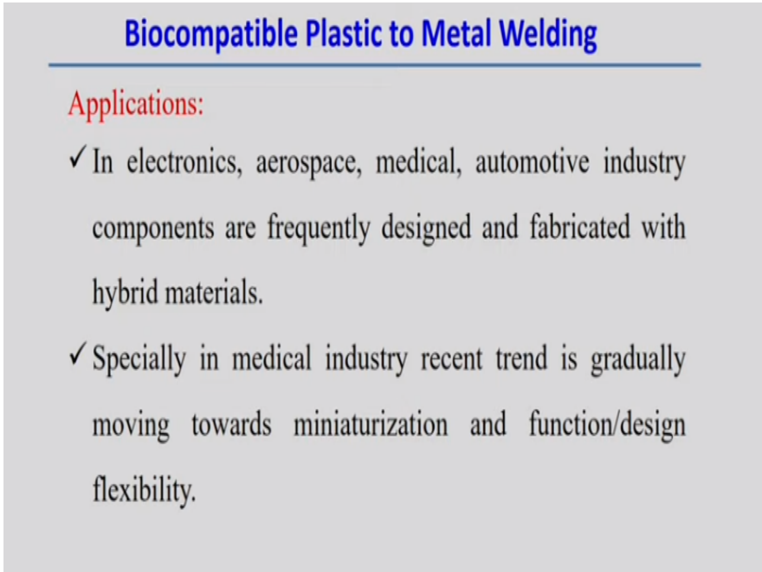

Application we can see in general the electronics, aerospace, medical, automotive industry components frequently fabricated with the hybrid materials. Then medical industry recent trend gradually moving towards the miniaturization function and design flexibility. That means in this case the different area, we can find out the application not only the medical industry, even for the electronics, aerospace also the different combination of the material even combination of the metal also not only materials is also applicable for a particular operation or particular functioning of a component.

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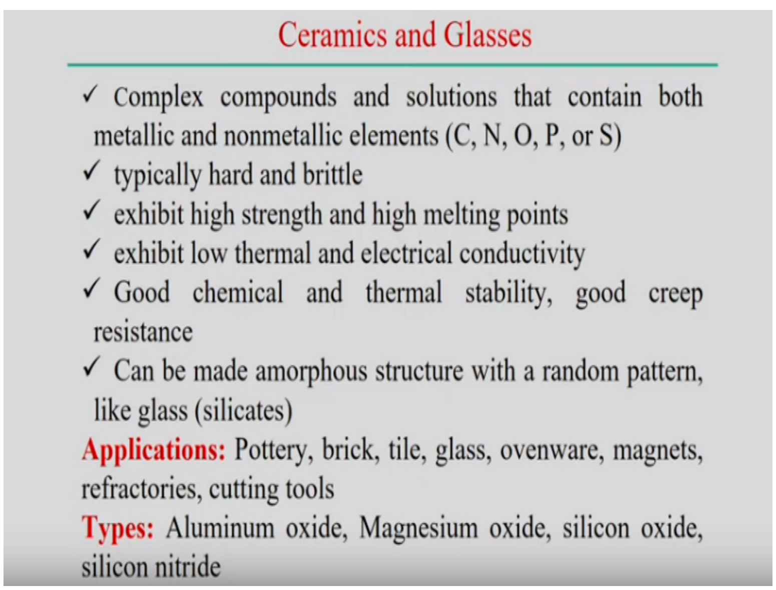

Now we try to look into that glass and ceramics that is another apart from the plastics, one other kind of nonmaterial metal we normally used in the different engineering application. But if we l look into the properties of these things, complex compounds and the solution that content with the metallic non-metallic material, but it is compound nitrogen, oxygen, phosphorus and sulphur.

These are the typical components of the ceramics and ceramics typically hard and very brittle very exhibit, very high strength, the high melting points, low thermal conductivity, a low thermal electrical conductivity, thermal conductivity, good chemical stability and thermal stability but it can resist very high temperature and very good creep resistant properties and it can be made amorphous structure with a random pattern like glass for example.

Silicates in that way. Applications pottery, brick. the tiles, these all are made from the ceramic materials. Magnets, refractories, cutting tools can also be made from the ceramic materials. Types what are the typical elements used for the ceramic aluminium oxide, magnesium oxide, Silicon oxide, silicon nitride all the ceramic components is normally produced and that is in general these are very brittle, very hard, high heat resistant properties. But the deformation cannot accept the deformation during the processing of this kind of ceramics.

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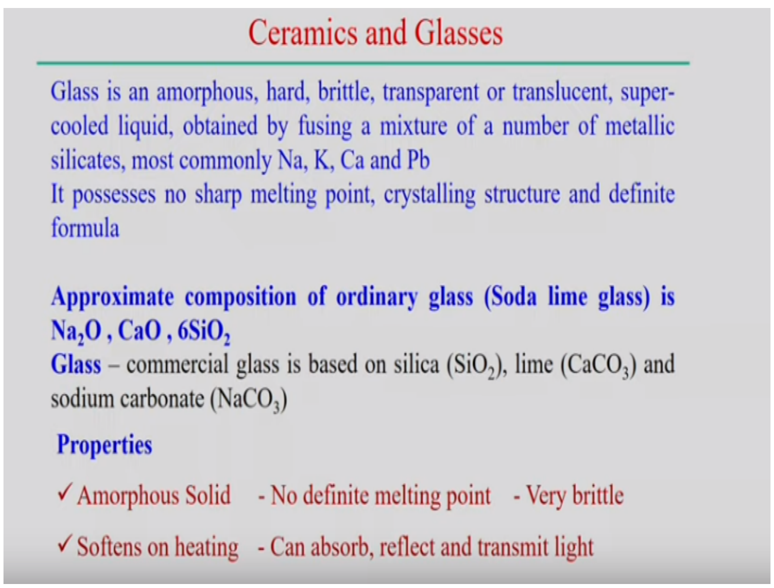

So if we look into the glass also glass is an amorphous hard, brittle, transparent or translucent material super cooled obtained by fusing a mixer of number of metallic silicates, most commonly the sodium, potassium, calcium and lead and it processes no sharp melting point crystalline structure and definite formula.

So therefore glass composition is like a composition of ordinary glasses. Soda lime glass is basically sodium Na2O,CaO,6SiO2. So therefore it is very difficult to not follow maybe particular combination formula a particular formula, but in general commercial glass is based on the silica lime and the sodium carbonate that we normally find out in the glass components.

The properties of the glass components you can see the amorphous solids it is a typical characteristic of the glass. We can say that this amorphous solid the glass is categories amorphous solid, no definite melting point temperature, very brittle, softens on heating definitively and then carbon absorbed, reflect and transmit light also. Other properties electrical insulator it can use that and affected by alkalis and these are the typical properties of the glass.

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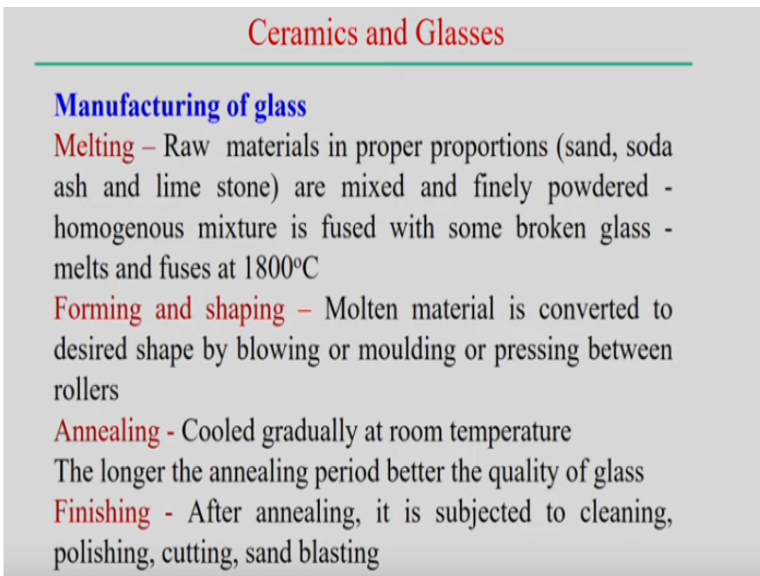

Now manufacturing of the glass is very follow certain basic steps. First it is mentioned to melting raw materials in proper properties sorry proportion way. For example, sand soda, ash, limestone mixed together we add the powder finely powder and homogeneous mixture is the basically fused with some broken glass and that actually melts and fuses at around 1800 degree centigrade.

So once it is melted, then it takes we tried to clear the particular shape the molten metal is converted to the desired shape by blowing or by moulding or pressing between the rollers we can get the desired shape of a glass product that is called the forming and shaping . Now annealing is basically cooling gradually at room temperature. Actually this, once we follow the annealing process of the glass component, in this case, the rate of the cooling should be very controlled and very low.

And we have to if we allow the longer time, a longer annealing period and the better quality the glass can be produced. And finally finishing up after annealing it is subject to cleaning, polishing, cutting sand blasting to get them to obtain the good surface finish of this product. So these are the basic 4 steps to produce the glasses.