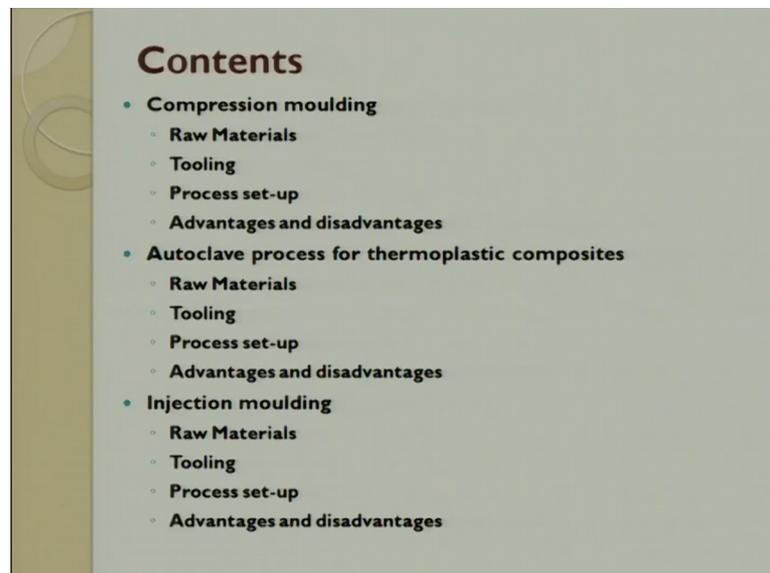


Manufacturing of Composites
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Lecture – 15
Thermoplastic Composites Manufacturing Processes:
Compression moulding, Autoclave and Injection moulding

Welcome to lecture number 15. So, this is the second lecture we will have on varying thermoplastic composites manufacturing process. As we said early itself thermoplastic composite has several challenges and now there is a pressing and pushing need. So, people have started working on novel processes and also trying to tweak those processes which was very well established in thermosets to get into thermoplastic here. And automobile industry and aerospace industry they were been working for a long time in metal forming. So, for them these processes tweaking became slightly easy. So, automobile and the aerospace are the 2 big industries which are driving through thermoplastic composites fabrication.

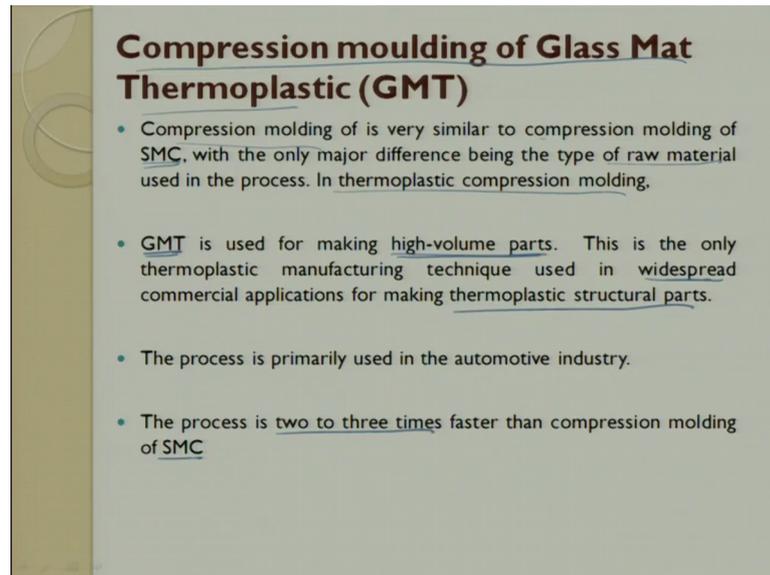
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In this lecture, we will see 3 processes, one is compression moulding process, the other one is autoclave for thermoplastic composites and the last one is going to be injection moulding process, in each of these topics we will try to see raw materials, toolings, process set up and advantage and disadvantages.

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Compression moulding of Glass Mat Thermoplastic (GMT)

- Compression moulding of is very similar to compression moulding of SMC, with the only major difference being the type of raw material used in the process. In thermoplastic compression moulding.
- GMT is used for making high-volume parts. This is the only thermoplastic manufacturing technique used in widespread commercial applications for making thermoplastic structural parts.
- The process is primarily used in the automotive industry.
- The process is two to three times faster than compression moulding of SMC

Compression moulding process: compression moulding process, it is very similar to that of the compression moulding what we saw in thermoset.

So, the compression moulding process of GMT - Glass Mat Thermoplastic, is a process which is slightly moving forward and there are lot of parts which are getting made through this process. In compression moulding process, it is very similar to that of your SMC. SMC, what we saw in thermo set processes, with the only difference during the type of raw material which is used here. Here, it is thermoplastic and there it was thermoset. So, GMT process is nowadays used for making very high volume parts and volume parts as well as varying size variation and shape variation. This is the only process which is widely used for various thermoplastic structural applications; for the process is 2 or 3 times faster than that of your SMC process what we studied earlier.

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Compression moulding of GMT

Raw Materials

- The raw material for thermoplastic compression molding process is GMT (glass mat thermoplastics).
- GMT is primarily made from polypropylene resin and continuous but randomly oriented glass fibers.
- Melt-impregnated GMT is the most common material form. Powder-impregnated, discontinuous fiber reinforced GMT is also used.
- A sheet of fiber glass impregnated with polypropylene is used in this process.
- These materials are available in pre-cut, pre-weighed pieces of sheet composite materials, called blanks, for processing.

Handwritten diagram: PP/TP + reinforcement $\left\{ \begin{array}{l} \text{natural} \\ \text{G, C, K} \end{array} \right. \rightarrow \text{Slice} \rightarrow \text{Pellets}$

So, what are all the raw materials which are used? The raw materials which are used for thermoplastic is a GMT is a Glass Mat Thermoplastic.

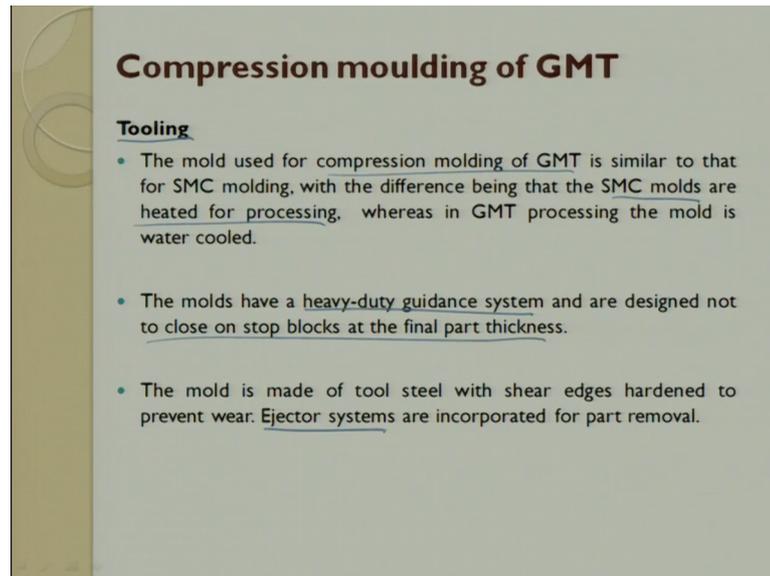
The Glass Mat Thermoplastic is predominantly made of pp polypropylene resin and continuous, but randomly oriented glass fiber. So, here what people do is, people try to melt impregnated GMT, is the most common metal form which is used or people also used the powder impregnated or discontinuous fiber reinforced GMT as a raw material. See, what people try to do is, nowadays they try to take a pp or they try to take any thermoplastic resin and then they try to add reinforcement and today people have started working on natural fibers also, apart from glass fiber, carbon, Kevlar, whatever it is or a combination. So, what people do is they try to mix, may be through mix and then they try to pultrude or extrude this and get an output and then what they do is they try to slice it and make it into pellets and these pellets are used for making this composites. This is one way one processing route of making it.

The other way of tools melt impregnation on GMT is already done and then we try to take it or in powder they try to mix it and then they try to get it. There can also be a sheet form of impregnation which is done with pp. So, people try to take or the what people try to do is they try to take a pp sheet and then they try to take a glass fiber, then keep a pp they try to consolidate get the requirement whatever it is and then they make a sheet out

of it, a composite sheet. The raw material is then pre-cut, pre-weighed and then try to make a composite and it is this one is called as a blank.

So, GMT is nothing, but Glass Mat Thermoplastic used for making compression moulding; in compression moulding process we try to get the required output.

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Compression moulding of GMT

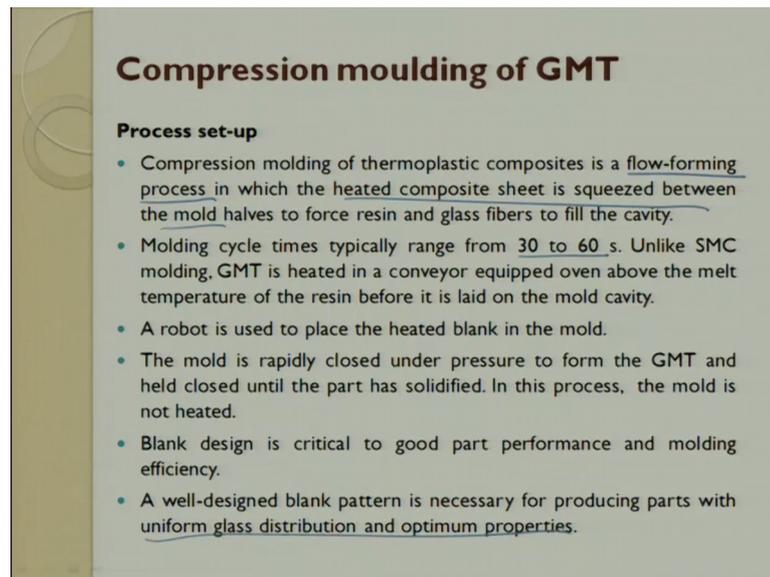
Tooling

- The mold used for compression molding of GMT is similar to that for SMC molding, with the difference being that the SMC molds are heated for processing, whereas in GMT processing the mold is water cooled.
- The molds have a heavy-duty guidance system and are designed not to close on stop blocks at the final part thickness.
- The mold is made of tool steel with shear edges hardened to prevent wear. Ejector systems are incorporated for part removal.

What is the tooling; tooling is naturally you need to have a die. In compression moulding of GMT is similar to that of SMC which we studied earlier. You should have a mould, which can be heated. Here, this heating is uniform heating, such that you get a proper consolidation.

The mould can be heavy duty; it can be used for making multiple parts, varying size. Heavy duty guidance systems are designed for not to open and close and get the final part done very fast. We also have an ejecting system to remove the component from the die.

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Compression moulding of GMT

Process set-up

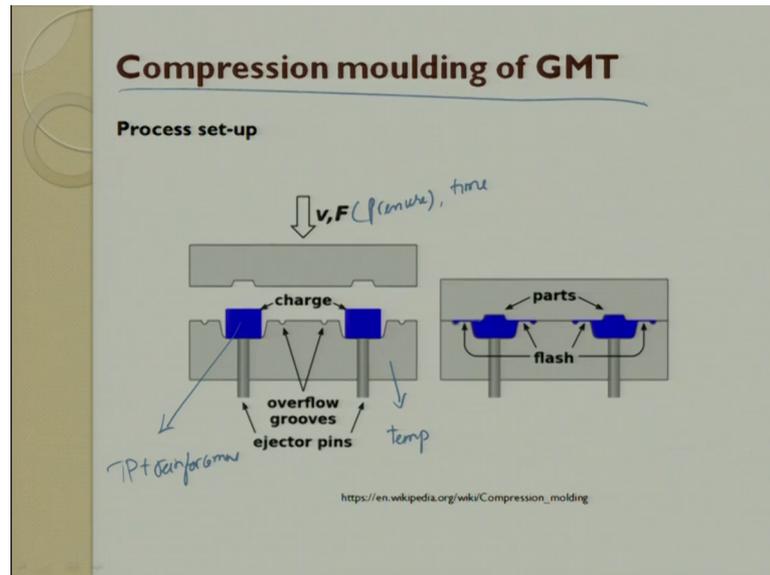
- Compression molding of thermoplastic composites is a flow-forming process in which the heated composite sheet is squeezed between the mold halves to force resin and glass fibers to fill the cavity.
- Molding cycle times typically range from 30 to 60 s. Unlike SMC molding, GMT is heated in a conveyor equipped oven above the melt temperature of the resin before it is laid on the mold cavity.
- A robot is used to place the heated blank in the mold.
- The mold is rapidly closed under pressure to form the GMT and held closed until the part has solidified. In this process, the mold is not heated.
- Blank design is critical to good part performance and molding efficiency.
- A well-designed blank pattern is necessary for producing parts with uniform glass distribution and optimum properties.

What are the processing steps: the first step is, the compression moulding thermoplastic is a flow-forming process in which the heat is applied to the composite sheet and it is squeezed between the moulds. It is maintained for 30 to 60 seconds then afterwards the mould, it is maintained heat for 30 to 60 seconds, then what do is, the mould is rapidly closed under very high pressure after this very high pressure, then what we do is, the part gets properly consolidated and then we try to get the required output.

So, first the compression moulding of the thermoplastic composite is of flow-forming process, because, the material has to melt and flow, and it is done by heating the composite sheet and then we try to squeeze it and then when you try to squeeze it, what we do is we keep it in a cavity, so that, it gets the shape. The mould time is 30 seconds to 60 seconds.

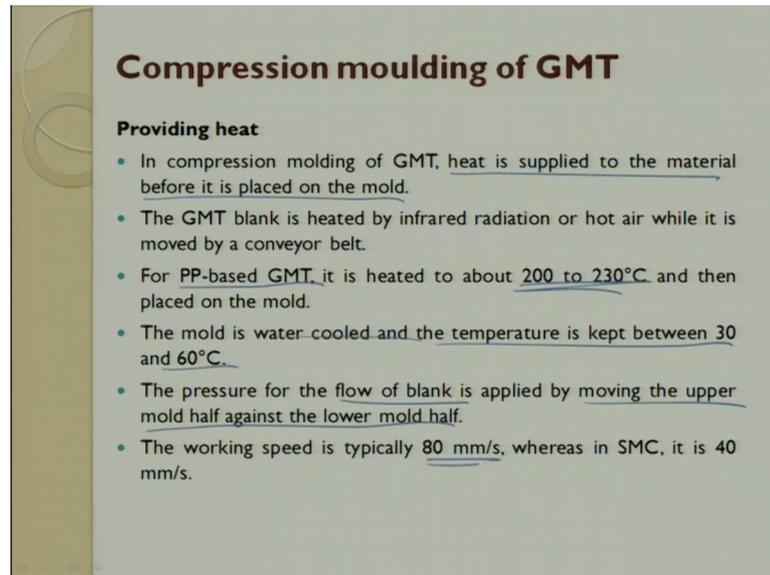
A robot is used to place the pre heated blank in a mould. The mould is rapidly closed under pressure to form the GMT and held closed unit the part for solidification. The blank design is critical, so that, you get a good part consolidation. A well-designed blank pattern is necessary for producing a good quality output with uniform glass distribution with optimum properties.

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So, this is what it is. What we do is, this is what is called as the charge. This charge is nothing, but the thermoplastic and the reinforcement. This is placed and then what we do is, this is what we say, you make a blank or whatever it is. This is done and then this is kept inside a die. In this die, you try to maintain a temperature and then here is the pressure what we apply and then you try to have with a constant time. During the time, the consolidation happens and here naturally what we do is we try to take excess charge, so that, what happens, this charge flows through this small dent which is called as a gutter. This charge flows to the gutter, once the gutter is filled, it tries to put a restriction of the further flow, this helps in consolidation of the shape of the charge to the die. This is what happens in this process, this is compression moulding of GMT.

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Compression moulding of GMT

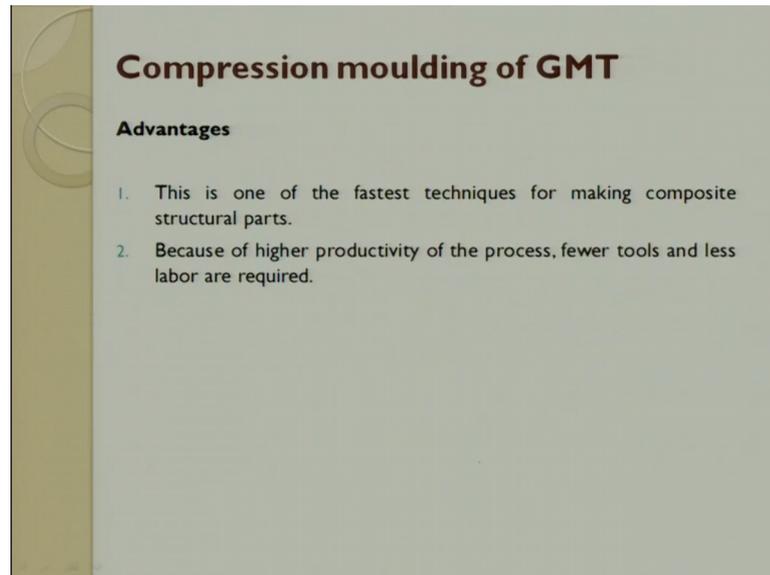
Providing heat

- In compression molding of GMT, heat is supplied to the material before it is placed on the mold.
- The GMT blank is heated by infrared radiation or hot air while it is moved by a conveyor belt.
- For PP-based GMT, it is heated to about 200 to 230°C, and then placed on the mold.
- The mold is water-cooled and the temperature is kept between 30 and 60°C.
- The pressure for the flow of blank is applied by moving the upper mold half against the lower mold half.
- The working speed is typically 80 mm/s, whereas in SMC, it is 40 mm/s.

So, why do we provide heat; the heat is used for proper consolidation only. Initially, we try to heat before we apply pressure. In compression molding, the heat is supplied to the raw material before placing it in the mold, so that, it tries to take into semi viscous state not completely visco-elastic, but at least to a soften state. The PP-based GMT, we try to take it to 200 to 230 degree Celsius and then it is kept inside the mold.

So, then inside the mold, the water is cooled and the temperature is kept around about 30 to 60 degrees Celsius. The pressure flow of the blank is applied by moving the part up or down to get the retirement. The speed with which it is operate is 80 millimeters per second.

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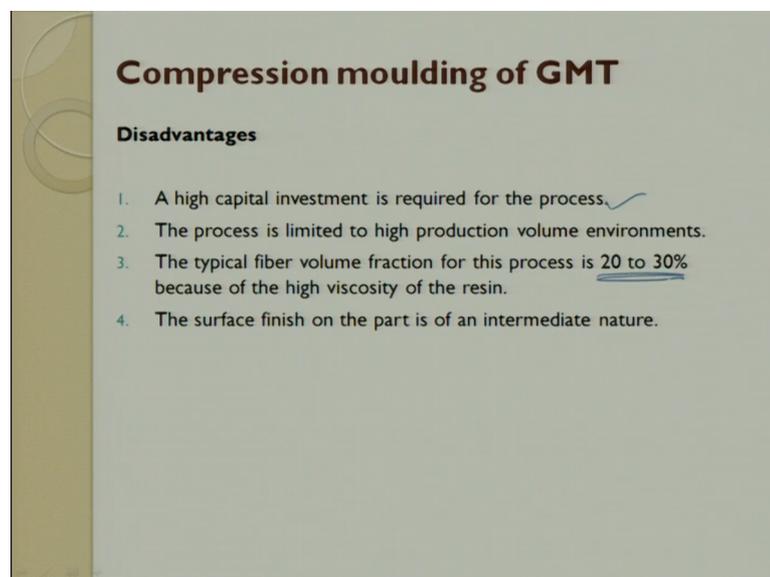
Compression moulding of GMT

Advantages

1. This is one of the fastest techniques for making composite structural parts.
2. Because of higher productivity of the process, fewer tools and less labor are required.

And this is much faster to that of your SMC. This is the most fastest technique in producing the thermoplastic composites parts, for requirements, if the productivity is very high.

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Compression moulding of GMT

Disadvantages

1. A high capital investment is required for the process.
2. The process is limited to high production volume environments.
3. The typical fiber volume fraction for this process is 20 to 30% because of the high viscosity of the resin.
4. The surface finish on the part is of an intermediate nature.

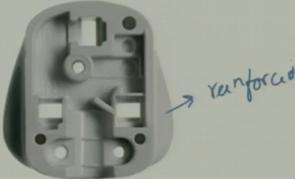
Capital intensive, the volume fraction cannot go more than 20 to 30 percent, this is the very important thing.

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Compression moulding of GMT

Applications

- This is the only thermoplastic manufacturing process used in industry for making structural thermoplastic composite parts.
- The process is used for making bumper beams, dashboards, and other automotive structural parts.



<http://www.appliance-design.com/articles/93925-compression-molding>

These are some of the parts which are made out of GMT. Here, we can see that bumper beams are made, dashboards are made, today, in automobile they are made out of compression moulding GMT and they are also getting reinforced. Please do not think it is not reinforced. It is reinforced.

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Compression moulding of GMT

Applications

- A painted kneebolster with molded-in texture can provide a Class A interior surface and heavy-truck dashboard. Cut-outs are recycled for reuse.



<http://www.mini2.com/forum/faq.php?do=search&q=bolster&match=all&titlesonly=0>

So, you can also see the painted knee bolster with molded-in-texture can provide a Class A interior surface and heavy-truck dashboards. These dashboards are used today in the

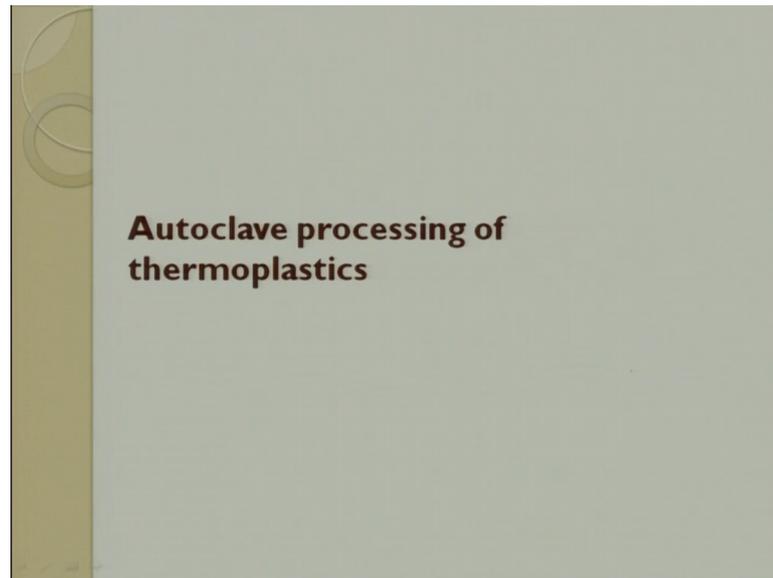
trucks and then whatever is the flash which comes out, that gets trimmed and those materials are recycled, since it is thermoplastic, it can be reused.

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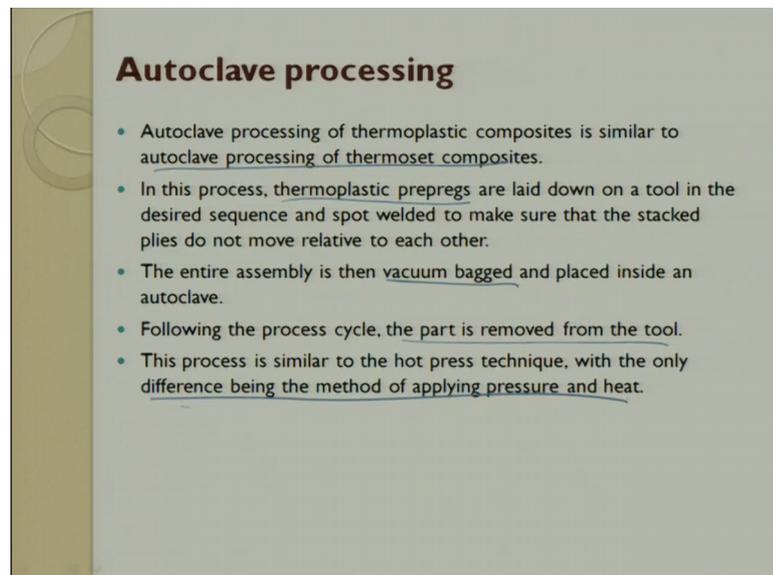
These are some of the commercial applications today and it looks like as though these things are made out of just thermoplast, but people have started making use of reinforcement in it and they have made the chairs much lighter than whatever is a ordinary plastic chairs are. Of course, it is expensive, the technology is getting refined. The helmets are made out of this technique. The other applications, like people have started making blocks, which are used in machine tools, they are done with this. And these are some of the covers, which are used for storing some defense applications, where in which, it can also try to maintain very high compressive load.

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So, the next process of discussion is going to be autoclave used for thermoplastic. The basics of autoclave last time itself we discussed. It is the same, but here there is a small modification, the thermoset is replaced to thermoplast, the rest all autoclave is the same. We will just quickly browse through it.

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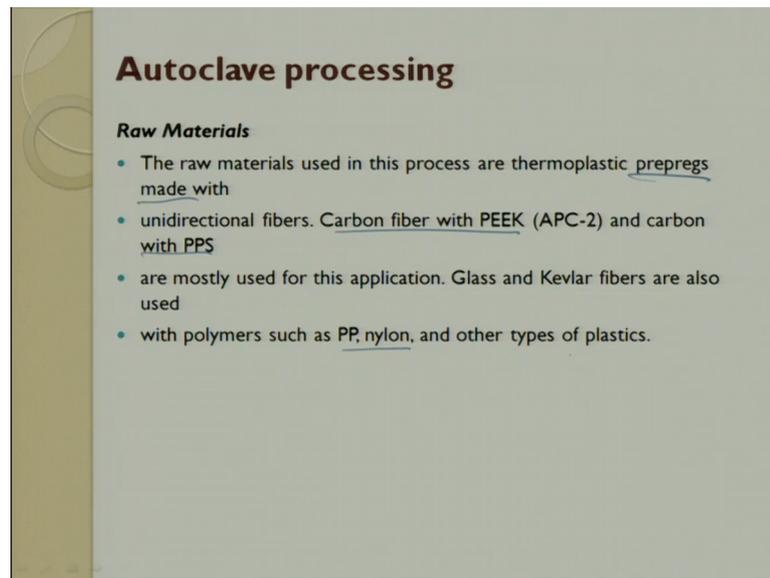


So, is very similar to that of thermoset composite the thermoplastic prepreg is laid on a tool the desired sequence you tried to maintain and spot welded to ensure that the stacks whatever are there, they do not move; there, they will never move in thermoset, but here

in thermoplast since it is visco-elastic you have to apply pressure, there is a possibility that the plies, inter-plyes can move, that has to be avoided.

We use a vacuum bag, is placed in an autoclave and following the process cycle, the part is removed from the tool and then you get whatever it is. This process has a very similar cycle of that of pressure and heat which is getting applied. The only difference between these 2 process is the magnitude and the timing.

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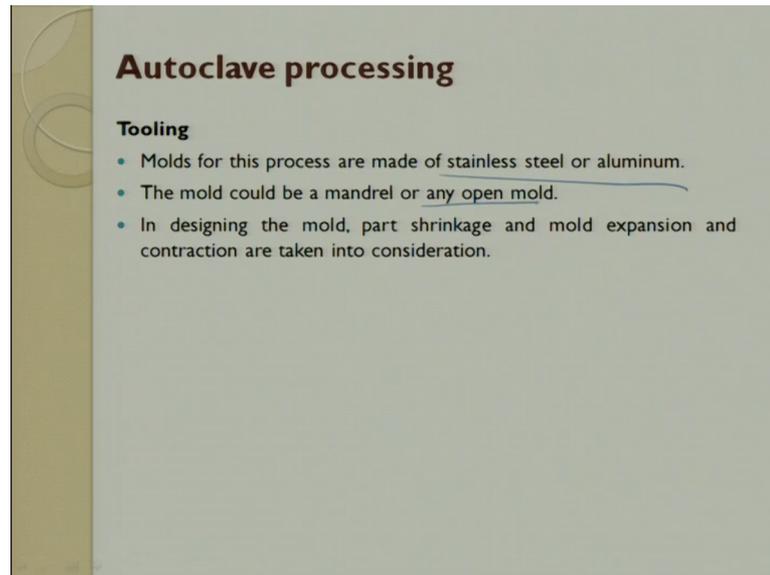
Autoclave processing

Raw Materials

- The raw materials used in this process are thermoplastic prepregs made with
- unidirectional fibers. Carbon fiber with PEEK (APC-2) and carbon with PPS
- are mostly used for this application. Glass and Kevlar fibers are also used
- with polymers such as PP, nylon, and other types of plastics.

The raw materials can be prepregs are available; wherein which you have carbon with PEEK and you can also have carbon with PPS. People are using it for aerospace application; this is finding lot of usage. So, you can also have nylon as for glass and Kevlar.

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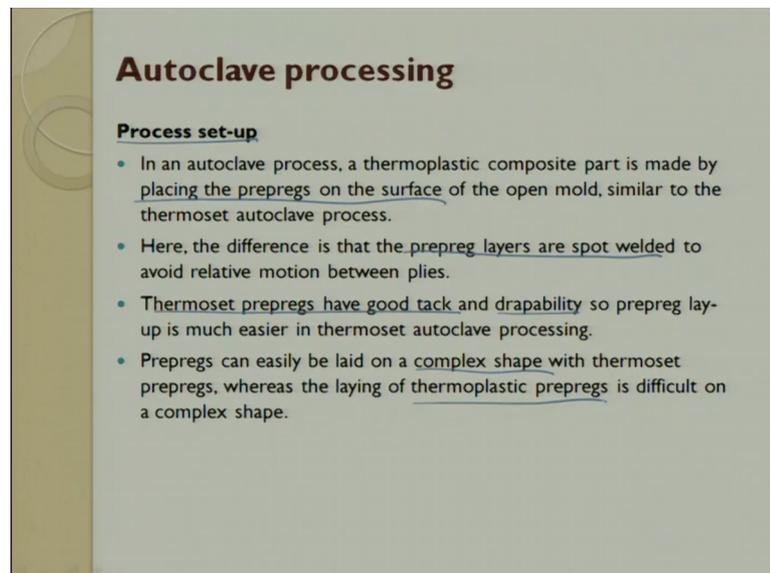
Autoclave processing

Tooling

- Molds for this process are made of stainless steel or aluminum.
- The mold could be a mandrel or any open mold.
- In designing the mold, part shrinkage and mold expansion and contraction are taken into consideration.

Tooling: it is made out of stainless steel, aluminum, composite, wood anything you can have. It is an open mold process, because the other side, the second half wherein which you are left free open, that you put a vacuum bag and that is consolidated through an autoclave, so you get a better consolidation.

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Autoclave processing

Process set-up

- In an autoclave process, a thermoplastic composite part is made by placing the prepregs on the surface of the open mold, similar to the thermoset autoclave process.
- Here, the difference is that the prepreg layers are spot welded to avoid relative motion between plies.
- Thermoset prepregs have good tack and drapability so prepreg lay-up is much easier in thermoset autoclave processing.
- Prepregs can easily be laid on a complex shape with thermoset prepregs, whereas the laying of thermoplastic prepregs is difficult on a complex shape.

The processing steps: are the part is made is placed on the prepreg on a surface in an open die. The difference is that, the prepreg layers are spot welded here, as compared to that of thermoset. The thermoset has good tack and drapability; that means, to say it can wrap

over any sharp edge and sharp consolidations, here it is slightly difficult. The complex shapes which can be made very easily with thermosets and here since the material cannot flow so easily over the sharp edges. So, sharp edge consolidation and complex shapes consolidation is not possible while using thermoplastic prepregs.

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Autoclave processing

Process set-up

- Before placing the thermoplastic tape, a release agent is applied to the mold surface for easy removal of the molded part.
- Once the prepreg layers are laid in the desired sequence, the entire assembly is vacuum bagged similar to the thermoset autoclave process.
- Vacuum bagging helps in removing the air from interfaces.

So, the thermoplastic tapes are releasing agent is applied at the mold surface, so that, it can be moved, all other things are especially same. The vacuum bag helps in removing the air, which are getting trapped at the interface, so you get a better consolidation.

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Autoclave processing

5-6 atmospheres pressure

To Vacuum Pump

Autoclave

Components

Simple

Complex

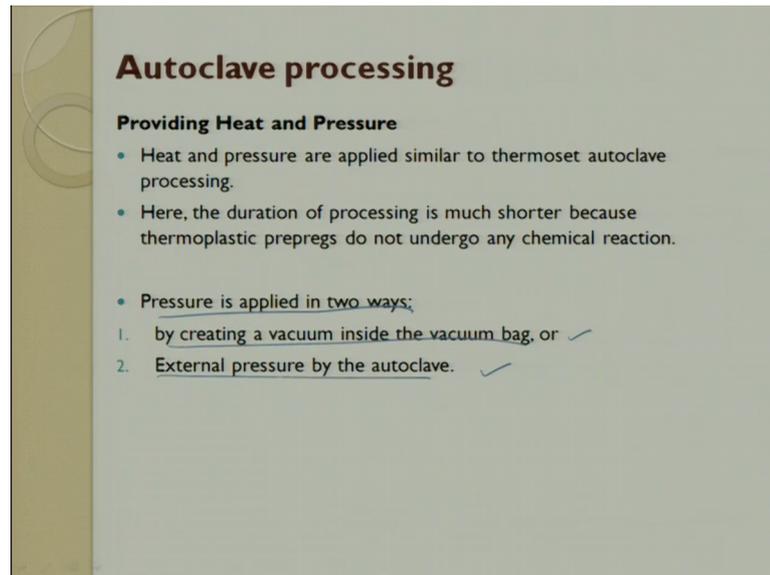
Single use

Double use

<http://www.ecc-fabrics.com/products/thermoplastic-prepreg.html>

It is almost the same, the pressures are slightly higher and then you have a vacuum pump to suck and here is your composite. And again, here you can have 2 types one is simple you can have, you can also have complex and in complex also if you are smart enough you can have single curvature, you can also have double curvature, to get the required output.

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Autoclave processing

Providing Heat and Pressure

- Heat and pressure are applied similar to thermoset autoclave processing.
- Here, the duration of processing is much shorter because thermoplastic prepregs do not undergo any chemical reaction.
- Pressure is applied in two ways:
 1. by creating a vacuum inside the vacuum bag, or ✓
 2. External pressure by the autoclave. ✓

So, heat apply; it is the same way, the heat and pressures are applied here. But, here the heat and pressures are not continuously applied, the heat and pressures are applied only for a short duration. In thermo sets you always apply for a longer time, so that, you get some chemical reaction, here you do not.

The pressure is applied in 2 ways; by creating a vacuum inside the vacuum bag and then applying external pressure. So, 2 ways it is done, both ways are used for getting consolidated output. A vacuum bag is used by creating a vacuum inside the vacuum bag and then external pressure by the auto clave.

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Autoclave processing

Providing Heat and Pressure

The pressure serves two functions.

1. It removes air from the interface and creates intimate contact.
2. It also helps in the flow of resin material during consolidation.

- The resin flow fills up irregular spaces at the interface.
- Resin flow occurs once the temperature of the thermoplastic nears its melt temperature.

T_g , T_m

The pressure serves 2 functions: one; it tries to remove the air from the interface and creates an intimate contact, two; it helps in flow of the resin. So, for these 2 we always try to apply pressure. The resin, if it does not flow properly, it tries to create an interfacial problem and then there will be a lot of defects which are there. In order to avoid this, we always try to apply pressure along with heat, so that, we get the proper consolidation.

So, the resin flow occurs once the temperature of the thermoplast is very close to that of their melting point. T_g is different; T_m is different melting point.

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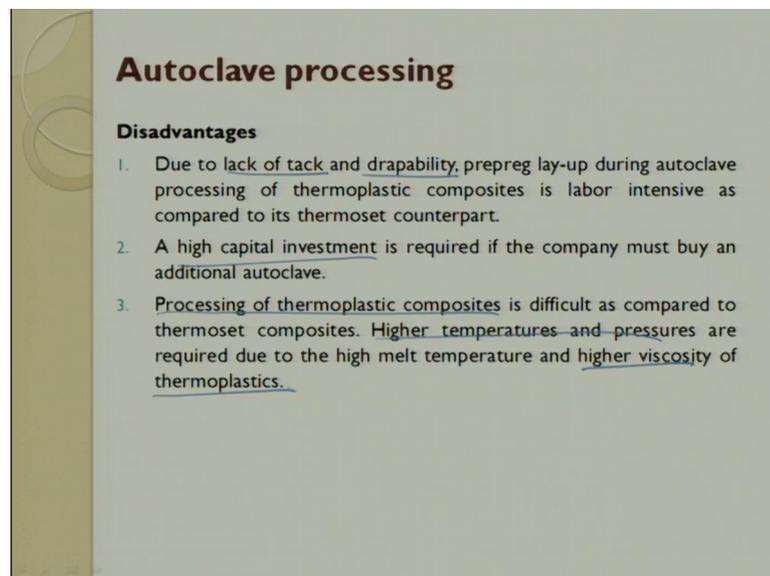
Autoclave processing

Advantages

1. It provides fabrication of structural composite components with a high fiber volume fraction.
2. It allows production of any fiber orientation.
3. It is simple and is basically a replicate of autoclave processing of thermoset composites. The same autoclave equipment as in thermoset processing is used for thermoplastic autoclave processing.
Equipment for thermoplastic filament winding and pultrusion is different than for its thermoset counterpart.
5. It is suitable for making prototype parts.
6. The tool design is simple for autoclave processing nears its melt temperature.

Advantages: it is used for structural applications. The fiber orientations you can decide here and then it tries to replicate the autoclave process of thermoset, whatever can be made there, can be made here. So, here large components can be made. The thermoplastic filament winding and pultrusion components, whatever is made, can also be further consolidated to get a good output through this. It is used for making very small prototypes also. This is the only process in thermoplastic, which gives you this freedom, for making prototypes and the all other thing, process parameters, tooling, everything is very close to that of the thermoplastic thermoset resin as well as this process is concerned.

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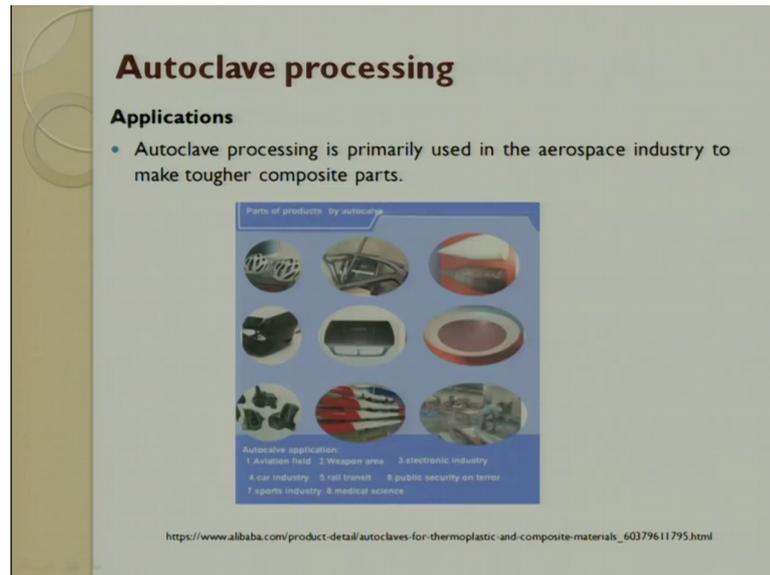
Autoclave processing

Disadvantages

1. Due to lack of tack and drapability, prepreg lay-up during autoclave processing of thermoplastic composites is labor intensive as compared to its thermoset counterpart.
2. A high capital investment is required if the company must buy an additional autoclave.
3. Processing of thermoplastic composites is difficult as compared to thermoset composites. Higher temperatures and pressures are required due to the high melt temperature and higher viscosity of thermoplastics.

So, here as I have told lack of tack and drapability is there. High capital investment; and the processing of thermoplastic is slightly difficult to that of your thermoset. Higher temperature and higher pressures are involved and there is a component of viscosity which plays a very important role while trying to wet this fiber.

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Some of the applications of these parts: it can be used in aviation industry, it can be used in defense, it can be used in electronic industry, car industry, trains; today rail transmission is also made, public security, sports and medical. Sports, lot of things are getting, lot of sports items are getting made out of thermoplast. So, this makes the product lighter and lighter and on top of it is also making it tougher and tougher.

So, wherever you want to have a compromise, people are using this. Thermoplastic composites are finding lot of applications today in sports. For example; tennis bats or racket, the tennis bat base, racket is made out of thermoplast composites and then which is reinforced with carbon fiber. So, it is very light, it gives you a huge strength; very light and when you try to play, you do not get into fatigue. The same way helmets are made out of it here and then the dive boats are made out it, skiing boards are made out of it which was earlier made out of wood, now, it is made out of these applications and for medical field also several applications are used of thermoplastic composites are getting used.

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Autoclave processing → Consolidation
 V_f 30% ~ 50% → TP

Applications

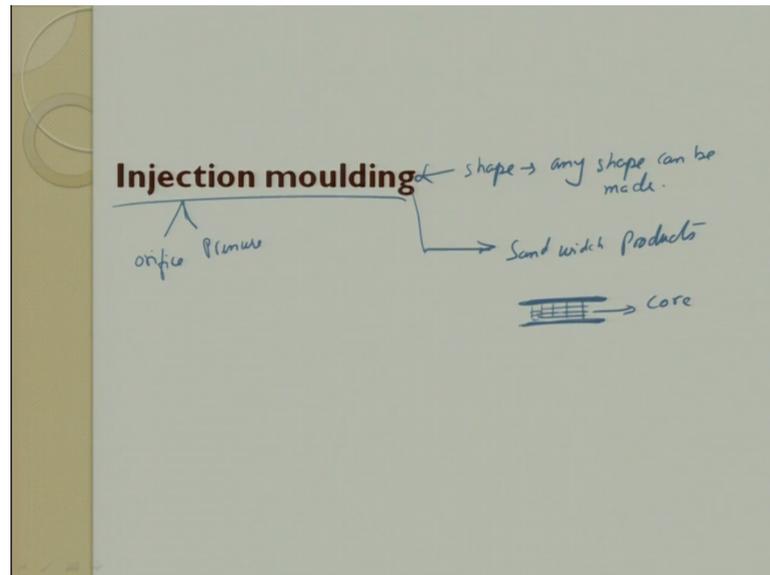
- FRE Composites (St. Andre, Quebec, Canada) has made robot arms for the international space station using this technique.
 - Robot arms were about 18 in. in diameter and 72 in. long. Carbon/PEEK composites were laid on a mandrel at the desired orientation.
 - Prepregs were spot welded to lay the prepregs on top of each other until a suitable thickness was developed and then vacuum bagged.
 - The entire assembly was then processed inside an autoclave.

TP + Composites → Under water / marine

So, robot arms are been made because for several applications. Another interesting application where thermoplastic composites are getting used is, under water or marine applications. Lighter and lighter floating boards, floating bodies are made, such that they can meet the requirements and second thing is, in under water as well as in marine, there is a tidal force, which is a random in nature and it is very difficult to control. There also thermoplastic composites are coming up in a big way. So, here the robot arms of 18 inch diameter and 72 inch long Carbon PEEK composites are made of required orientation and then final consolidation they have been made through, tape casting process and then they have tape winding process and then they have come to auto clamp process to get consolidation. The prepregs are spot welded, so that, they do not move and then the entire process is done in auto clamp. So, auto clamp is the other big process. Auto clamp process, you can put it in this way, it is used for better consolidation.

So, this consolidation helps us to push the volume fraction from 30 percent, now, we have gone up to 50 percent in thermoplastic, which is a big challenge and then it is used for only consolidation. So, autoclave is not a basic process, wherein which you try to make the shape. Rest all things, is like you can make it through compression moulding, you can make it through tape wrap process, you can make it through pultrusion process and come here for better consolidation. So, you can do it.

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So, the last process for discussion as far as thermoplastic composites is, injection moulding process. Injection itself says, it has to be an orifice, wherein which through this orifice, I tried to pressurize the liquid or the polymer to get the required shape, so, the shape is given by the mold, that gives the shape. Any shape can be made and interestingly, you can also make sandwich products, wherein which you have thermoplastic of glass fiber, thermoplastic of glass fiber and in between you can have a core which is of a different material, you can try to make it. So, people when they try to make something like ib menology, you can also make this to get the required output.

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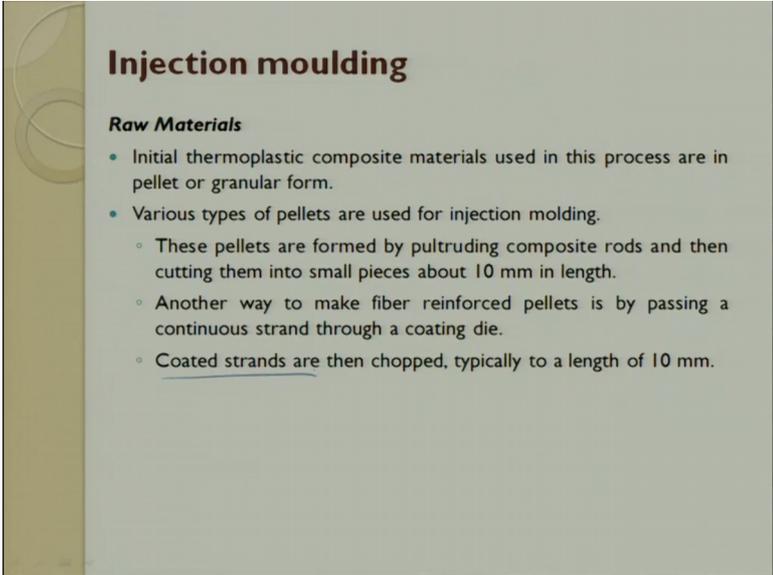
Injection moulding

- Injection moulding is a very common processing method used to form different- shaped products with thermoplastics.
- The same method can also be used to form thermoplastic composites with short fibers, but the incorporation of fiber will increase the melt viscosity.
- Another method has been developed to overcome the problem of high melt viscosity and the method is called as reinforced reaction injection molding (RRIM).
- Actually this is an extension of reaction injection molding (RIM) of polymers.
- In RIM, two liquid precursors of the polymer are pumped at high speed and pressure into a mixing head and then into a mold where the two components react and polymerize rapidly.

Injection moulding process is a very common process which is used, as far as thermoplastic is concerned. You can use the short fibers and these short fibers, what we do is, we try to blend them with thermoplastic, so, when the sharp fibers are impregnated or incorporated, it increases the melt viscosity; so that means to say, the viscosity is going to go high. So, if the viscosity is going to go high, then you are supposed to give in more pressure for injection.

So, the other method which was developed to overcome this very high pressuring is, very high viscosity, is the method of reinforcing reaction injection moulding. Here, the reinforcement will be reacted and it is generated during the injection moulding process. The other extension for this reaction injection moulding which is called, as a RIM. In RIM process, basically, what happens is, I tried to take 2 different precursors made out of polymer and they are pumped at very high speeds and very high pressure, in fact, queue and then it is mixed in a head and then it is molded, so, wherein which, these 2 components react, polymerize and give me the required output. So, those process is called has RIM process which is reaction injection moulding process.

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Injection moulding

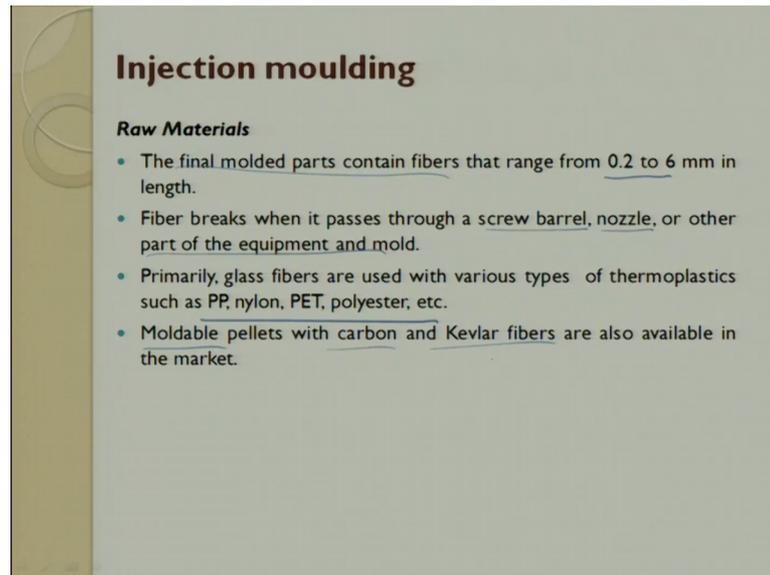
Raw Materials

- Initial thermoplastic composite materials used in this process are in pellet or granular form.
- Various types of pellets are used for injection molding.
 - These pellets are formed by pultruding composite rods and then cutting them into small pieces about 10 mm in length.
 - Another way to make fiber reinforced pellets is by passing a continuous strand through a coating die.
 - Coated strands are then chopped, typically to a length of 10 mm.

So, here, the raw material in injection moulding process will always be a pellet. The pellet can be thermoplastic, thermoplastic with glass fiber reinforced, thermoplastic with whisker reinforced, thermoplastic with ceramic also. Depending upon the requirements you can choose the pellet. So, these pellets are basically extruded and then they are cut

into small pieces, so that, you get small button like structures. These pellets are put inside the injection moulding machine, so, the pellets or the granular, is the shape which we have and then we try to get this. They also can be coated strands that are chopped, typically of a required length of 10 millimeter length, so that, you get the required output.

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Injection moulding

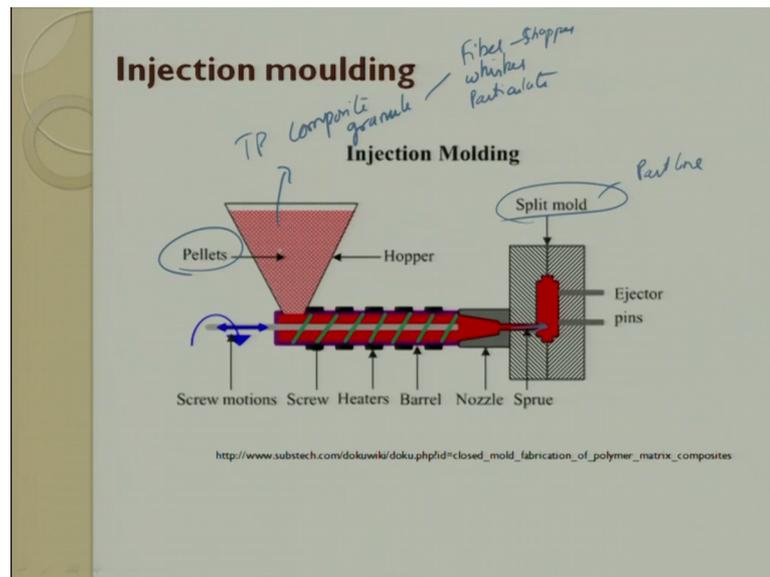
Raw Materials

- The final molded parts contain fibers that range from 0.2 to 6 mm in length.
- Fiber breaks when it passes through a screw barrel, nozzle, or other part of the equipment and mold.
- Primarily, glass fibers are used with various types of thermoplastics such as PP, nylon, PET, polyester, etc.
- Moldable pellets with carbon and Kevlar fibers are also available in the market.

The pellets are made and then when the pellets are made, these pellets are asked to pass through a barrel and in this barrel you try to apply high pressure, high temperature and then you try to, the other end of the barrel is attached to a nozzle and through this nozzle very high pressure, you try to inject it inside a die and in that die the part gets consolidated to make a required output.

So, that is what is entire process. The final mold part contains a fiber that can range from this to this and then the fibers when it passes through different parts of the injection moulding process, can get broken down. So, it is always advisable to use small reinforcement to it. The general matrix which are used is poly propylene, nylon, PET, polyester etcetera and the pellets are made out of carbon, Kevlar, glass as well as ceramic.

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Tooling: let me explain the machine first and then come here. So, this is the pellet, this is a hopper, here, you put the thermoplastic composite granule, are put inside this. This granules can be a fiber, chopped, whisker or a particulate and then what happens is, this is allowed to move inside a barrel. In this barrel, you have heaters, this heaters heat the barrel and then the pellets which fall down, has to be slowly moved towards the other end of the nozzles, such that, it gets injected into the die. So, what happens is, there is a screw, this screw keeps rotating and this screw has a interesting geometry. It has a taper and this taper is inverse taper, the gap keeps on reducing as and when it moves towards the other end.

So, what happens is, at the initial there will be huge amount of gaps, lot of pellets fall in this and then it gets it this screw moves rotates and so, the feed also moves forward. So, there is a inverse taper, as and when, the space is less, there is friction between the pellets which is moving and there is heat which is getting applied. This tries to increase the temperature and because of the increase in temperature, they go to a visco-elastic state and then through that visco-elastic state we try to inject it in through the nozzle to the die and then we try to get the shape whatever you want.

The die design is a big challenge. The splitting of die, which leads to parting line, this parting line has to be found out and then we try to decide the die to get the required output. Once the part is made, then we use the ejector pin, to eject the component out, to

get the required output. So, this is the complete injection moulding process. Here, the thermoplast is made into pellets; these pellets are used to make the required product.

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Injection moulding

Tooling

- Steel molds with single or multiple cavities are used to make injection molded parts.
- Air-hardened tool steels are generally chosen in order to maximize the life and performance of the mold.
- A mold made with tool steel typically costs 5 to 10% more than steel tool but it is important to buy quality material to increase the life of the mold.
- Multiple-cavity molds are used to increase the production rate of thermoplastics such as PP, nylon, PET, polyester, etc.
- Moldable pellets with carbon and Kevlar fibers are also available in the market.

So, here, a steel mold with single or multiple cavities, what we saw is only one cavity, you can have multiple cavities, with the injection moulding you can get the required one. The steel are always chosen to, such that, they have lot amount of fatigue resistance. The mold with tool steel is typically 5 to 10 percent more costlier than steel. So, we always make multiple cavity molds can increase the production, you can also have single, you can also have multiple, single means large part. Multiple means surface to area, surface is large and area is small. So, this is large, so you make multiple components. For example, spoon, plate all these things. You also use this pellets, which I have already discussed.

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Injection moulding

Process set-up

- Most injection molding machines have a reciprocating screw-type barrel that transports pellets through heating stages before the material is injected.
- Other systems use a plunger (called a torpedo) that forces the stock around a heated mandrel.
- The cylinder temperature increases to the melt temperature of the resin as the material flows toward the nozzle.
- The purpose of heating the cylinder that surrounds the barrel is to transform the solid pellets into a viscous liquid or melt that can be forced through the connecting nozzle, sprue, and runners to the gates that lead into the mold cavities.



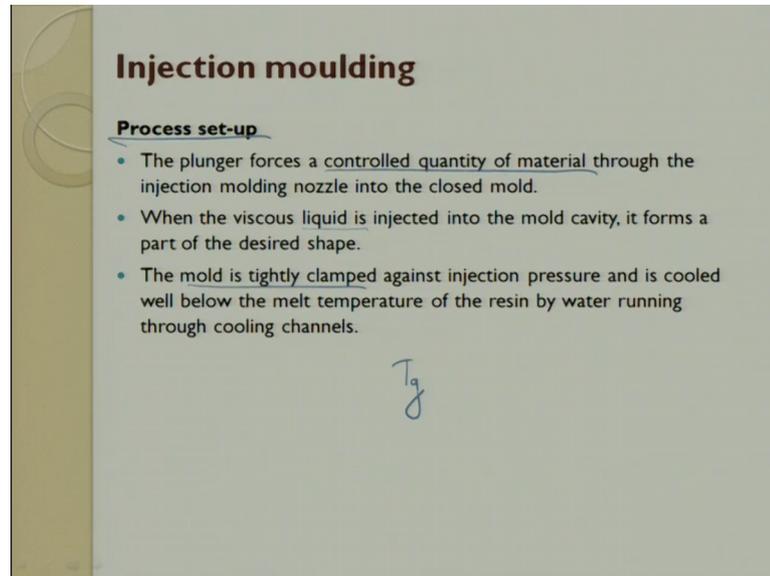
Injection moulding machine there are 2 types you can have reciprocating type or you can also have a reciprocating screw type. So, reciprocating screw type barrel is one we discussed here. Here, there is a screw, which keeps rotating and keeps moving, so that, you can try to move the material from one extreme end to the other extreme end and then it gets injected.

So, the other way round is, you can directly use reciprocating plunger, you fill all the ingredients, the charge material and then you just push it inside, those things are called as plunger base material. It is one short process. The entire stock which is there, is consolidated, pushed, into the die and you get the output, but whereas in injection moulding, it is continuous, you can keep going. The cylinder temperature is increased to melt the raw material and as and when it moves towards the nozzle.

So, the purpose of heating the cylinder is to transform the solid into a viscous elastic liquid and then force them through the nozzle, sprue, runner and through the gate, that leads to a mold cavity, so that, you get the better output. The sprue, runner, gate all these thing are, say for example; basically you have a nozzle and then this nozzle if you directly inject, it will try to restrict the flow. So, what we do is, we try to reduce the flow in multiple ways and so that, we get a better consolidation and curing. So, those things are done by this sprue, runner, gate and then you get the final components. This is the component; this is how it is linked. If you study injection moulding in detail, you will

understand the need for sprue, runner and other things. Basically, sprue, runner and the gate are used for pushing the thermoplast resin along with the reinforcement, inside the die, in a very controlled fashion and it also tries to allow you to solidify much faster.

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Injection moulding

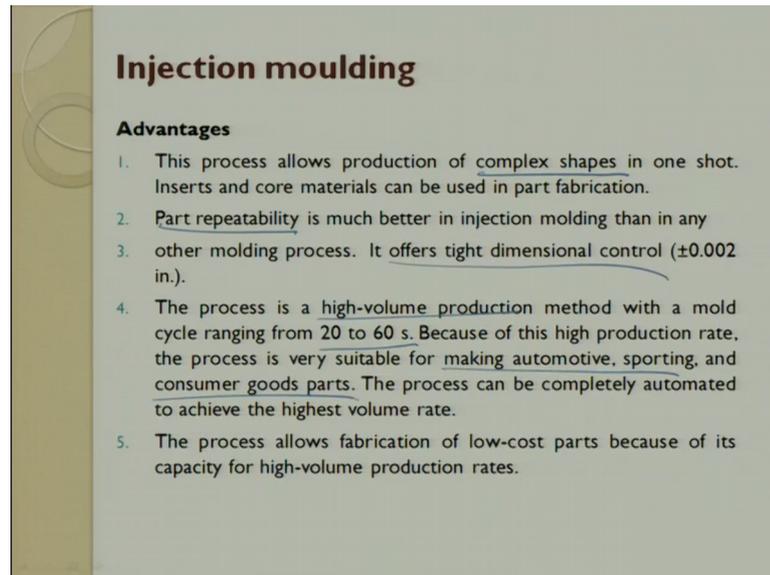
Process set-up

- The plunger forces a controlled quantity of material through the injection molding nozzle into the closed mold.
- When the viscous liquid is injected into the mold cavity, it forms a part of the desired shape.
- The mold is tightly clamped against injection pressure and is cooled well below the melt temperature of the resin by water running through cooling channels.

T_g

The processing set up: the plunger forces a controlled quantity of the material through the nozzle die into the closed die, so the visco-elastic liquid is injected into the cavity and allowed to cure. The mold is held tight and then it is held for some time, such that the temperature comes to T_g state and then you start consolidating and releasing the component. This we have dealt it in detail.

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Injection moulding

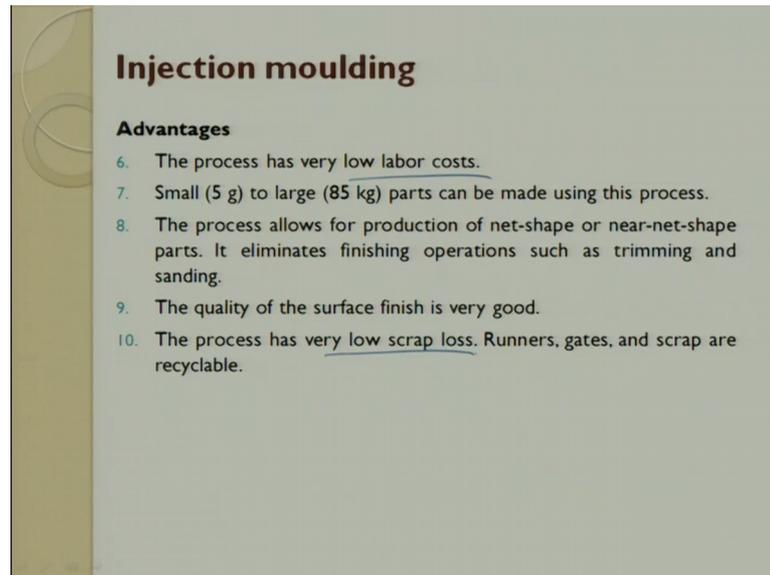
Advantages

1. This process allows production of complex shapes in one shot. Inserts and core materials can be used in part fabrication.
2. Part repeatability is much better in injection molding than in any
3. other molding process. It offers tight dimensional control (± 0.002 in.).
4. The process is a high-volume production method with a mold cycle ranging from 20 to 60 s. Because of this high production rate, the process is very suitable for making automotive, sporting, and consumer goods parts. The process can be completely automated to achieve the highest volume rate.
5. The process allows fabrication of low-cost parts because of its capacity for high-volume production rates.

What are the advantages of this process: the advantages of this processes is, any complex shapes can be made, it is a one short process. This process, it has a very good repeatability, all the injection molded components, plastic components, all those components can be made through this, using the pellets, wherein which you have reinforced with some glass fiber or carbon fiber or Kevlar fiber. So, the process is the same.

The dimension accuracies can be high; it is very high volume production. It happens 20 to 60 seconds is the processing cycle time. It can be used in any of the applications. A huge application industries are now focusing on it.

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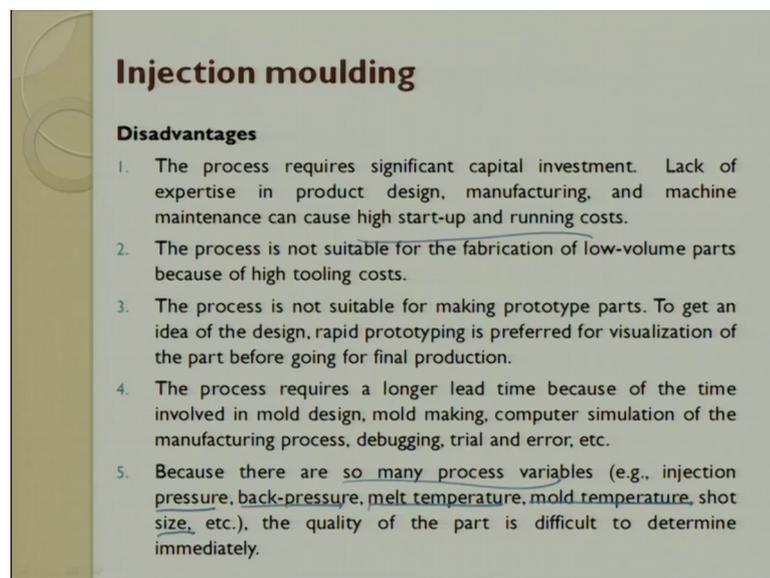
Injection moulding

Advantages

6. The process has very low labor costs.
7. Small (5 g) to large (85 kg) parts can be made using this process.
8. The process allows for production of net-shape or near-net-shape parts. It eliminates finishing operations such as trimming and sanding.
9. The quality of the surface finish is very good.
10. The process has very low scrap loss. Runners, gates, and scrap are recyclable.

So, it is low labor cost and whatever is the scrap, is reused. So, that you try to get a required, so that, you try to recycle the part.

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Injection moulding

Disadvantages

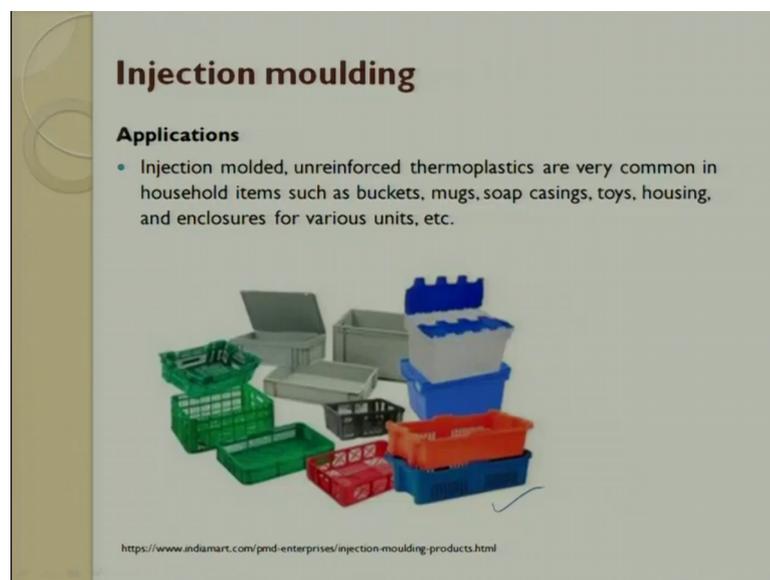
1. The process requires significant capital investment. Lack of expertise in product design, manufacturing, and machine maintenance can cause high start-up and running costs.
2. The process is not suitable for the fabrication of low-volume parts because of high tooling costs.
3. The process is not suitable for making prototype parts. To get an idea of the design, rapid prototyping is preferred for visualization of the part before going for final production.
4. The process requires a longer lead time because of the time involved in mold design, mold making, computer simulation of the manufacturing process, debugging, trial and error, etc.
5. Because there are so many process variables (e.g., injection pressure, back-pressure, melt temperature, mold temperature, shot size, etc.), the quality of the part is difficult to determine immediately.

The disadvantages are yes, it needs to have a huge running cost is one and suppose you want to make only 25 parts, small prototypes cannot be made, because the barrel length is too high and it is not good for small volume production and it needs to have a die and die designing is very difficult and on top of it, there are some process variables, like injection pressure, back pressure which gets built, melting temperature, mold

temperature, shot size, all these things have to be optimized to get the required quality output.

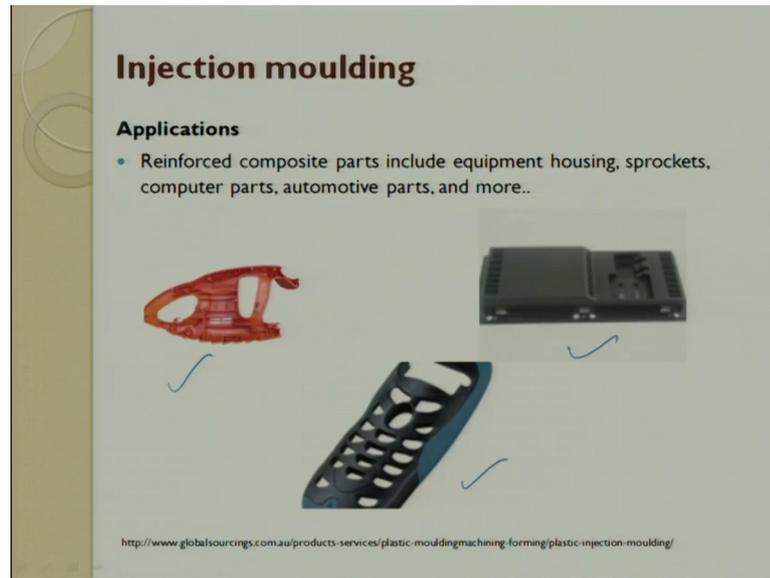
So, back pressure is, see you are trying to inject it and if there is a resistance which is given because of the air gap or something, that is the back pressure which is there, that also has to be balanced to get the required output. These are some of the components which are made out of it for several applications. So, today all these things are now started getting into structural applications.

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So, every structure, what we make it though, here whatever we have displayed is thermoplastic components, but in reality what is happening is, all these things are now converted into reinforced parts which are using for structural applications.

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So, these are some of the parts which are used for sockets, equipments and it has now got into the entertainment industry also, we are trying to make much lighter parts.

So, with this we come to an end to the different processes, which are made under thermoplastic composites fabrication.

Thank you very much.