Advanced Manufacturing Processes
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Module - 2
Advanced Metal Casting Processes
Lecture - 6
Ceramic Shell Investment Casting Process

Welcome to this session on ceramic shell molded investment casting under the course on advanced manufacturing processes. This is in continuation with the other lectures previously delivered on at other advanced casting processes. In this session, we will study about the ceramic shell investment casting processes.

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In this process a near net shape product can be produced. This is very widely used technique now a days.

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The process is based on expandable wax pattern for producing joint less moulds that are required for near net shape castings. Before we start discussion on the ceramic shell investment casting process, it is desirable to understand in brief, the sequence and differences of this process from investment casting process which we have discussed in the earlier session.

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Now, let us see the difference between investment casting process and the ceramic shell investment casting. The main difference between the investment casting processes and the ceramic shell investment casting is that, in the former process prior to the waxing the wax pattern it is immersed in a refractory aggregate.

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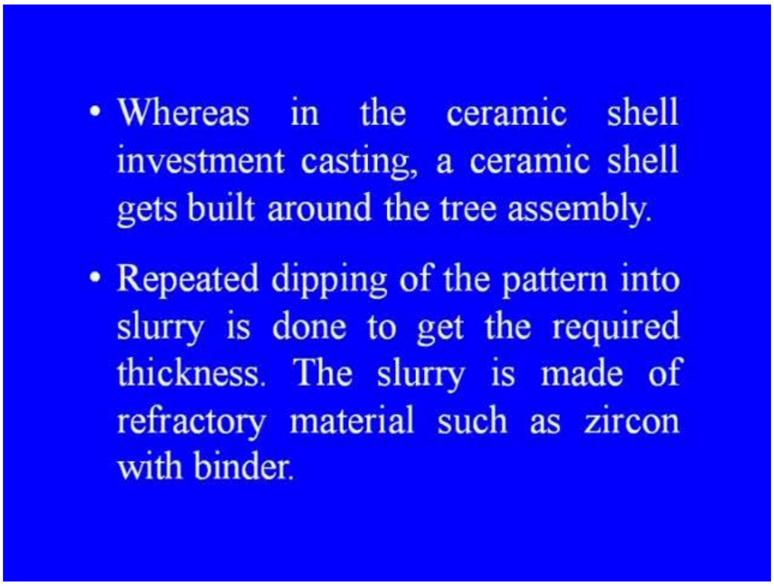

Whereas, in the ceramic shell investment casting a ceramic shell gets built around a three assembly. Repeated dipping of the pattern into slurry is done to get the required thickness the slurry is made of refractory material such as zircon with binder. After getting the required thickness of cross section, the three assembly is de-waxed the shell obtained is further immersed in a refractory coating and the metal is poured into it. In this processes a wax pattern or a assembly is first dipped in to a ceramic slurry, but for its primary coating.

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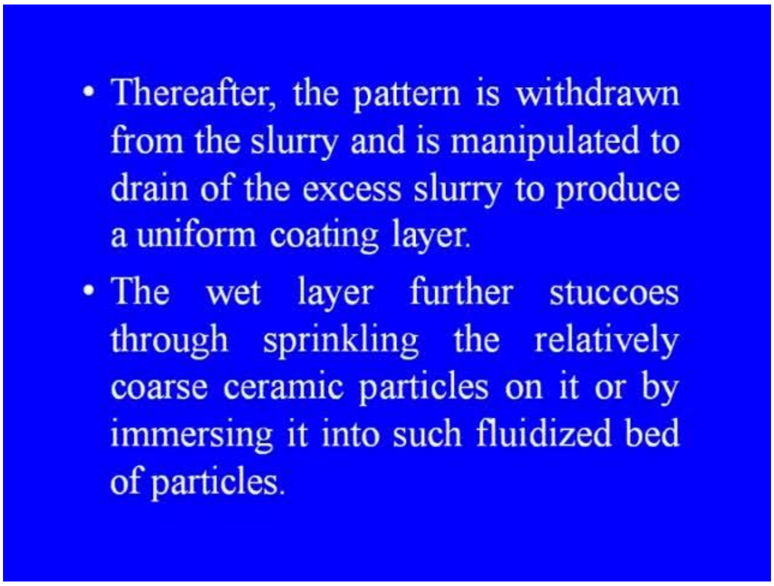

Thereafter, the pattern is withdrawn from the slurry and is manipulated to drain of the excess slurry to produce a uniform coating layer. The wet layer further stuccoes through sprinkling the relatively coarse ceramic particles on it or by immersing it into such fluidized bed of particles. The ceramic coating is built by successive dipping and stuccoing process this procedure is further repeated till the desired shell thickness is obtained up. On completion, the entire assembly is placed into an autoclave or flash fire furnace at a high temperature.

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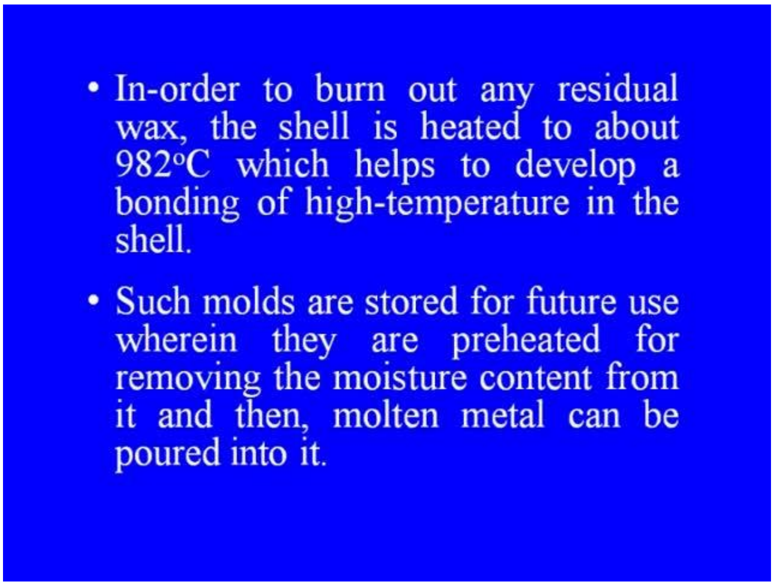

In order to burn out any residual wax the shell is heated to about 920 sorry, 982 degree celsius, which helps to develop a bounding of high temperature in the shell. Such moulds are stored for future use wherein they are preheated for removing the moisture from it and then molten metal can be poured into it. Now, let us see the process sequence in ceramic shell investment casting the process sequence of ceramic shell investment casting is given in the figure one.

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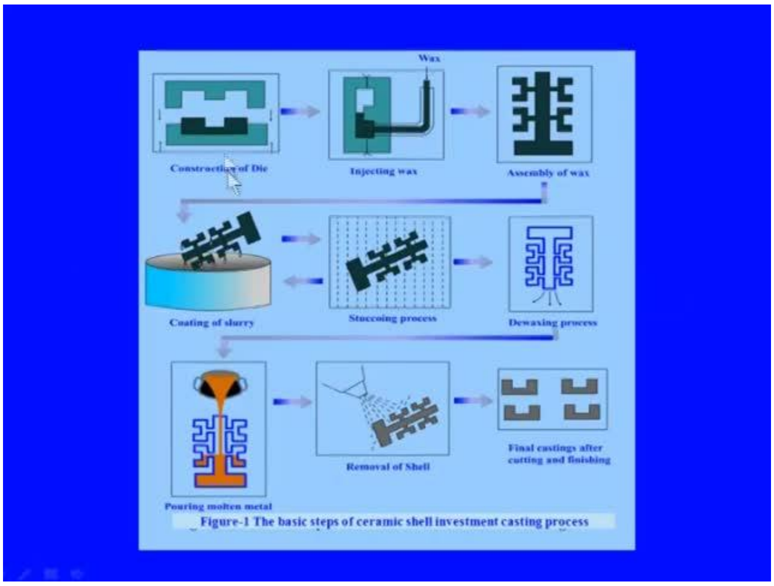

In this processes, the first step is the construction of die, which is followed by injection of the wax through through a system like this. Then the assembly of the wax are created like this, which is then dipped into a slurry for the coating. Then it undergoes this stuccoing process and depending on the thickness of the coating required it is dipped in the slurry for several times. Then it is taken for de-waxing process, where the wax is removed. Now, the moulds is ready for the pouring, where the molten material is poured like this. This is followed by the shell removal process finally gives the products like this this steps involve. Manufacturing of the master pattern of wax through the master dies.

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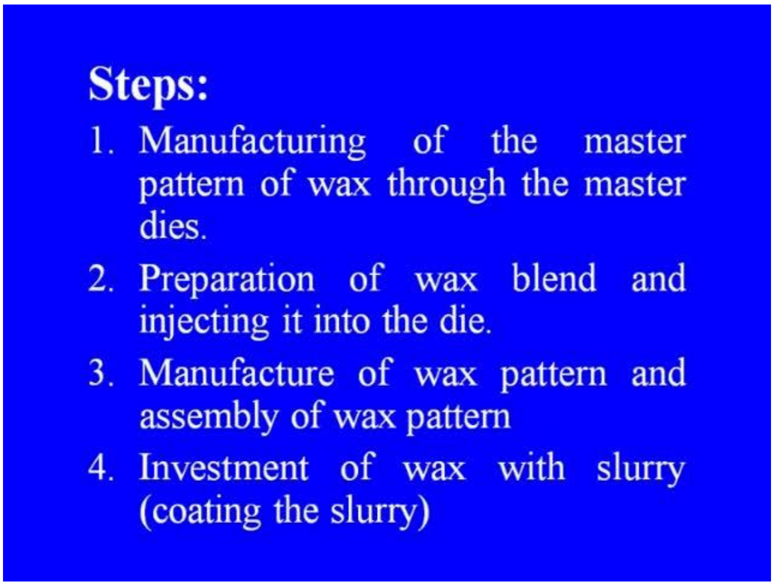

Then preparation of the wax blend and injecting it into the die. In the third step, the wax pattern is manufacture and assembled. It is followed by investment of wax with slurry that is also known as coating. The slurry, which is followed by drying of shell thickness also called stuccoing processes. This is followed by de-waxing of the raw moulds followed by heating and baking of the shells. This is followed by pouring of the moulds with molten metal. Once the metal is solidified, the shells are removed, then cutting of of the gauge and risers are taken place to obtain the finished product.

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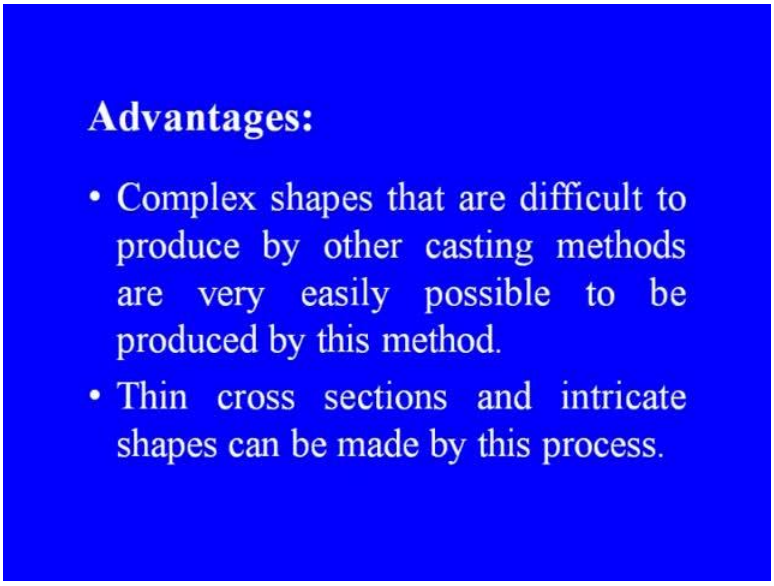

The advantages of the process are, complex shapes that are difficult to produce by other casting methods can easily be manufacture by this method. Thin cross sections and intricate shapes can be made by this process. Then finish machining is considerably reduced or almost eliminated on the castings made by the process, making it economical. The process has no metallurgical limitations; this process produces castings with excellent surface finish. Now, let us see few disadvantages of the process as well.

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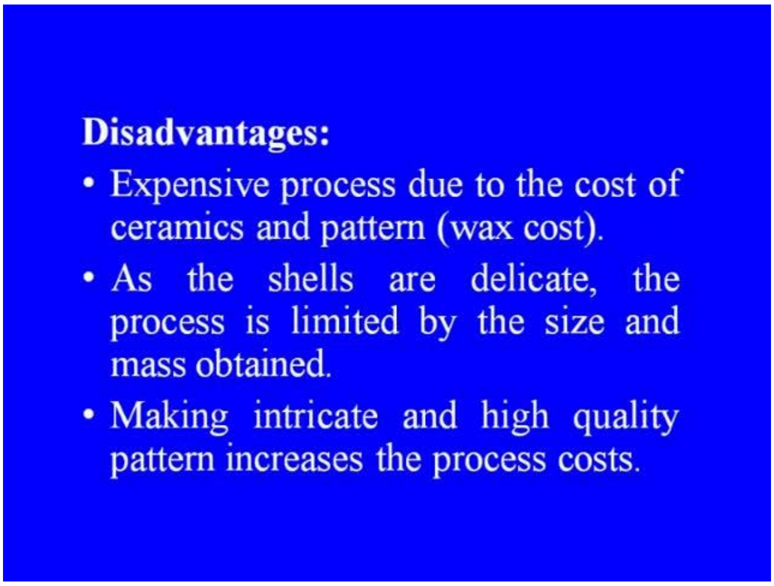

The process is expensive process due to the cost of ceramics and the pattern, which is made of wax. As the shells are delicate, the process is limited by the size and mass obtained. Making intricate and high quality pattern increases the process costs. Let us come to the applications of this process, the process is used for making parts those are used in aircraft.

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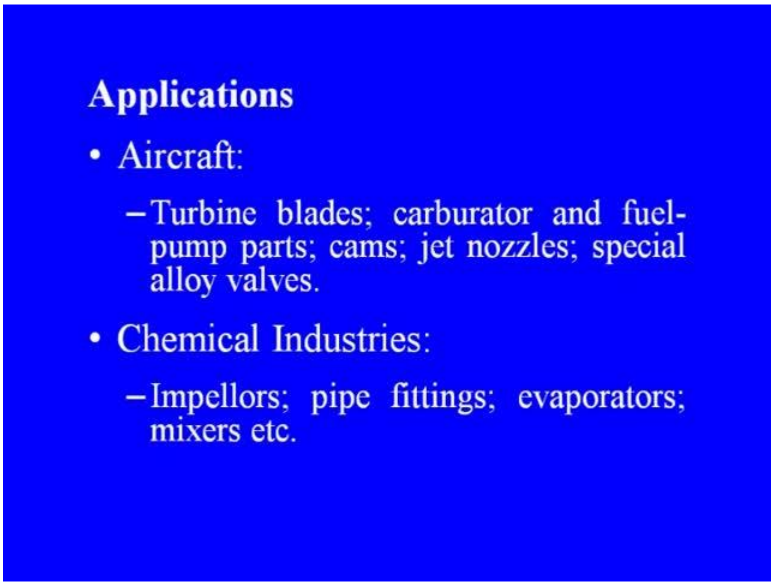

For example, turbine blades, carburetor and fuel pump parts, cams, jet nozzles, special alloy valves etcetera. The parts required in chemical industries are also produced by this process, this include impellors, pipe fittings, evaporators, mixers, etcetera. The parts required in tool and die making are also being produced using this process, which include milling carters.

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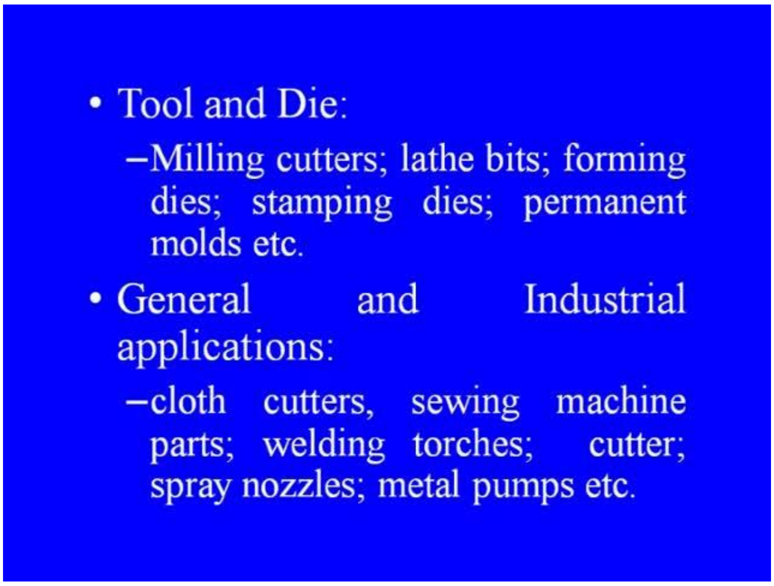

Let beets forming dies, stamping dies permanent moulds etcetera. Some general and industrial applications like, cloth cutters, sewing machine parts, welding torches, cutter spray nozzles, metal pumps etcetera. Now, let us see the types of wax. The pattern material selection is the most important issue in the ceramic shell investment casting also known as CSIC process. The patterns are prepared through injecting wax into the die, which we have already seen in the schematic diagram. The patterns thus made should be factor registered and distortion free such that parts accuracy is maintained the key.

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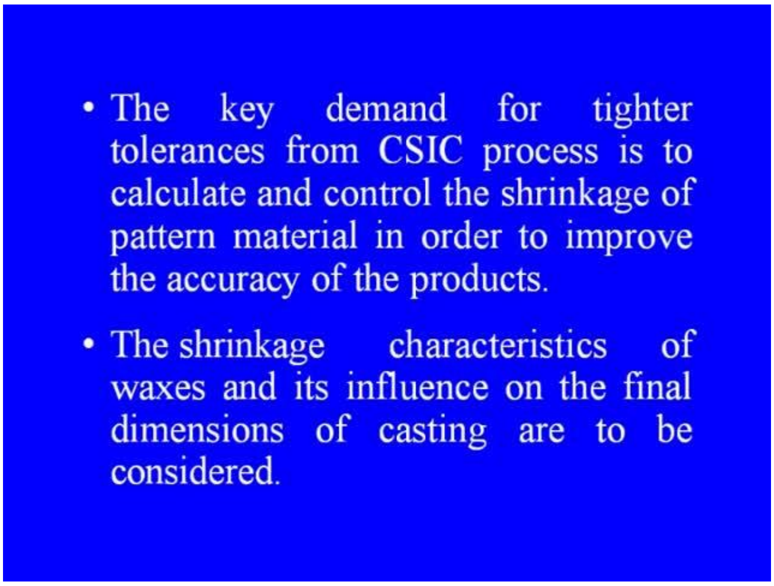

Demand for tighter tolerances from CSIC process is to calculate and control the shrinkage of pattern material. In order to improve the accuracy of the products the shrinkage characteristics of waxes and its influence on the final dimensions of casting are to be considered.

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The wax is of great fundamental importance in getting, high quality castings, minimizing product cost and low scrap rates. Numerous factors can affect the degree to, which contraction in dimension can occur. While taking into account wax pattern accuracies obtained through such patterns from the die types of waxes and wax blend composition.

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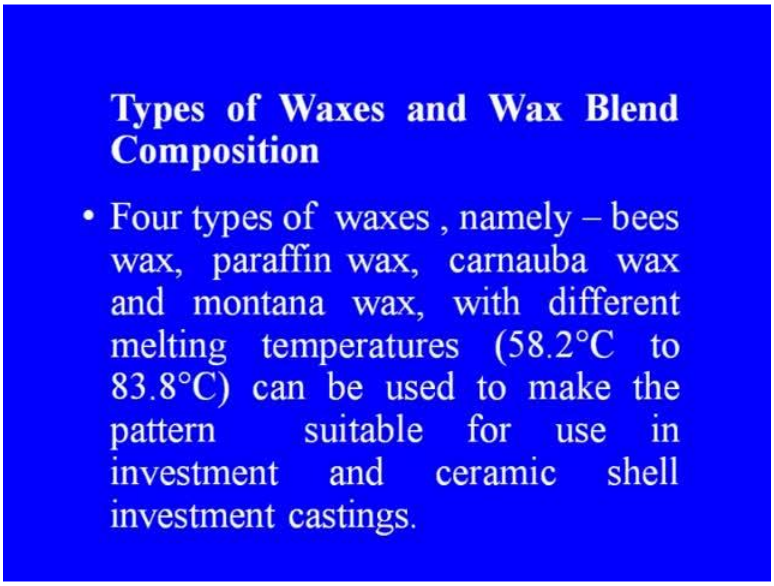

Four type of waxes namely, bees wax, paraffin wax, carnauba wax and montana wax with different melting temperatures ranging from 58.2 degree celsius to 83.8 degree celsius can be used to make the pattern suitable for use. In investment and ceramic shell investment casting the physical properties of various waxes used in this process are given in the table.

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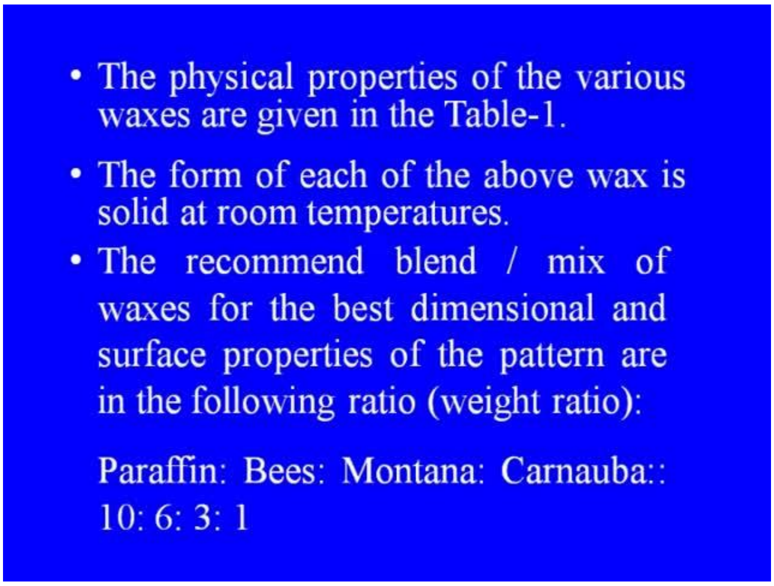

The form of each of the above wax is solid at room temperatures. The recommend blend or mix of waxes for the best dimensional and surface properties of the pattern are in the following ratio, by weight paraffin is the 10 percent, bees wax is 6 percent, montana wax 3 percent and carnauba wax 1 percent, that is paraffin is to bees is to montana is to carnauba is 10 is to 6 is to 3 is to 1 ratio by weight.

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Table -1

Wax	Color	Melting Point (°C)	Density (gm/cc)
Bees Wax	White	58.2	0.97
Paraffin Wax	White	58.5	0.94
Carnauba Wax	Black	81.9	0.99
Montana Wax	Brown	83.8	1.02

This table shows different waxes used in this process. These are mostly widely used waxes. Mainly bees wax, which appearances is white and melting point is 58.2 degree celsius, which gives the density in 0.97 gram per c c cubic centimeter. Then paraffin wax also appears white melting temperature is almost similar to that of bees wax, which is 58.5 degree celsius and density is also in the similar lines, slightly less than the bees wax, this is 0.94 gram per cubic centimeter. Then carnauba wax appears black and which has got much higher melting point in comparison to the previous two waxes bees wax and paraffin wax, this is 81.9 degree celsius and density wise also, it is slightly more that stands at 0.99 gram per centimeter cube.

On the other hand montana wax appears brown in color and the melting point is also the highest among these four classes of wax we have discussed, which strands at 83.8 degree celsius with the highest density of 1.02 gram per c c. Now, let us look in to the process parameters, that effects the quality of wax pattern. Like the earlier cases, to identify the process parameters, let us draw one ishikawa cause and effect diagram as show in figure two.

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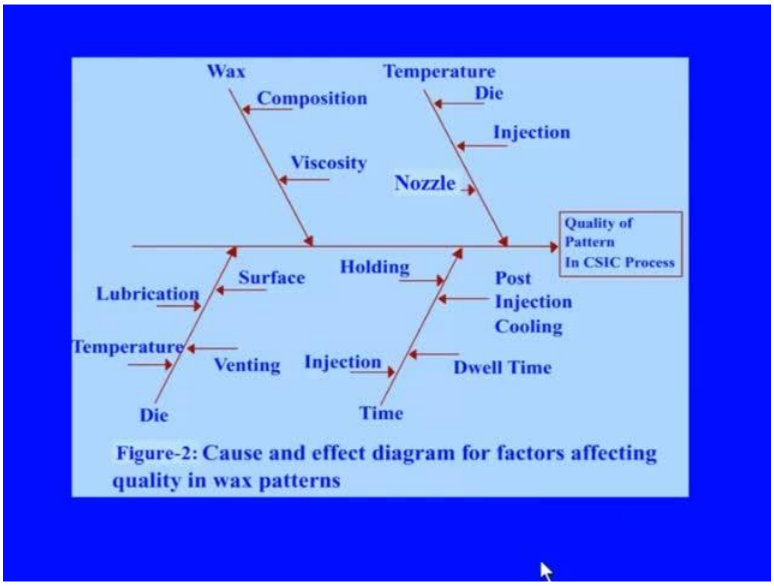

This is the cause and effect diagram given after the name of ishikawa in which there are four main categories of parameter. These are wax based temperature, based die based and time based in wax based. Parameters composition of the wax and viscosity are the most important parameters, that effects the ultimate product quality. Then as we have already spoken, temperature is one of the major parameters that should be maintained properly here. Temperatures of the die temperatures during the injection, that is of the material and the temperature of nozzle that can affect the product quality coming to the die die temperature.

As I I have already indicated, in case of temperature based parameters, then lubrication of the die that affects, then the surface of the die which can affect the surface of the mould. Finally, the cast product and then venting of the die, which is responsible for escaping the gases. Then other parameters, time base parameters are very important. Parameter is injection time, then holding time of course, then post injection cooling and dwell time. These are the most important parameters that influences the quality of a product obtained by this CSIC process. This diagram depicts that the parameters are quality based parameters, which affects dimensional accuracy surface roughness mechanical and metallurgical properties.

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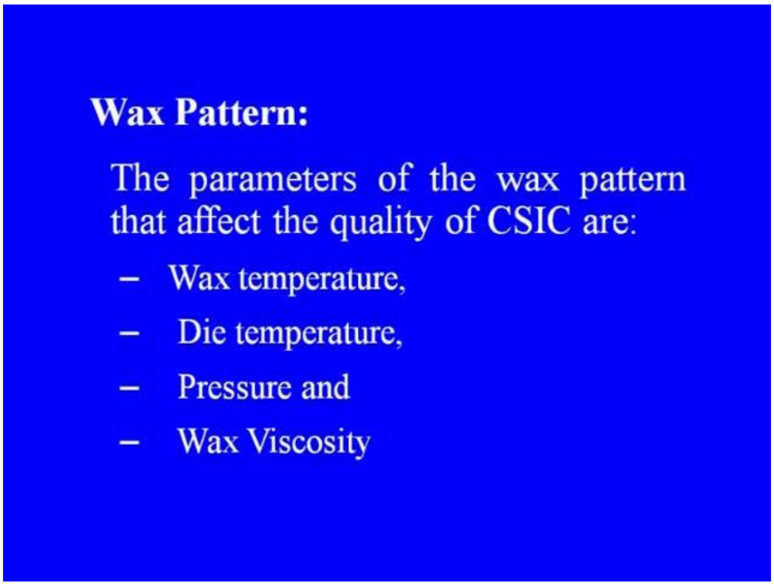

The wax patterns, the parameters of the wax pattern, that affect the quality of ceramic shell investment casting are wax temperature, die temperature, pressures and wax viscosity. Of course, then stucco based parameters, that are the type composition size and size distribution.

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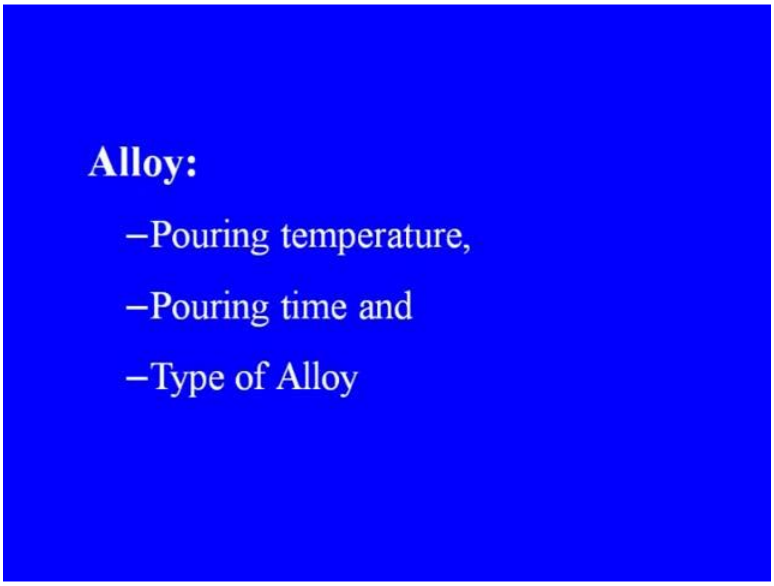

Then alloy, parameters that is pouring temperature pouring time and type of alloy. Then regarding ceramic slurry pH value of the slurry, density of the slurry and viscosity of the slurry are the parameters of major interest.

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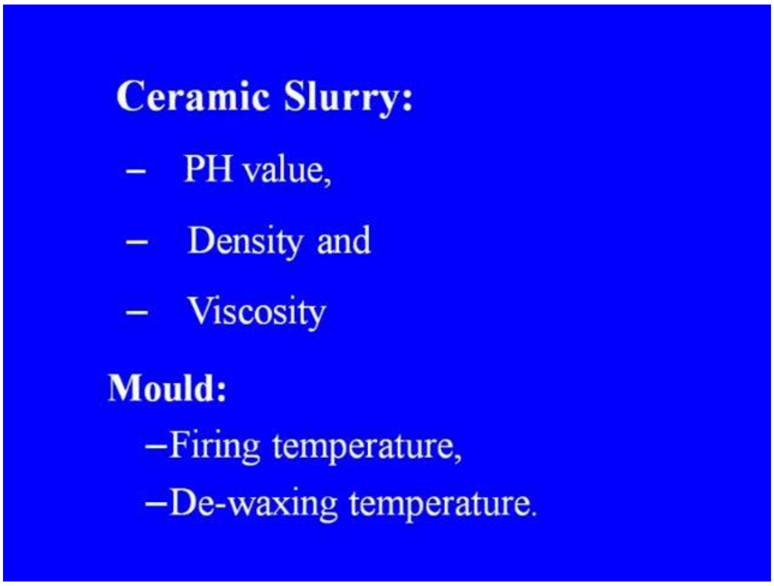

Then mould, based parameters include firing temperature and de-waxing temperature. Thus it indicates, that the following process parameters have an effect under quality of the wax patterns with respective to dimensional accuracy and surface roughness made from the dies.

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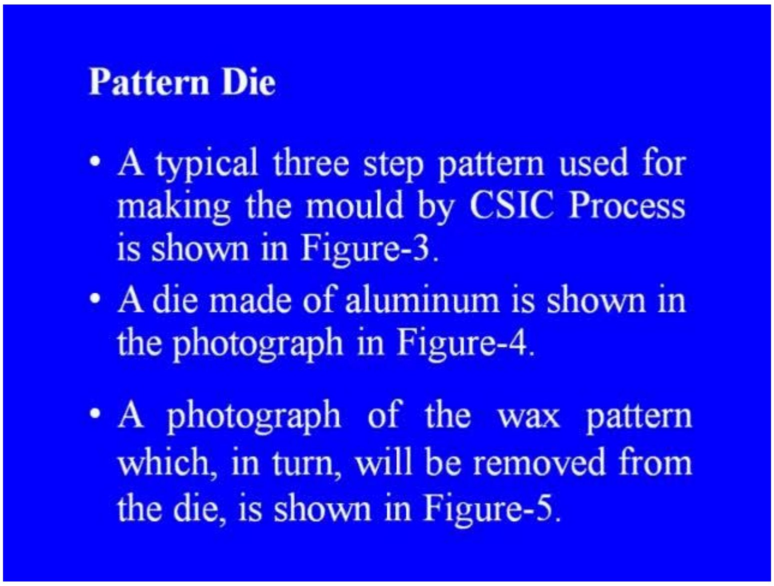

Let us see the pattern die, a typical three step pattern used for making the mould by ceramic shell investment casting process is shown in the figure three. A die made of aluminum is shown in the photograph in figure four. A photograph of the wax pattern which intern will be removed from the die is also shown in figure five.

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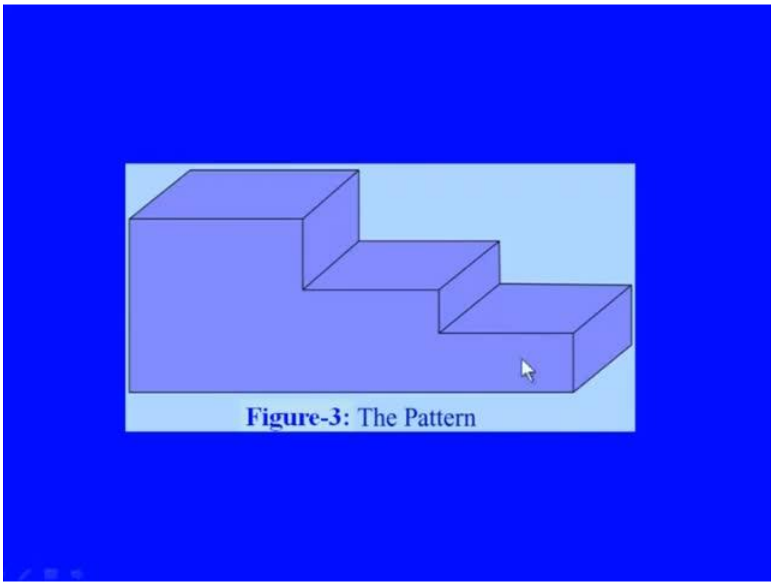

This is the pattern a three step pattern.

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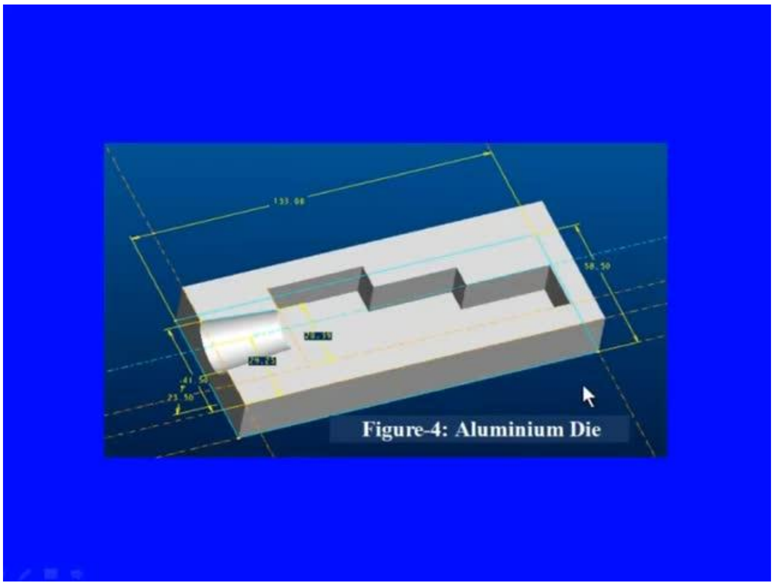

And this is the aluminum die in which this three step mould is created.

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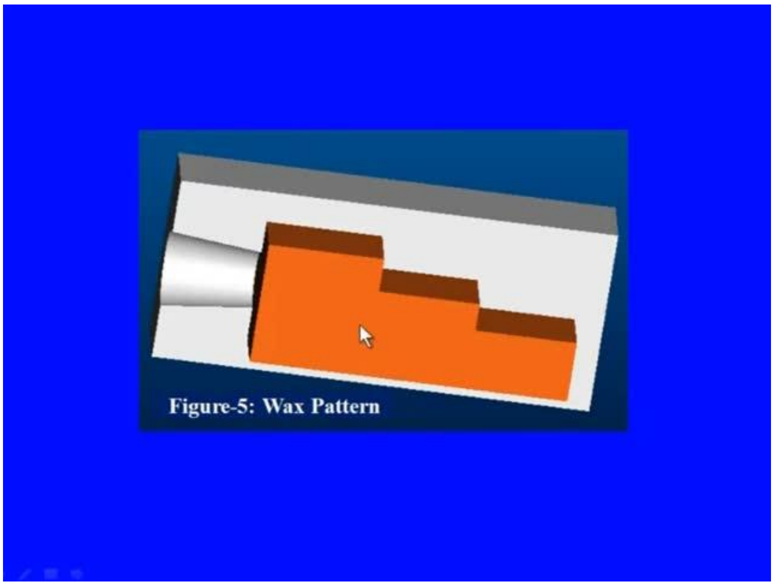

This is the wax pattern. Now, let us see some details about a wax injection machine. A wax injector is a machine, which makes use of an earlier conditioned wax and injects it into a die. In order to produce our wax pattern and injection machine was design and fabricated at IIT Roorkee and is shown in figure six.

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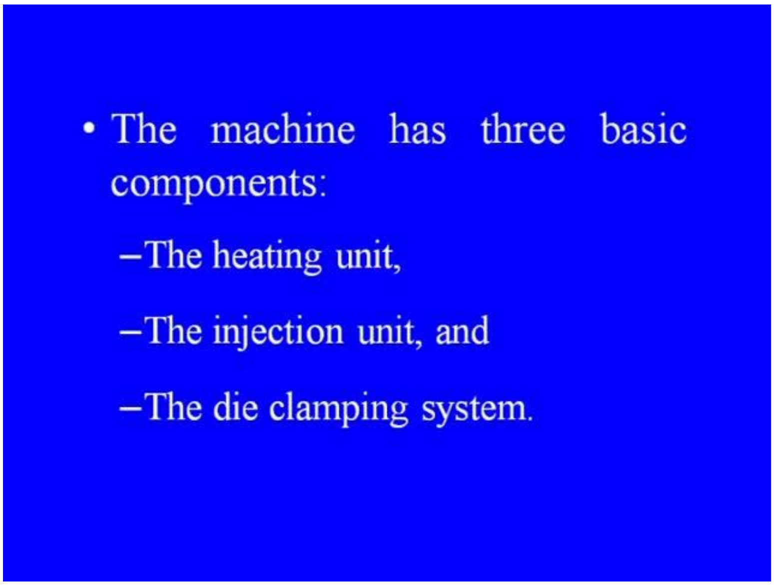

The machine has three basic components. the heating unit to maintain the temperature. the injection unit and the die clamping system. This machine has the following essential components and provisions a jacket provided for heating and melting of the wax that occurs in an aluminum reservoir with provision for slow speed, staring injection of the liquid wax from the brass cylinder under pressure into a closed mould.

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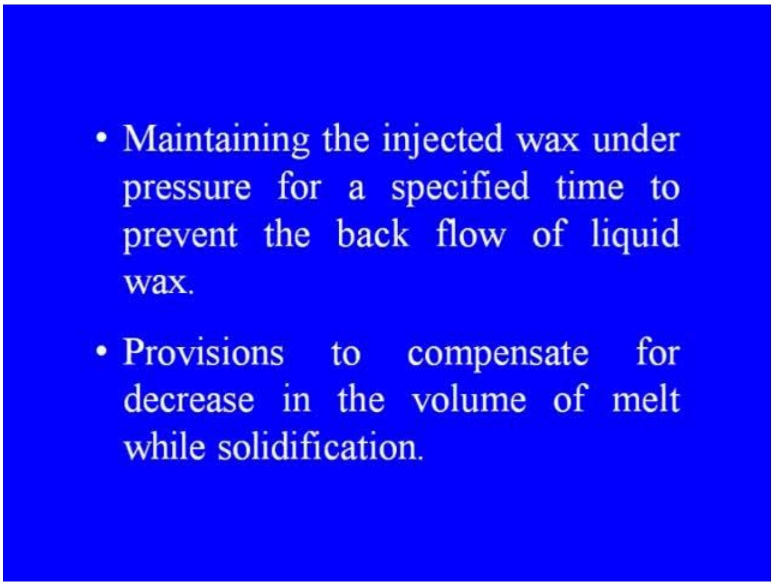

Then maintaining the injected wax under pressure for a specified time to prevent the back flow of the liquid wax. Then provisions to compensate for decrease in the volume of melt while solidification. Through this basic functions, the mechanical and terminal inputs of the injection. Equipment are coordinated in line with the basic properties and behavior of the wax under process. The injection process includes some other sub processes such as, feeding of the brass cylinder through an aluminum reservoir gravimetrically.

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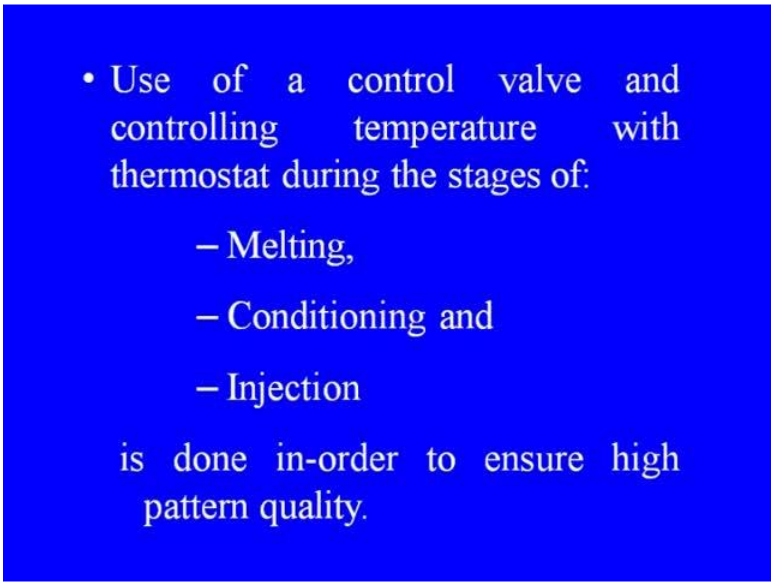

Use of a control valve and controlling temperature with thermostat during the stages of, melting, conditioning and injection is done in order to ensure high pattern quality.

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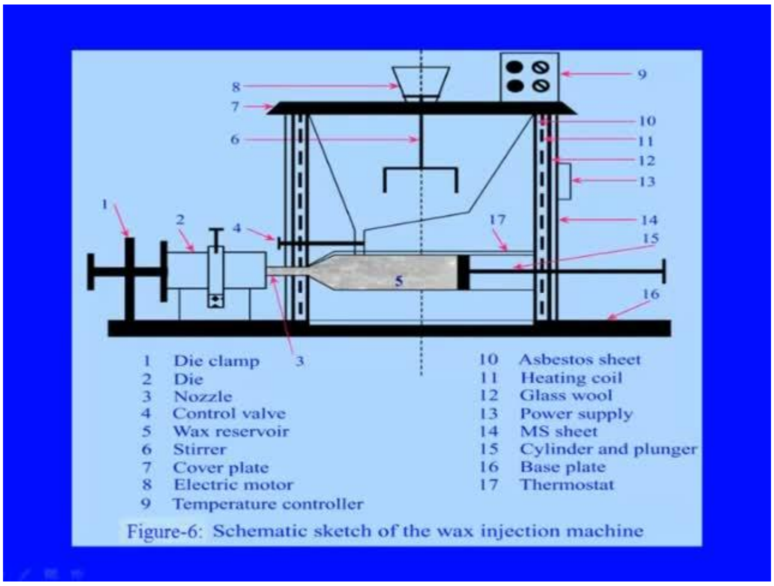

This is the schematic sketch of the injection wax, injection machine in which this is this is the nozzle and this is the wax reservoir. This is the plunger and cylinder arrangement through which this is pressurized. Other components are in the screen a temperature control is made use of controlling the temperature during wax injection in this set up.

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Let us discuss few recent trends in investment casting process. The benefits of investment castings are tremendous. We can manufacture complex parts as close as to the final part as possible. This considerably reduces the costly post processing activities involved. This post processing as well as casting is concerned is a very costly. Activity in may cases fine features are to be created, which could not be produced in the casting process or in some cases the surface finish has to be obtained with the help of some secondary operations, which we call as post processing. In some cases the casting needs to be machined again to obtain the desired dimensions, which also falls under secondary processing or post processing.

Therefore, this adds to the coast of the product. As well as this causes loss in the material it causes tool cost and as well as it cost in terms of times required to produce the part. All these things can be eliminated to large, a extent large, extent in the investment casting process here. Very fine intricate shapes can be produced as we see, in in case of fine products can be produced by using this investment casting process.

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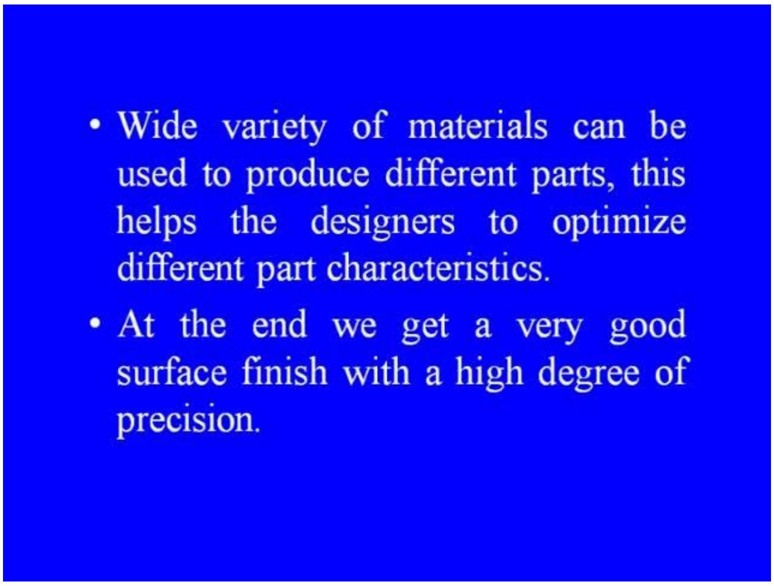

Wide variety of materials can be used to produce different parts this helps the designers to optimize different part characteristics. At the end we get a very good surface finish with a high degree of precision, which is very important as I have already indicated. Otherwise we may have to go for secondary operations, some machining operations or finishing or polishing operations which involves cost. Investment casting is a flexible process with a possibility to use large variety of materials due to this flexibility, it is easily suited for automation as well.

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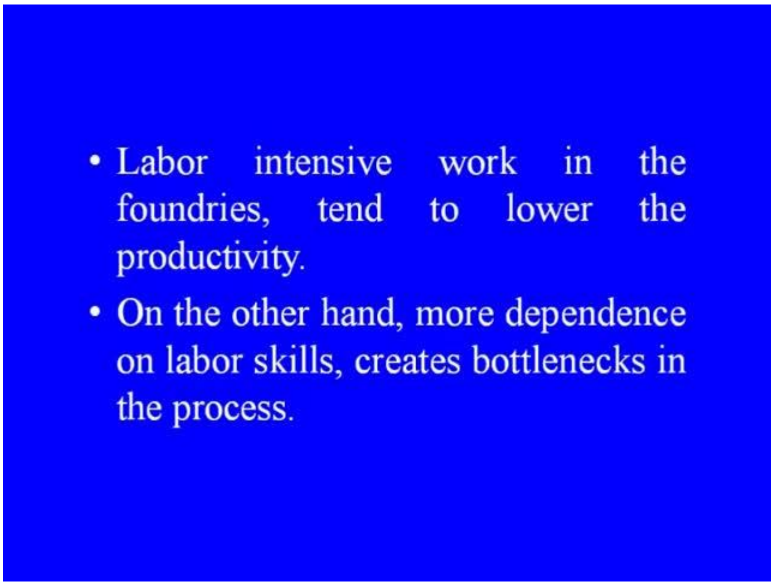

Labor intensive work in the foundries tend to lower the productivity. So, this might be due to the labor unrest labor unavailability labor fatigue, so on or unavailability of the skilled labor and so on. Therefore, this situation should be brought under control and one way to bring this or counter, this is use of automation. One more factor is more dependence on labor skills, creates bottle necks in the process because a factory can afford to a limited number of skilled persons and the process goes to a bottle neck situation, where this skilled persons are or the intervention of the skilled persons are necessary. Thereby it makes the entire process slower or in other words the productivity gets affected become slower further.

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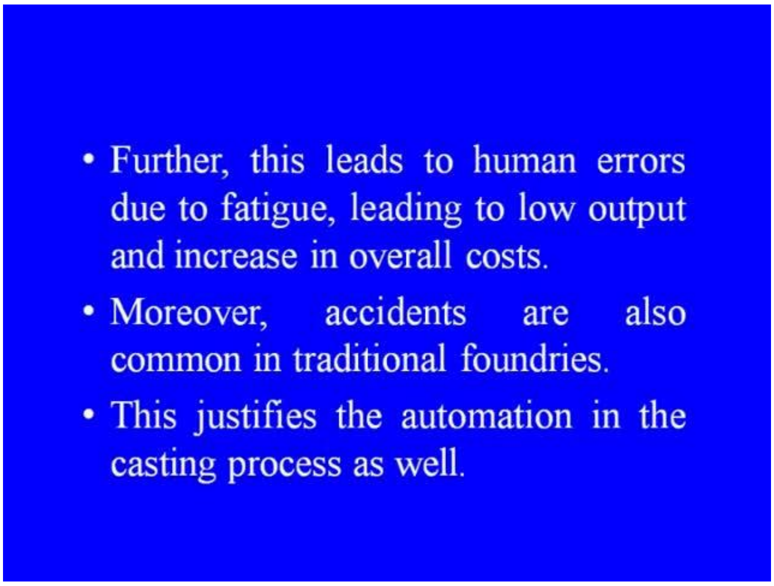

This leads to human errors due to fatigue leading to low output and increase in overall costs. As we know time can be correlated with cost therefore, higher the time for manufacturing or higher the lead time higher will be the cost. Moreover, accidents are also common in traditional foundries. As we have already indicated earlier foundry industries is an industry, which is considered as labor intensive and which has got number of processes, which are potentially dangerous for the workers like it handles high load, it handles high temperature. Therefore, all this needs to be carefully controlled to avoid accidents or unwanted activates. This justifies why the automation in the casting process is necessary as part of automation.

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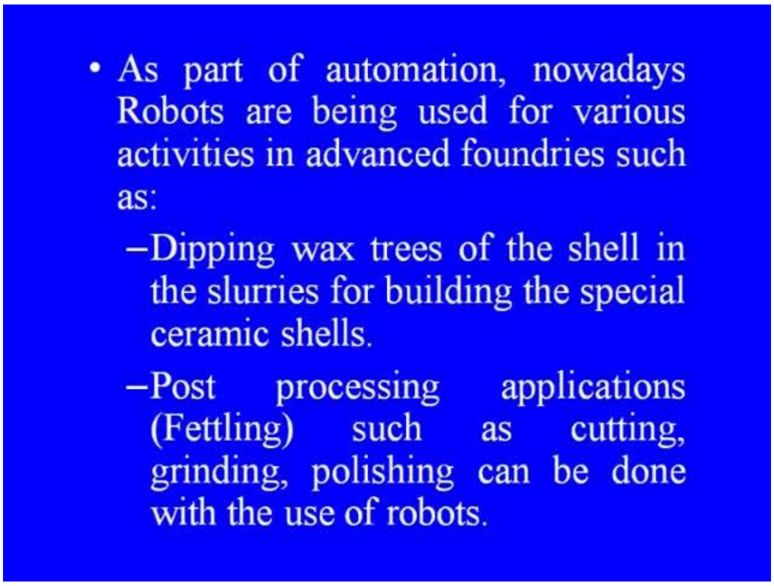

Nowadays robots are being widely used for various activities in advanced foundries such as for dipping of wax trees of the shell in slurries for building the special ceramic shells. This is a very, very monotonous job and also health wise it is not very worker friendly. Therefore, this particular activity can be very well attributed to or assigned to robots, where this health hazard factor can be very well taken care of apart from the monotony factor or the fatigue factor.

Then another important thing is, post processing applications which which is also called fettling, such as cutting, grinding, polishing all this can be done with the use of robots because once the pattern is fixed, once the part to be produce cast is fixed. Then the defects that will be produced will also be fixed for a particular pattern or we can say if it is batch one, then for that batch. Therefore, robots can be easily programmed to remove that additional material or for getting that additional polish on the surface etcetera with this predetermined information, which can be already acquired and stored in the system.

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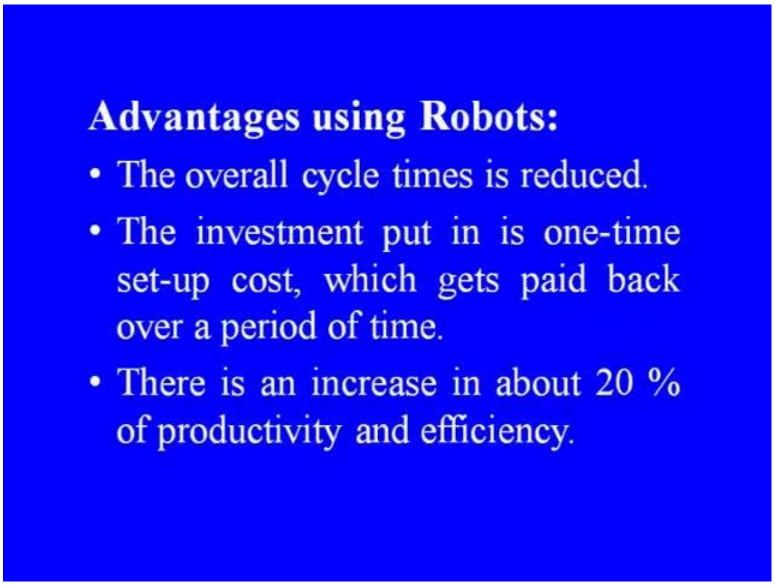

Let us quickly look at that advantages that one can derive using robots, the overall cycle time can be reduced. This is a very important factor as far as the yield of the factory is concerned, the investment put in is one time setup cost say for example, one robot is put in place, then it will be working for number of cycles. Therefore, overall investment will be investment per product will be much less all though the initial investment will be huge, which gets paid back over a period of time.

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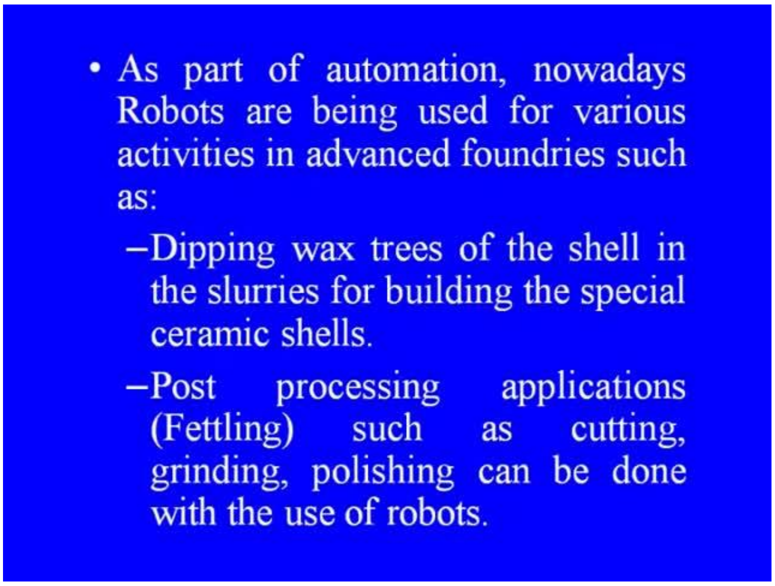

There is an increase in about 20 percent of productivity and efficiency with the use of robots.

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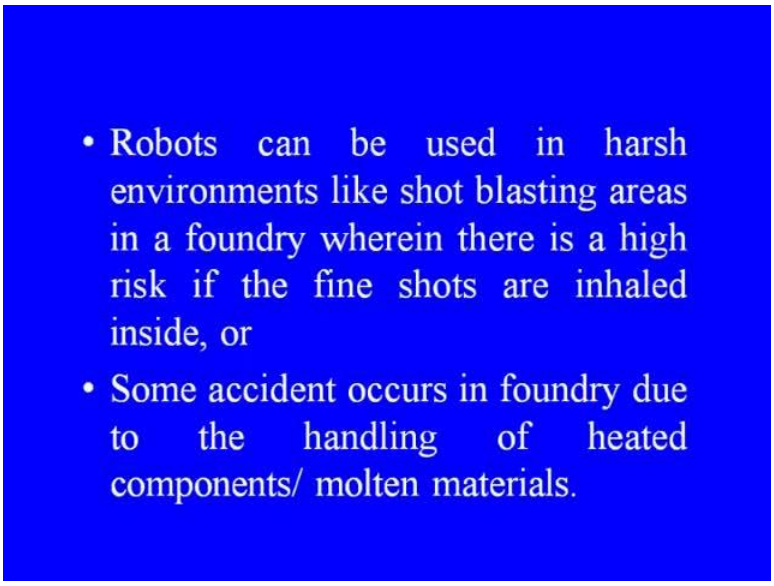

In these shops, which is substantial 20 percent of increase in productivity robots can also be used in harsh environments like shot blasting areas in a foundry wherein there is a high risk if the fine shots are inhaled inside. As we know shot blasting is a process where generally small particles, say around 50 micron diameter or 20 micron diameter, as the case would be particles or of the materials can be castinal materials or can be ceramics like alumina or something like that or silicon carbide. Generally cast iron particles are also used and these particles are used to short blast a surface, means they are accelerated towards the surface at very high velocity. This causes the surface to hit and induce some rough nesses, so this can be explained like this.

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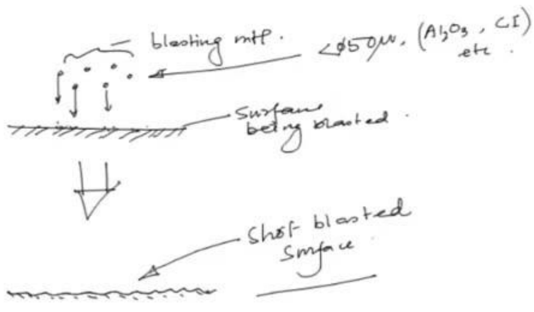

A plan surface being hit by these are the blasting material, these are blasting material and this is the surface being blasted, surface being blasted and this particles will hit this surface and cause some deformation here, plastic deformation here. This will ultimately, eventually result in a surface something like this. So, this is we can say, this is the shot blasted surface these particles, these are something around say less than 50 micron in diameter and they can be of say alumina or they can be in some cases cast iron etcetera. Now, these particles if inhaled by any worker; that is certainly not a healthy situation. This situation can be avoided by use of robot.

Moreover some accidents occur in foundry, due to the handling of heated components or molten materials. This also we have already indicated. Foundry industry or foundry shop is a place, where people will have to handle high temperature materials, that is molten materials, which could be several hundred or even in access of thousand degree celsius, which is potentially very, very risky situation.

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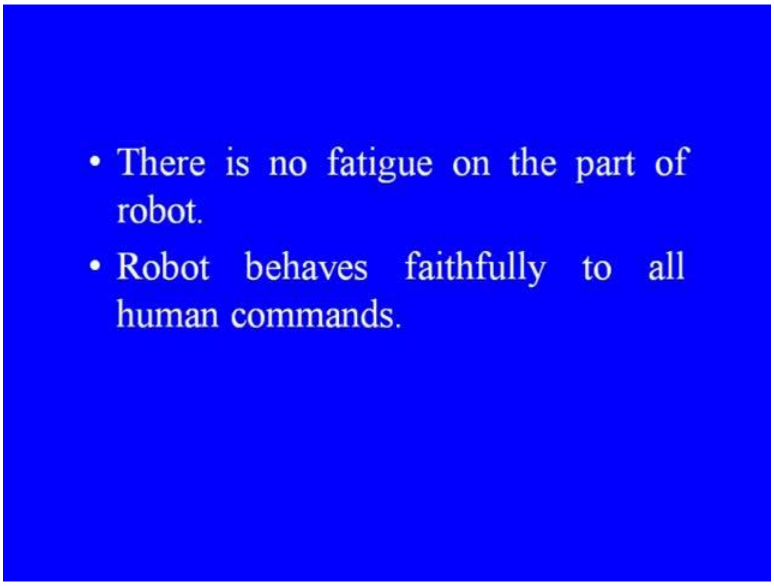

There is no fatigue on the part of the robot, which is a very common in case of human being. Robot behaves faithfully of all human commands, this is another important aspect where there is no question of descent being shown by any workers, once the command goes unfavorable to him.

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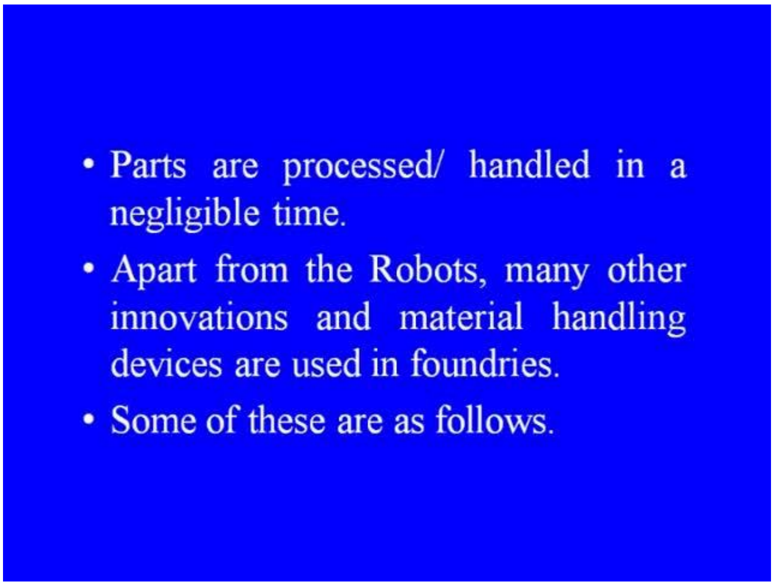

Then with the use of robot parts are processed or handled in a negligible time. Apart from the robot may other innovations, and material handling devises are used in foundries some of these can be listed as follows.

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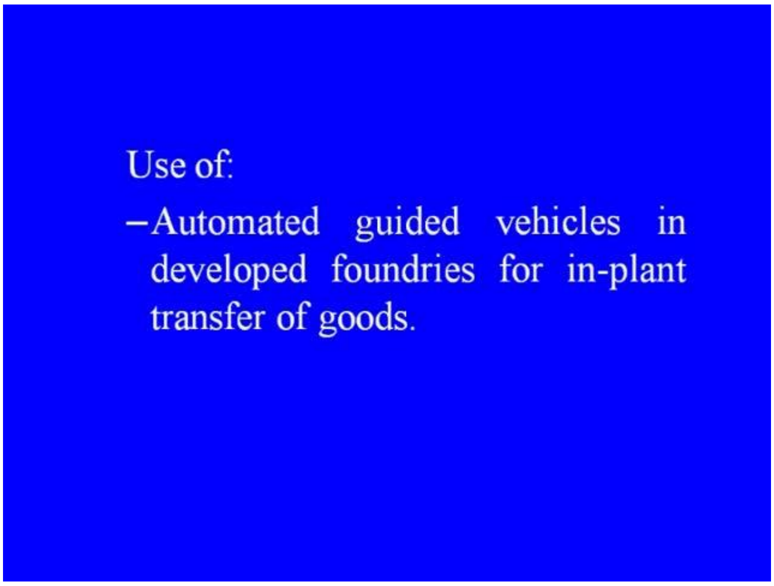

For example, number one, use of automated guided vehicles also known as AGV’s in developed foundries for in plant transfer of goods. This is a very, very significant aspect of automating the shops, where a frequent transfer of parts or the cost product from one unit to another unit is to be done or the finished cast should be transferred to the stores or something like that or the yield of the casting should be sent for the secondary processing or the post processing, that needs frequent handling and frequent trans, transfer of the materials.

That can be done through AGV’s automated guided vehicles. Of course, there are different types AGV’s etcetera, which are discussions are beyond the scope of this discussion. So, different types of, as the the situation demands, the AGV’s type of, suitable type of AGV’s can be used for transferring the material from one shop to another or from one place to another, for the purpose for which it is being transported.

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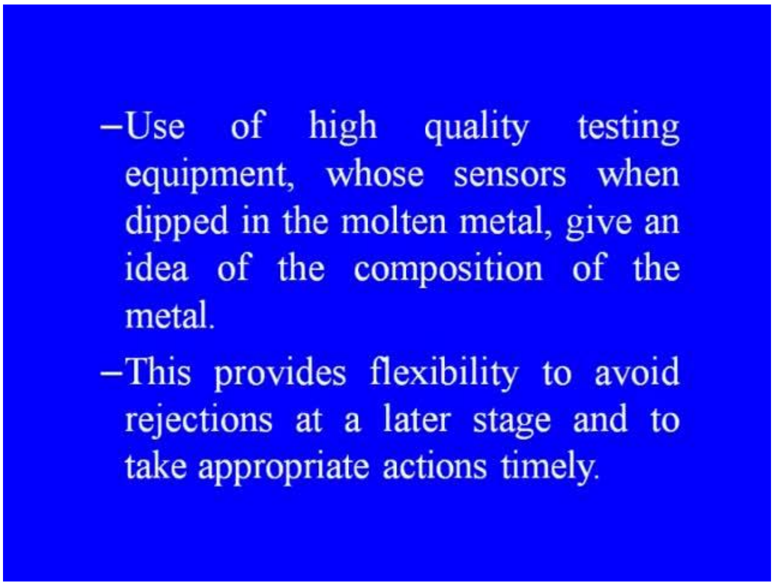

Then use of high quality testing equipment whose sensors when dipped in the molten metal given an idea of the composition of the metal. This is another use of high tech equipment by using sensory systems will be able to know the composition of the liquid material. That means the molten material, which is important sometimes the material could be toxic as well or could cause harm to the human being, this can be avoided. This provides flexibility to avoid rejections at a larger stay or at a later stage and to take appropriate actions timely.

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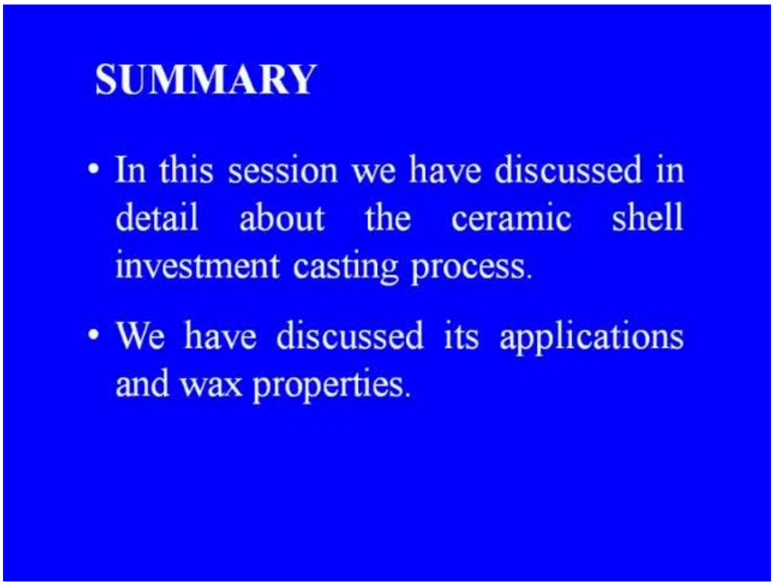

Now, let us summarize what we have discussed in this session. In the present session, we have discussed in details about the ceramic shell investment casting process, then we have also discussed its applications and some of the recent trends in this process including the automation aspects and use of robotics in this casting process, which can enchase the productivity in the longer run. We hope to discussion was informative and interesting.

Thank you.