Advanced Manufacturing Processes

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Module - 2
Advanced Metal Casting Processes
Lecture - 7
Shell Molding Process

Welcome to this session on shell molding process under the course advanced manufacturing processes. Let us first look into a brief history and features of this shell molding process.

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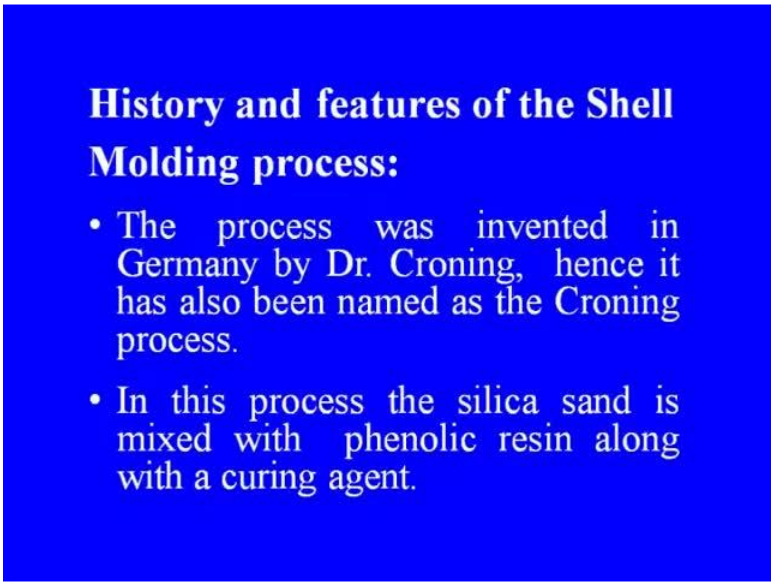

This process was invented in Germany by Doctor Croning, hence it has also been named as the Croning process. In this process the silica sand and is mixed with phenolic resin along with a curing agent. Starting with the year 1929 Johannes Croning performed extensive test on the application of high frequency melting equipment to produce all three parts of the casting process namely melting, pouring and solidification. And all these were done in a permanent mold.

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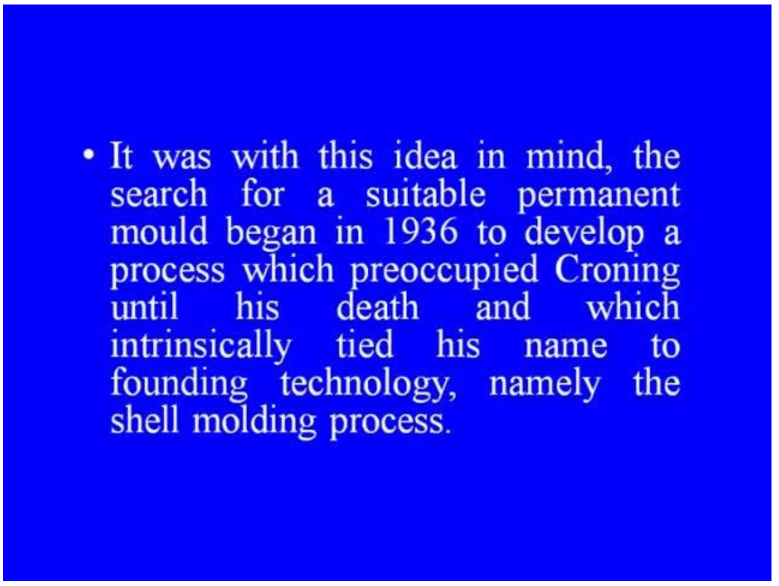

It was with this idea in mind, the search for a suitable permanent mold began in the year 1936 to develop a process which preoccupied Croning until his death and which intrinsically tied his name to founding technology, namely the shell modeling process. He started his considerations with experiments on a transfer of the flip casting process developed for the manufacture of ceramic products which lead to a patent in 1936. This process used a split plaster mold of the object to be cast to produce hollow bodies.

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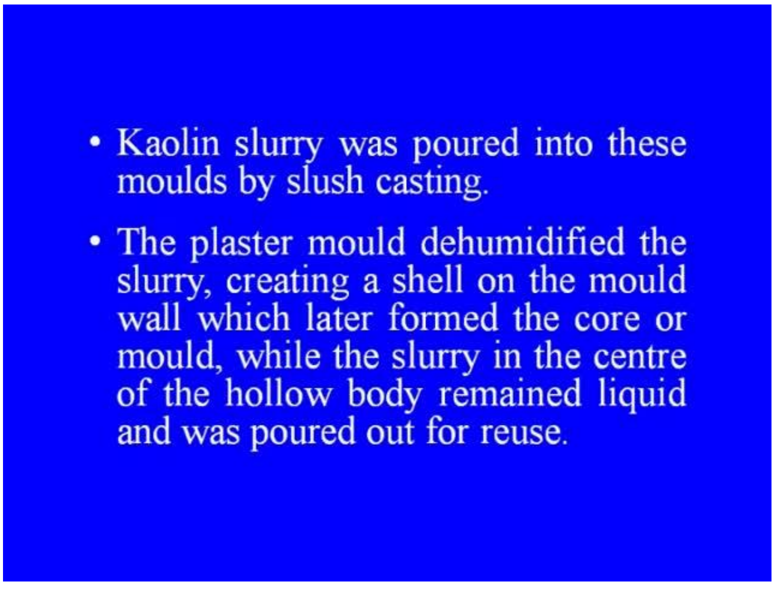

Kaolin slurry was poured into these molds by slush casting. The plaster mold dehumidified the slurry, creating a shell on the mould wall which later formed the core or mould, while the slurry in the center of the hallow body remained liquid and was poured out for reuse.

Now, the foundations were laid that lead to a continuous advancement of the shell molding process through numerous development steps. The shell molding process had been used for making cores for hand grenades and missile parts during the Second World War.

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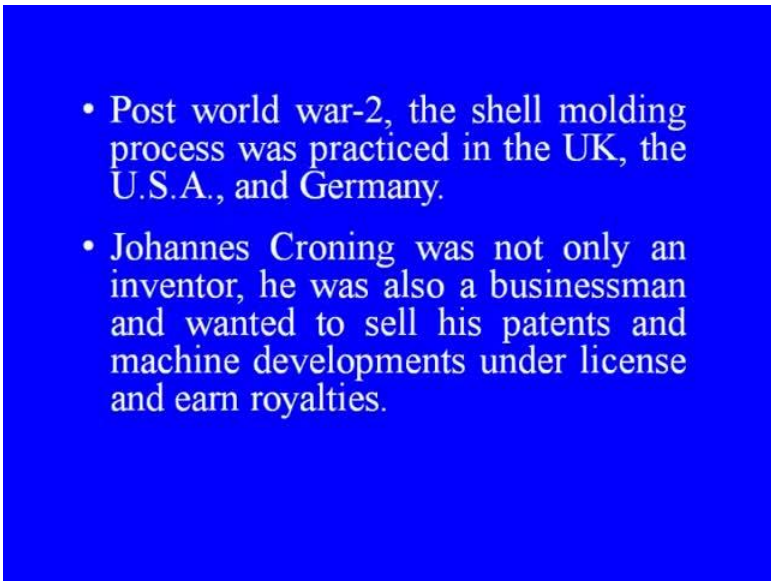

Post World War 2 shell molding process was practiced in the United Kingdom, the USA and in Germany. Johannes Croning was not only an inventor he was also a businessman and he wanted to sell his patents and machine developments under license and earn some royalties.

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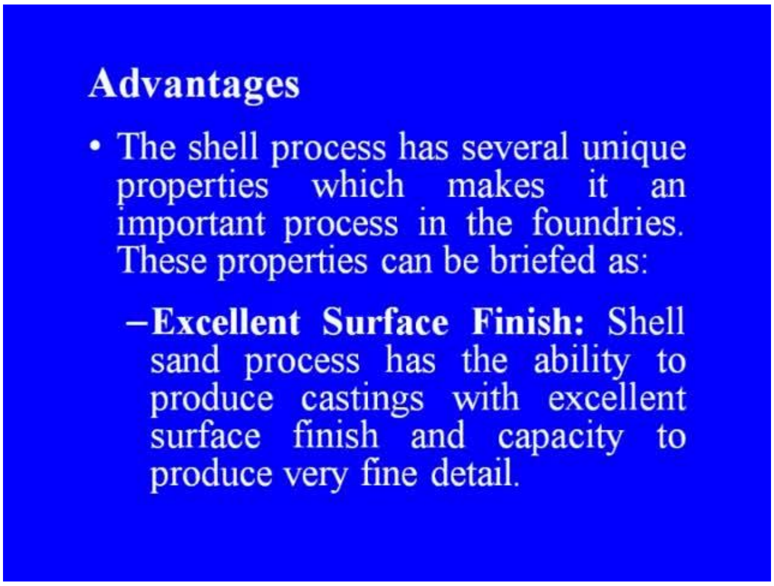

Let us see the advantages of this process. The shell molding processes has several unique properties which makes it an important process in the foundries. These properties can be briefed as the excellent surface finish. Shell sand process has the ability to produce casting with excellent surface finish and capacity to produce very fine details.

Next advantage is dimensional accuracy to be obtained. The process has an ability to produce castings to tight dimensional tolerances, due to this characteristic machining allowance can be reduced whose ultimately helps in reduction of the flatting and finishing costs. The shell molding process accommodates easily deep drawn patterns with less steppers then conventional production processes.

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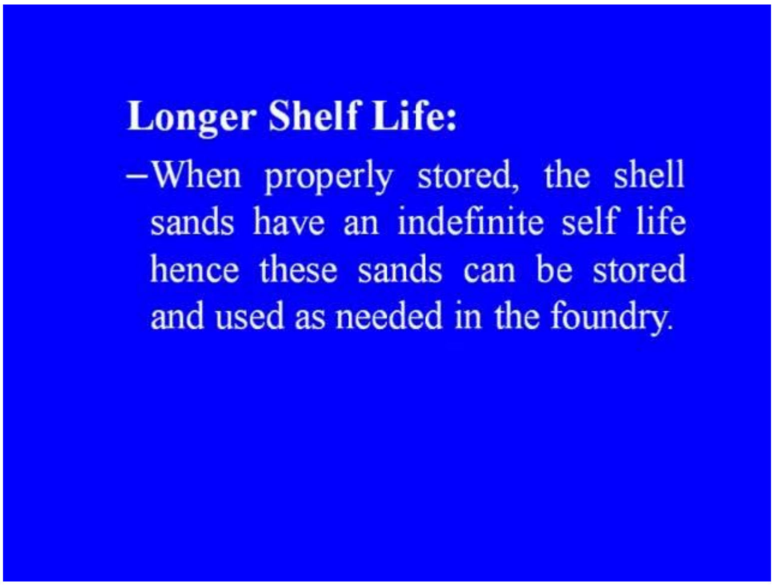

Another advantage is longer shelf life. When properly stored the shell sands have an indefinite self life, hence these sands can be stored and used as needed in the foundry.

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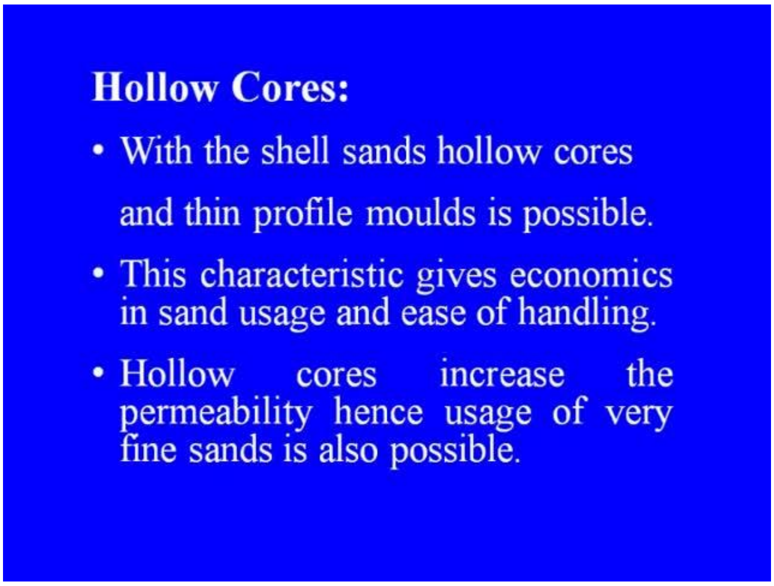

Next is the hollow cores, with the shell sands hollow cores, the thin profile moulds is possible. This characteristic gives economics in sand usage and ease of handling. Hollow cores increase the permeability and hence usage of very fine sands is also possible. Sand to metal ratio, this is a unique process that gives hollow cores and thin wall moulds. The hollow cores help in improving the permeability and act as a basis for the evolved gases to come out. It results in substantial weight reduction and material savings. The normal sand to metal ratio is one is to one which is much lower than other processes.

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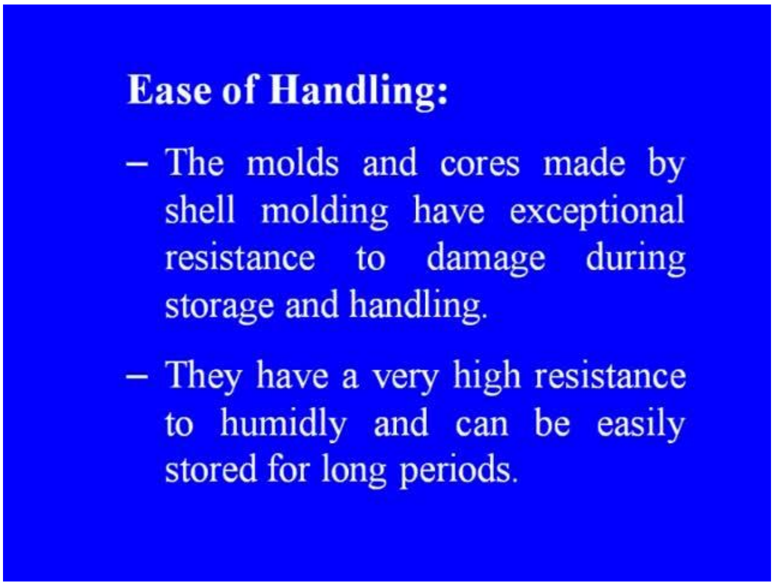

Ease of handling is another big advantage of this process. The molds and cores made by the shell molding have exceptional resistance to damage during storage and handling. They have a very high resistance to humidity and can be easily stored for long periods.

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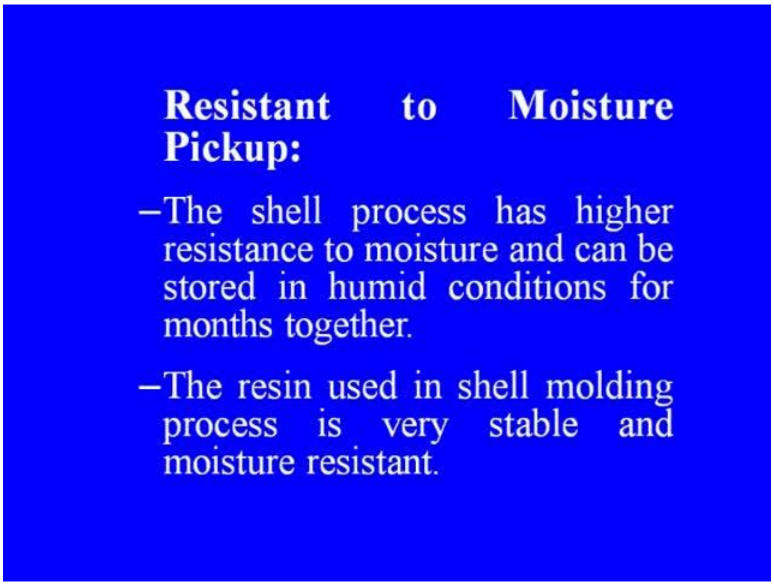

Resistance to moisture pickup this is another big advantage. The shell process has higher resistance to moisture and can be stored in humid conditions for months together. The resin used in shell molding process is very stable and moisture resistant.

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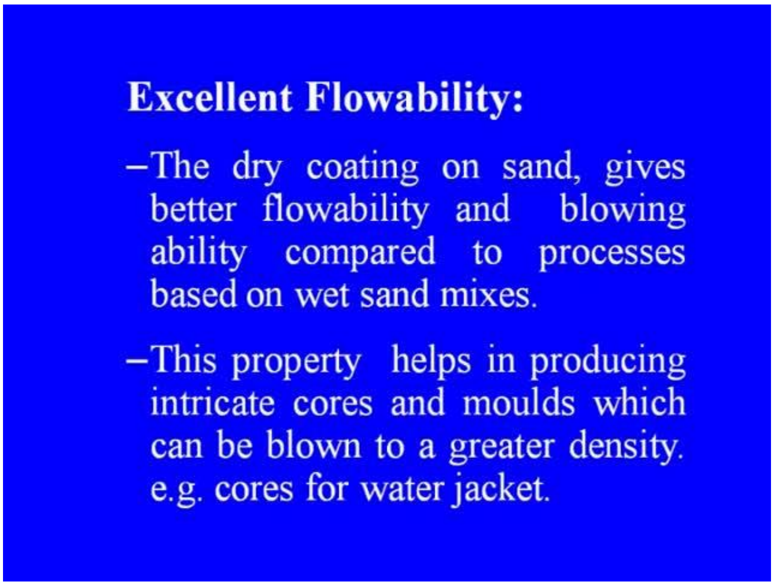

Excellent flow ability is another advantage of the process. The dry coating on sand gives better flow ability and blowing ability compared to processes based on wet sand mixes. This property helps in producing intricate cores and molds which can be blown to a greater density for example, cores for water jacket.

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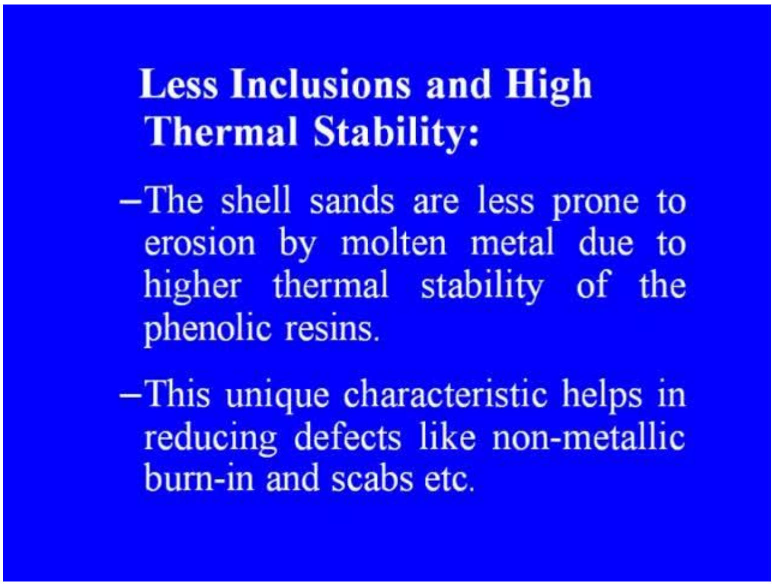

Less inclusions and high thermal stability is another advantage of this process. The shell sands are less prone to erosion by molten metal due to higher thermal stability of the phenolic resins. This unique characteristic helps in reducing defects like non metallic burning and scabs etcetera.

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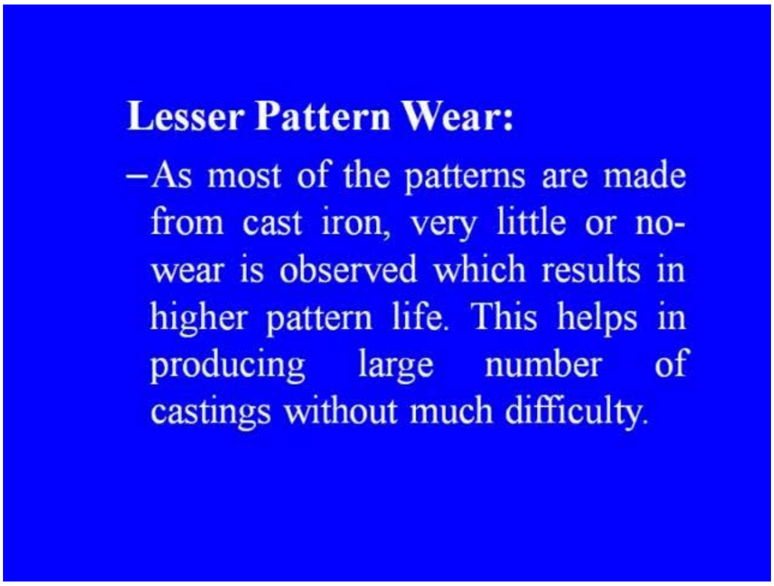

Another advantage of this process is lesser pattern wear. As most of the patterns are made from cast iron, very little or no wear is observed which results in higher pattern life. This helps in producing large number of castings without much difficulty. Now, let us also look into some of the limitations of this shell molding process. To name the first is the high cost of this process.

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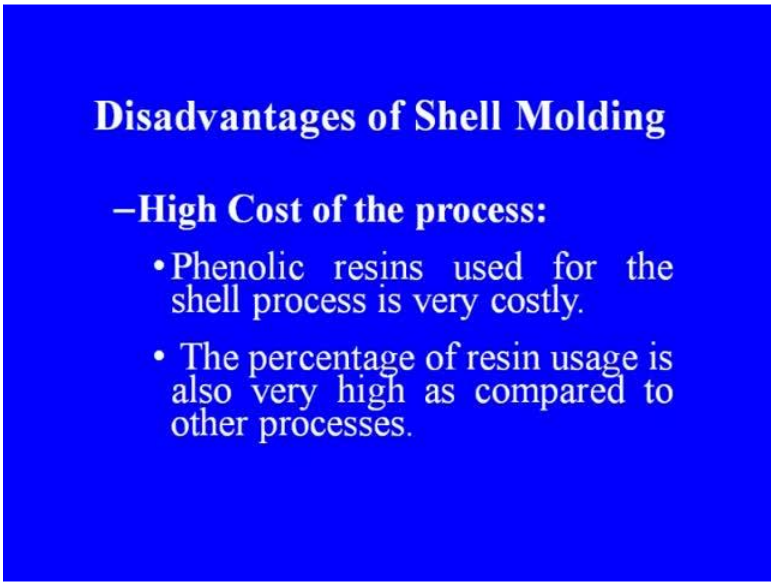

The phenolic resins used in this process is very costly. The percentage of resin usage is also very high as compared to other processes, which adds to the high costs of the process. The process also requires very tight control of the shell thickness; else the competitiveness of the process will be sacrificed. Smaller shell thickness limits the weight of the castings that are produced by this process. Producing bulk air castings can lead to shell breakages as it cannot bear more weights.

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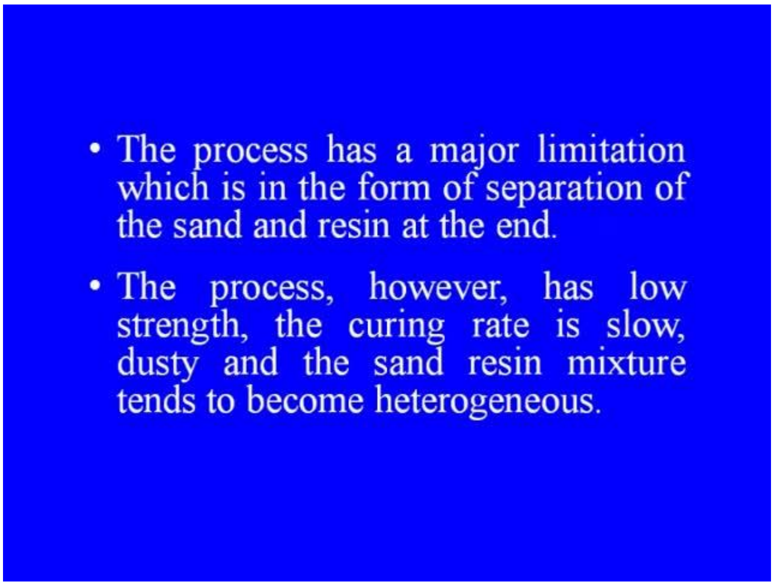

The process has a major limitation which is in the form of separation of the sand and resin at the end. The process however has low strength, the curing rate is slow, dusty and the sand resin mixture tends to become heterogeneous. In order to overcome these issues novolac phenolic resin dissolved in alcohol is used and the sand is warm coated with it, using this technique better strengths will achieved with lower resin addition along with excellent curing characteristics with lesser dust problem.

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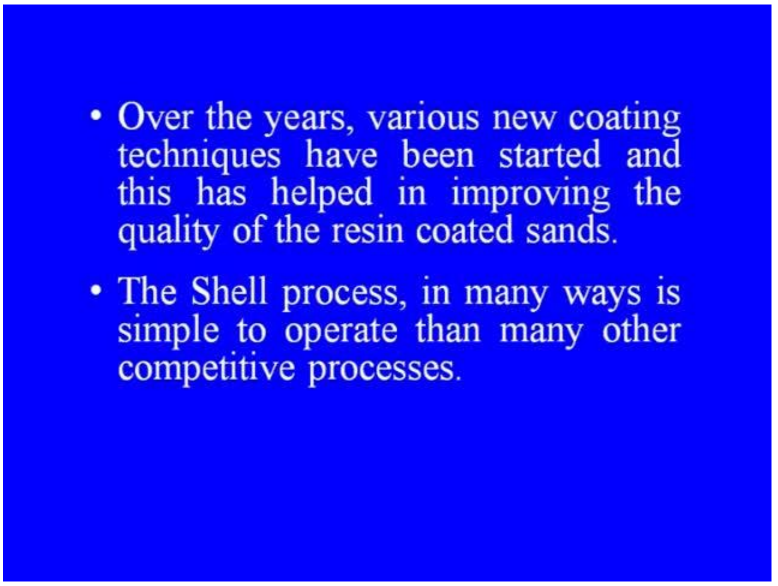

Over the years, various new coating techniques have been started and this has helped in improving the quality of the resin coated sands. The shell process in many ways is simple to operate than many other competitive processes. High tooling cost, the shell process is thermo set in nature there by requiring higher curing temperatures. The patterns used are of cast iron with smooth surfaces which have very low expansion coefficient.

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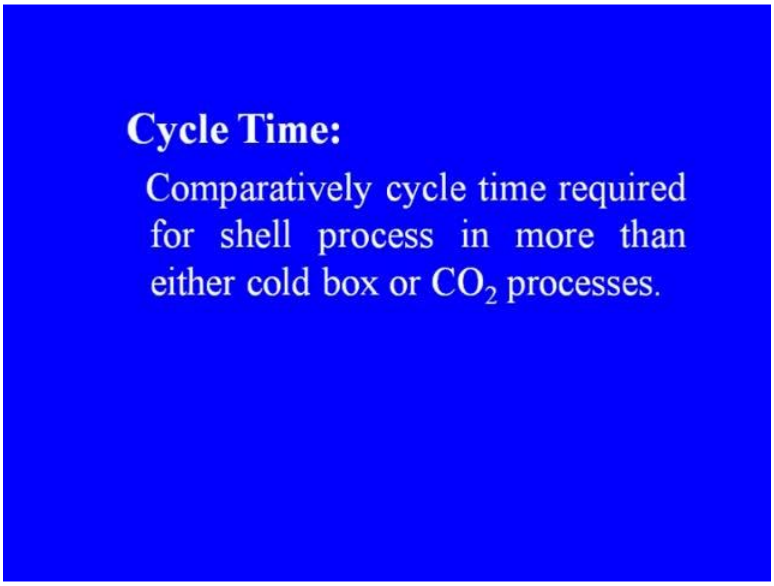

Cycle time, comparatively cycle time required for shell process in, is more than either cold box or carbon dioxide processes.

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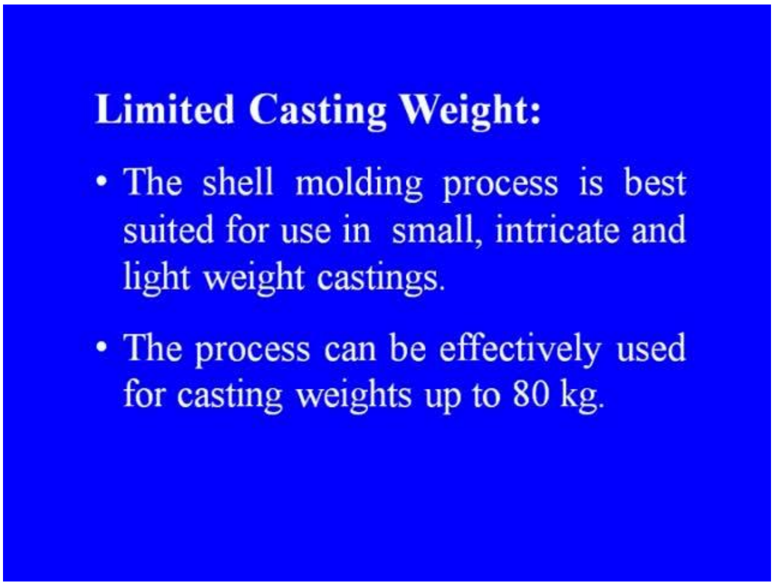

Limited casting weight, the shell molding process is best suited for use in small, intricate and light weight castings. The process can be effectively used for casting weights up to 80 kilograms.

Now, let us see the process of shell molding very briefly. In the shell molding process the molds and cores are prepared by mixing the dry free flowing sand with thermo setting resins and then heating the aggregate against a heated metal plate.

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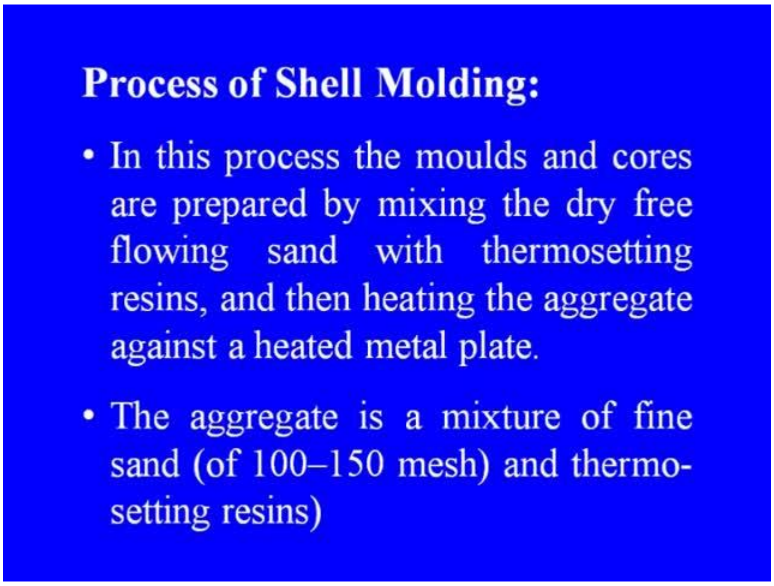

The aggregate is a mixture of fine sand of 100 to 150 mesh size and thermo setting resins due to the heat the resin cures, which causes the sand grains to get bonded with each other and it forms a hard shell around the metallic pattern.

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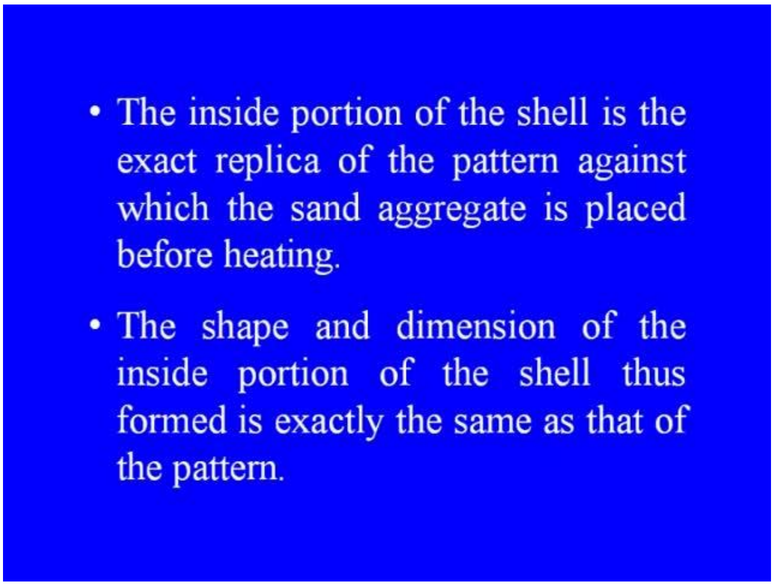

The inside portion of the shell is the exact replica of the pattern against which the sand aggregate is placed before heating. The shape and dimension of the inside portion of the shell thus formed is exactly the same as that of the pattern. If the pattern is of two pieces then the other half of the shell is also prepared in the same way, two halves of the shells prepared are placed together after inserting the core, if any to make the assembly of the mold.

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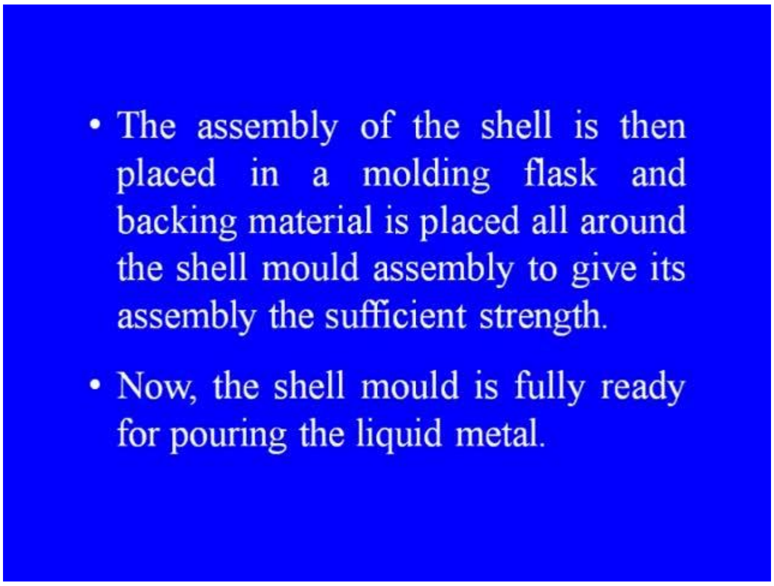

The assembly of the shell is then placed in a molding flask and backing material is placed all around the shell to give its assembly the sufficient strength. Now, the shell mold is fully ready for pouring the liquid metal. Let us see the type of sand.

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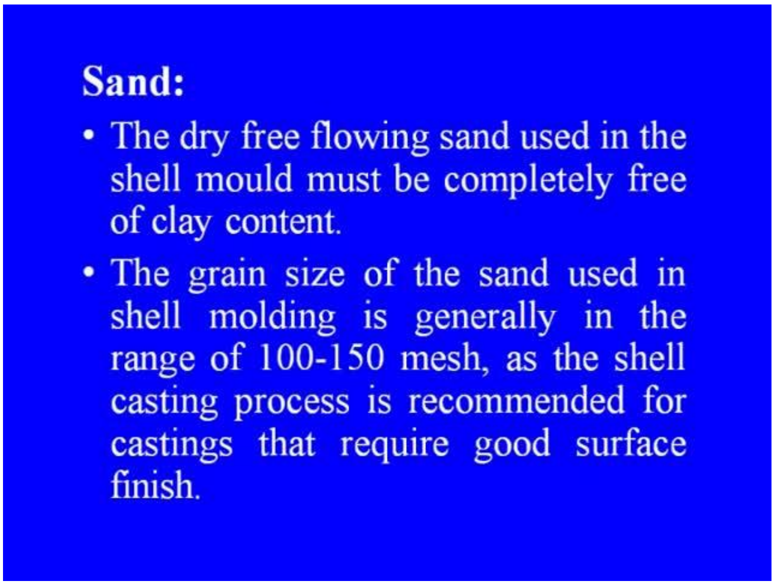

The dry free flowing sand used in the shell mold must be completely free of clay content. The grain size of the sand used in the shell molding is generally in the range of 100 to 150 mesh size. As the shell casting process is recommended for castings that require good surface finish. However, depending on the requirement of surface finish of the final casting the grain size of the sand can be ascertained. If the grain size is very fine it requires large amount of resins making it further expensive. Now, let us see the characteristic of resin and catalyst.

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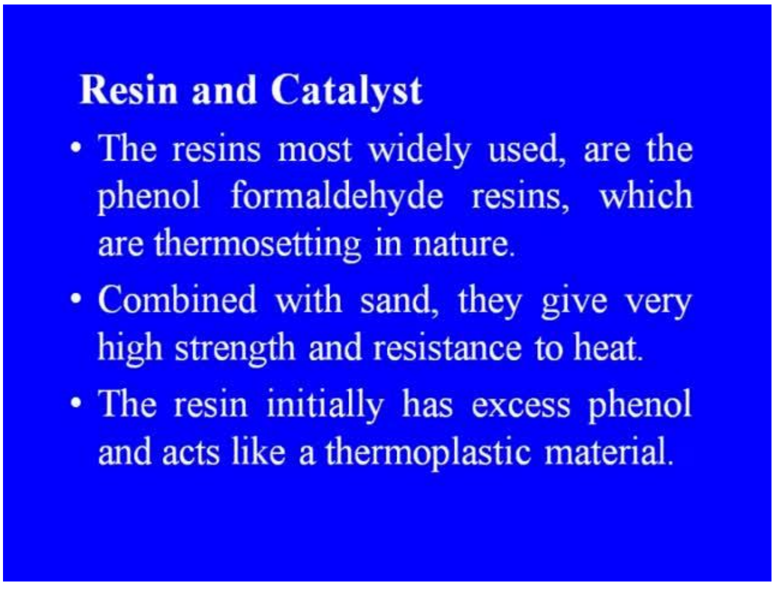

The resins most widely used are the phenol formaldehyde resins, which are thermo setting in nature. Combined with sand they give very high strength and resistance to heat the resin initially has excess phenol and acts like a thermoplastic material. In order to develop the thermosetting properties of the resin the coating of the sand is done with resin and a catalyst. The catalyst is hexamethylenetetramine also known as hexa in short.

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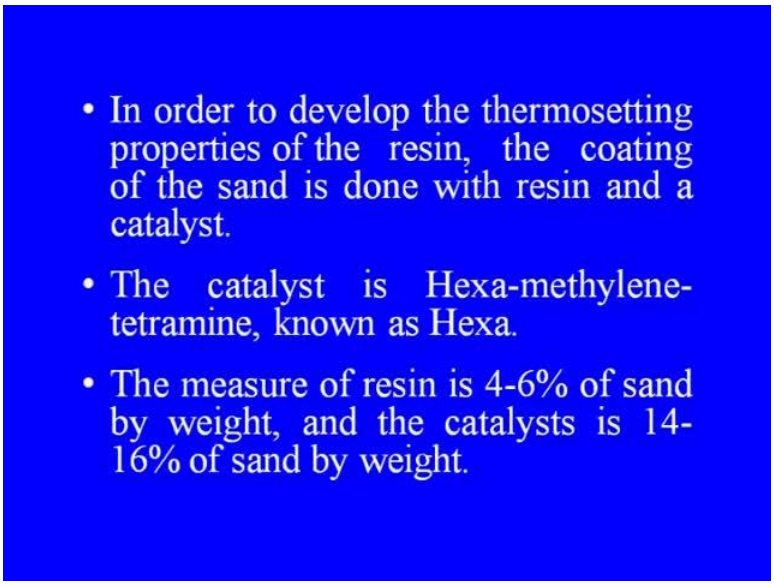

The measure of resin is 4 to 6 percent of sand by weight and the catalyst is 14 to 16 percent of the sand by weight.

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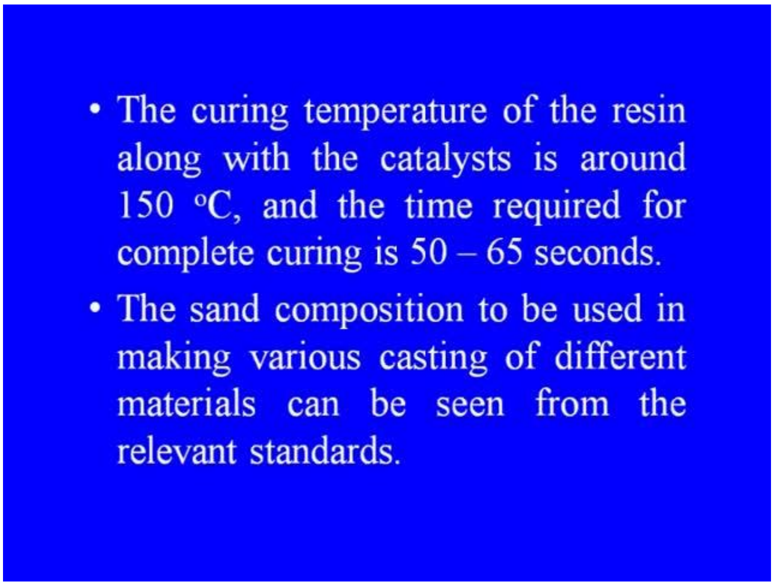

The curing temperature of the resin along with the catalyst is around 150 degree Celsius and the time required for complete curing is nearly 50 to 65 seconds. The sand composition to be used in making various casting of different materials can be seen from the relevant standards.

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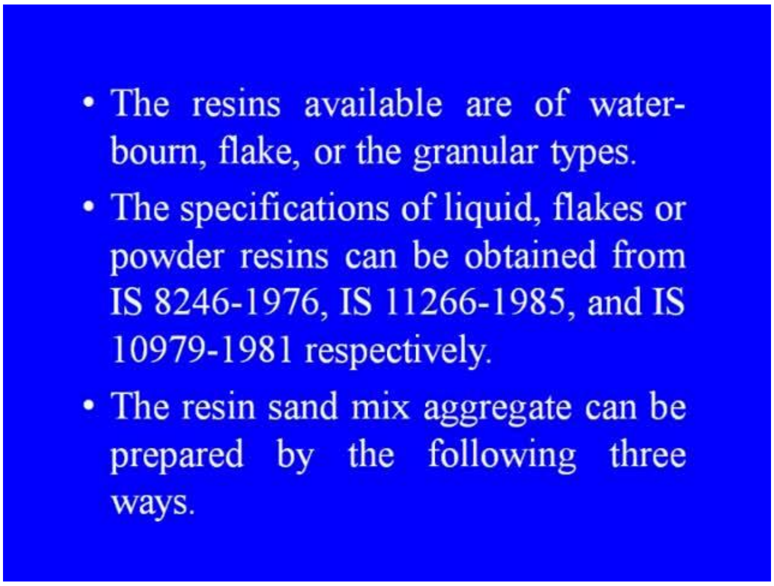

The resins available are of water bourn, flake or the granular types. The specifications of liquid, flakes or powder resins can be obtained from Indian standard 8246 1976 Indian standard 11266 of 1985 and Indian standards 10979 of 1981 respectively. The resin sand mix aggregate can be prepared by the following three ways; number one, warm coating process. In this process different sand formulation which is liquid solvent solution is used and curing takes place at around 80 degrees centigrade. The process is simpler than hot coating, but the quantity of resin consumed is larger.

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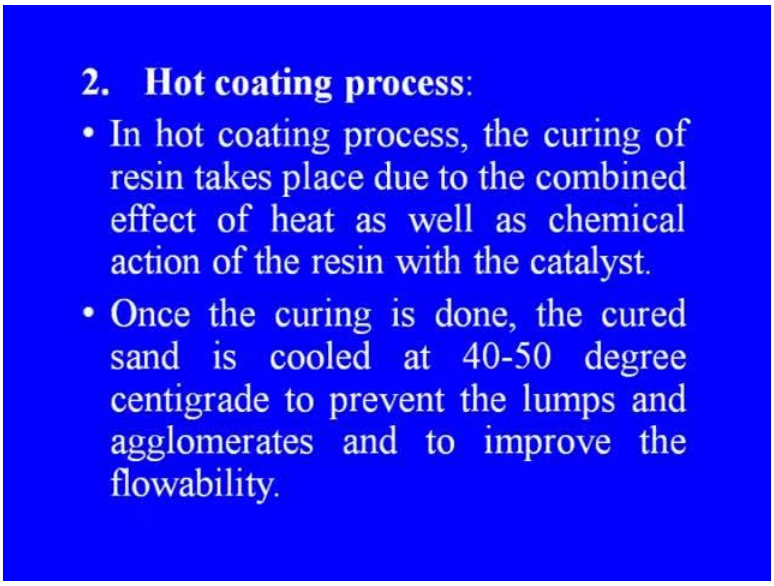

The second process is hot coating process. In hot curing process the curing of resin takes place due to the combined effect of heat as well as chemical action of the resin with the catalyst. Once the curing is done the cured sand is cooled at 40 to 50 degrees Celsius to prevent the lumps and agglomerates and to improve the flow ability. The third process is the cold coating process. In this process, the sand is first mixed with catalyst, then the resin mixed with alcohol is added to the aggregate. The amount of resin requirement is the highest in comparison to the amount required in hot and warm coating processes.

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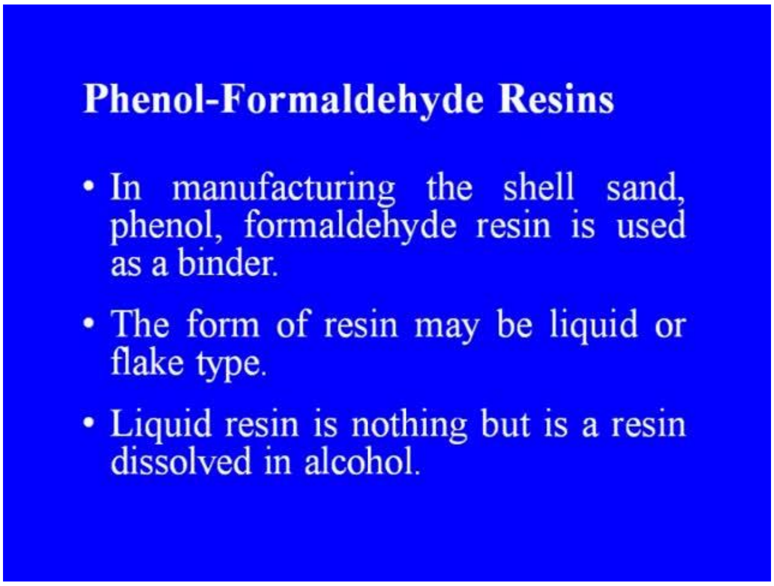

Phenol formaldehyde resins, in manufacturing the shell sand phenol formaldehyde resin is used as a binder. The form of resin may be liquid or flake type. Liquid resin is nothing but it is a resin dissolved in alcohol. Liquid resin is used for manufacturing shell sand by either warm air process or by ignition process whereas solid or flake resin is used for hot coating process. Most of the Indian manufacturers of shell sand use liquid resin because of the easiness of the resin of the process.

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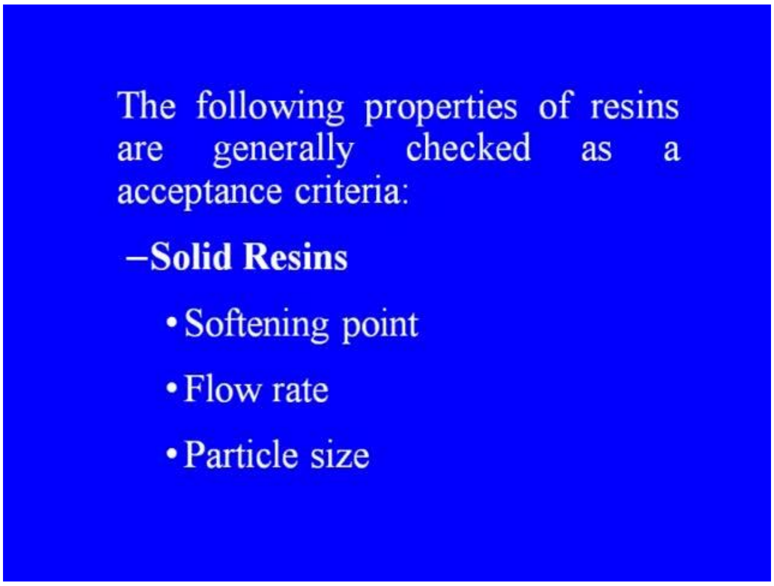

The following properties of resins are generally checked as a acceptance criteria for solid resins, softening points, flow rate and particle size.

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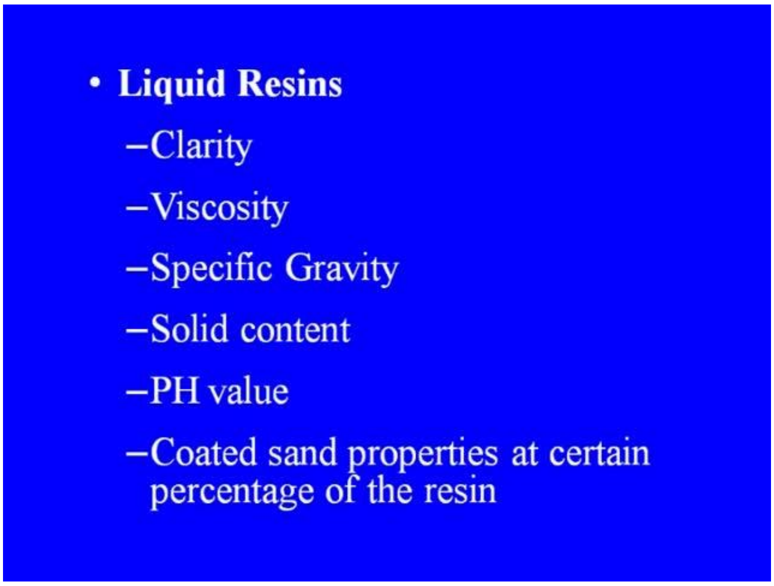

For liquid resins clarity, viscosity, specific gravity, solid content, PH value and coated sand properties at certain percentage of the resin. Now, let us see the hexa catalyst. The phenol formaldehyde resins are thermo plastic in nature and require a formaldehyde donor to cure at a certain temperature, thus after blending of the resin and the catalyst it becomes thermo set in nature and thus the formation of shell molds and cores is accomplished.

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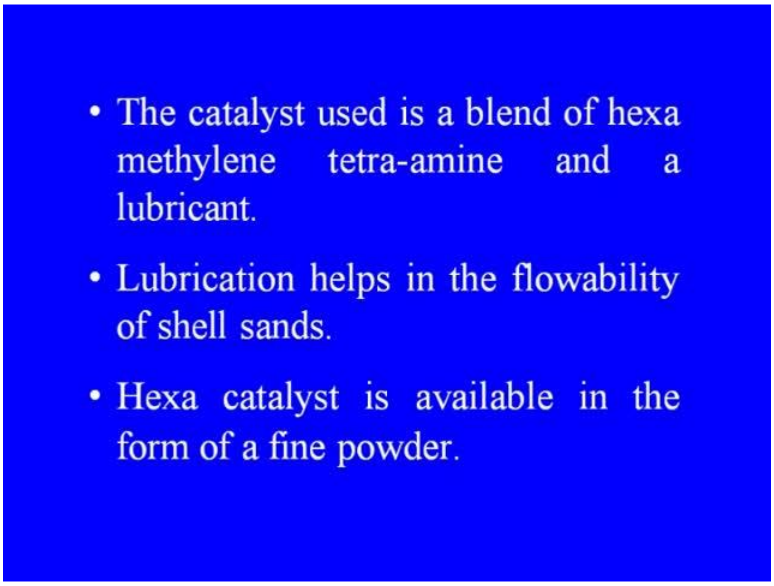

The catalyst used is a blend of hexa methylene tetra amine and a lubricant. Lubrication helps in the flowability of shell sands. Hexa catalyst is available in the form of a fine powder. Now, let us look into the steps in preparing shell molds. The steps to prepare the shell mold are shown in the figure one which will be shown just after this.

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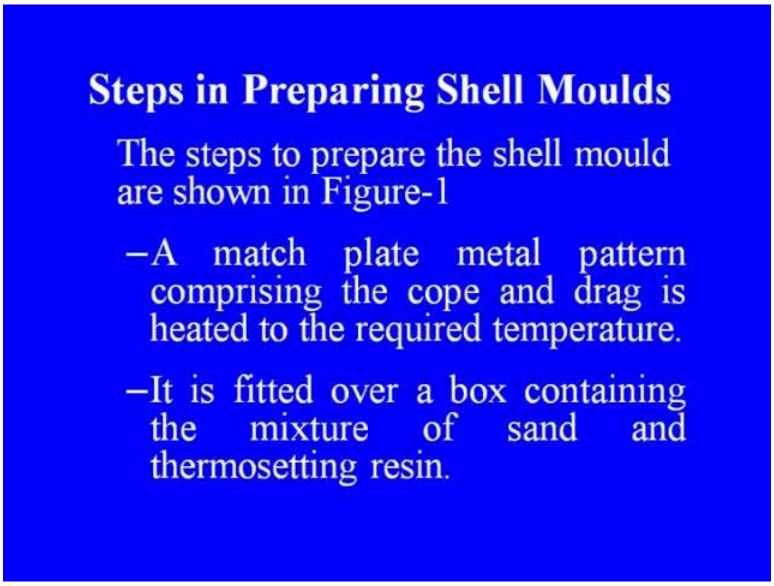

A match plate metal pattern comprising the cope and drag is heated to the required temperature. It is then fitted over a box containing the mixture of sand and the thermosetting resin. Next, this box is inverted such that the sand resin mixture falls on the hot pattern, this cures layer of the mixture to a certain extent and forms a heard shell. Once the desired thickness of shell is achieved the box is rotated back to its original off side position, the excess sand then falls back into the box, thus forming a shell over the pattern.

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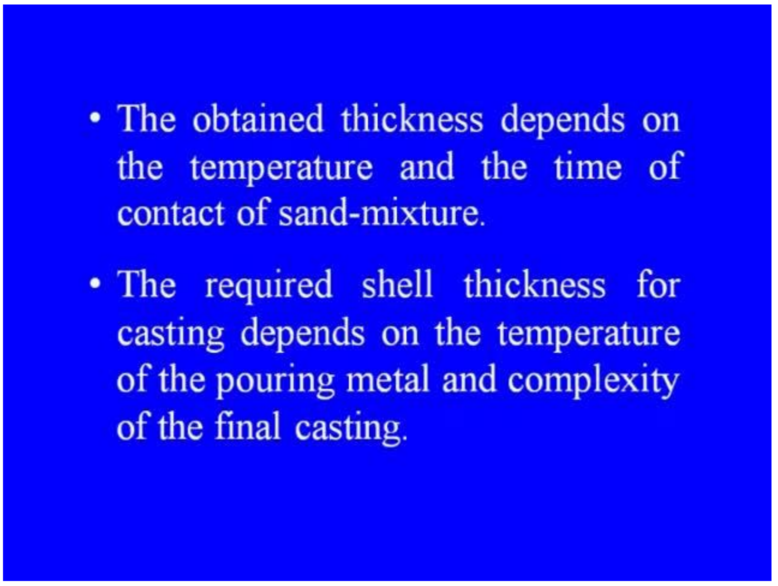

The obtained thickness depends on the temperature and the time of contact of sand mixture. The required shell thickness for casting depends on the temperature of the pouring metal and complexity of the final casting. The shell thickness can range from 2 to 8 millimeter depending on the requirements. In order to complete the curing process the sand shell along with the metal plate is heated in an oven for calculated time.

The heat from the pattern helps in melting of the resin and formation of the bond with the sand thereby forming the, the obtained shell mold from this process is removed from the pattern. Now, the two portions cope and the drag of the shell mold which are manufactured by the similar process are thereby assembled. It forms the complete mold along with the gating system.

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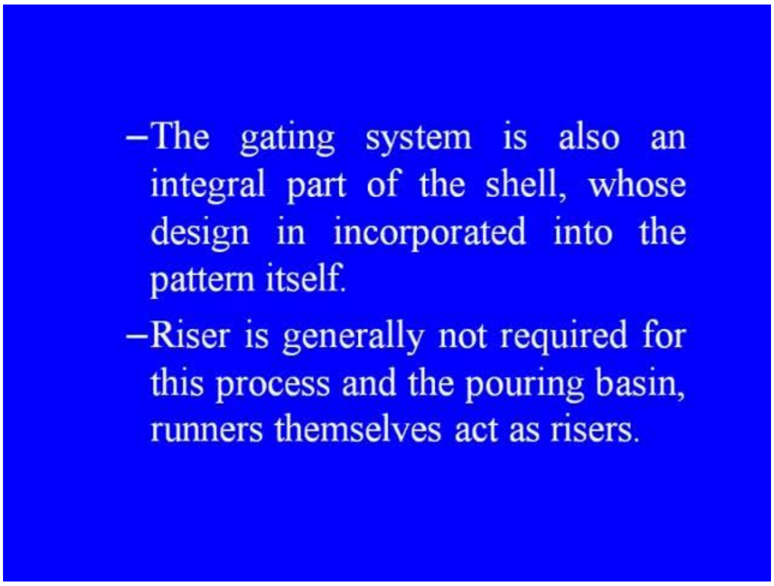

The gating system is also an integral part of the shell whose design is incorporated into the pattern itself. The riser is generally not required for this process and the pouring basin runners themselves act as risers. Some sand particles or metal shots are used in a box for support purpose to add stability to the shell and a pouring is done. After it gets cooled the finished casting along with spew is taken out and fettling is done. The sequence of the discussed steps are illustrate in this figure.

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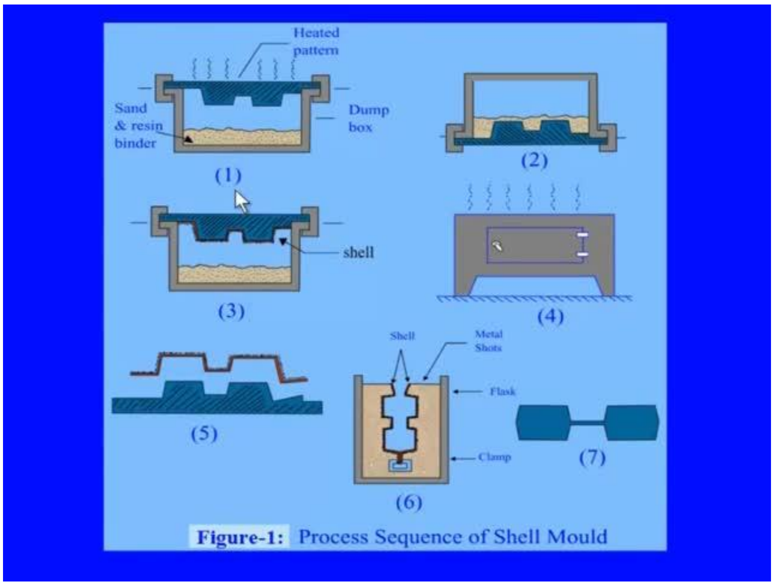

Figure-1: Process Sequence of Shell Mould

In this first step sand and resins with resin binder kept like this. The pattern is heated to some extent; the entire thing is kept on this box. Now, this is, the box is inverted as can be seen in the screen. The shell is prepared like this, again it is made upright, then it is kept inside an oven for heating, in which the binder gets melted and binds the sand and then the mold is ready. And if there are two halves, the two halves can be assembled like this. This is placed in a flask and clamped. This forms the shell for the casting to be made like this which will eventually produce the casting like this.

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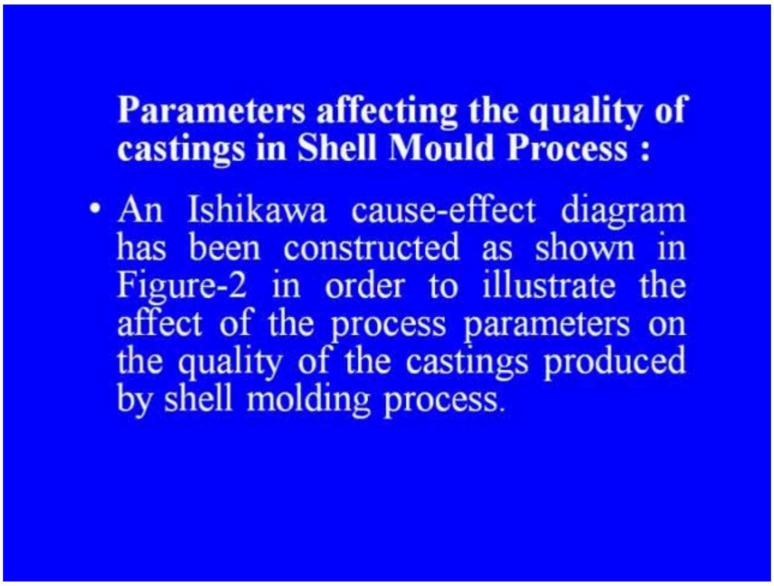

Now, let us also see the parameters affecting the quality of casting in shell molding process. An Ishikawa cause effect diagram has been constructed as shown in the next figure in order to illustrate the affect of the process parameters on the quality of the castings produced by shell molding process. This we have been doing for almost all the processes for correlating the influence of the process parameters with that of the quality of the process.

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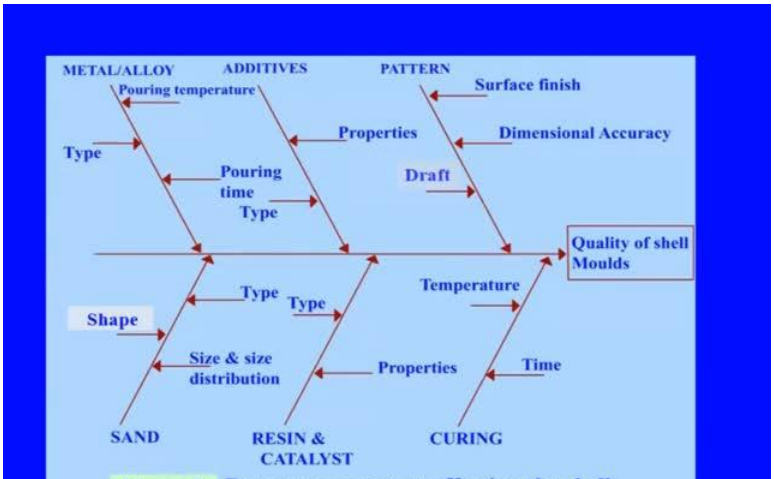

Figure-2: Process parameters affecting the shell molding process

Here is the process Ishikawa cause and effect diagram in which as shown in the screen there are groups of parameters like metal and alloy base parameters which includes pouring temperature, type of the metal or alloy and then pouring time. Then another group is based on the additives which includes the properties and the type of the additives. This ultimately affects the quality of the products being produced by this process. Then there are few pattern based parameters as you can see in the screen like surface finish, dimensional accuracy of the pattern and then draft.

The other parameters based on the sand which are considered to be very important are the shape of the sand, the type of the sand and the size and size distribution of the sand, for this size and size distribution influences the finishes that are, that can be obtained. Then other parameters like resin and catalyst based parameters, in this also the type of the resin and catalyst and their properties these can influence the overall quality of the product. The other important category of parameter is curing based parameters. Here the curing temperature and the curing time are the most important parameters that affects the ultimate quality of the products.

The process parameters that affect the casting quality are shown here; this qualities are dimensional accuracies, thin surface roughness, mechanical and other metallurgic properties. How this metal or alloy based parameters can influence the product?

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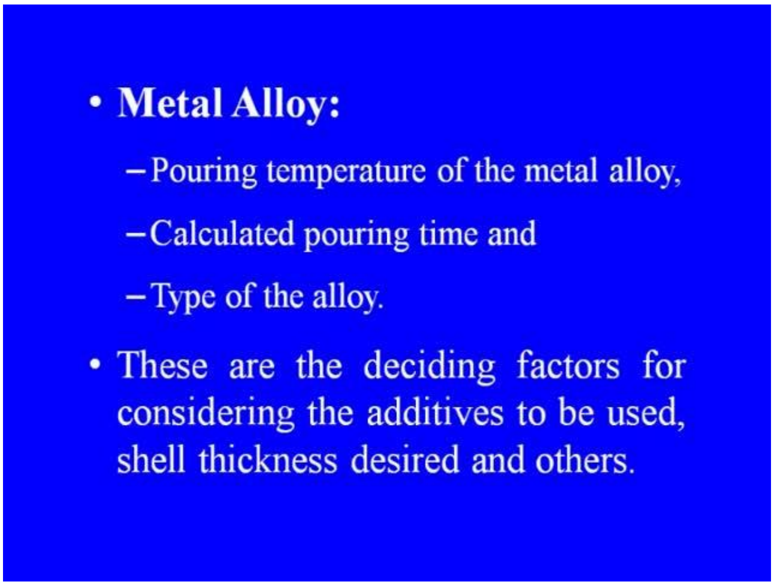

These are pouring temperature of the metal and alloy, then calculated pouring time and type of the alloy. These are the deciding factors for considering the additives to be used, shell thickness desired and others. Then in the category of additives this use of correct additive and its composition is decided considering the following factors.

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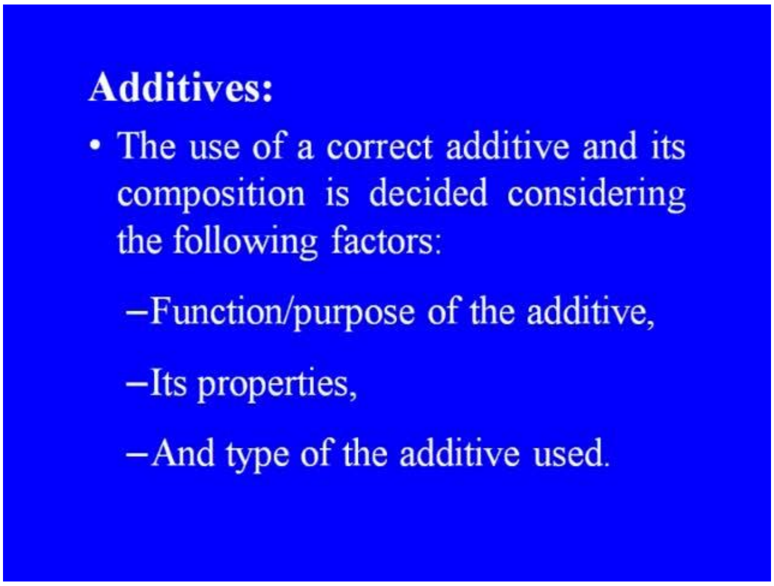

Number one, function or purpose of the additive, its properties and the type of the additive used, then the pattern, the pattern design is crucial and has a profound effect on the end casting quality in terms of the following.

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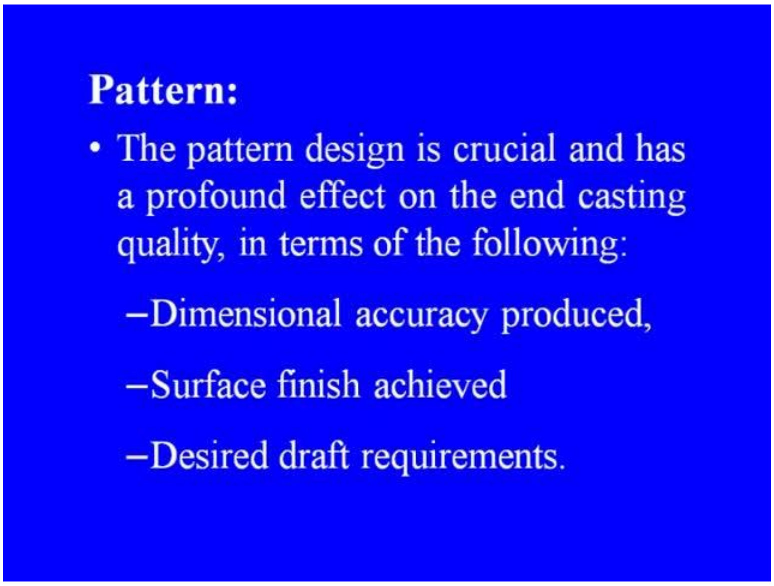

Number one, dimensional accuracy produced, number two surface finish achieved and number three desired draft requirements. Now, let us see little about optimum pattern design. Minimum values for dimensional finish and lesser draft can be set. Since, the process inherently provides good surface finish. The draft can be negligible as the shell is broken out to take the finished casting from it.

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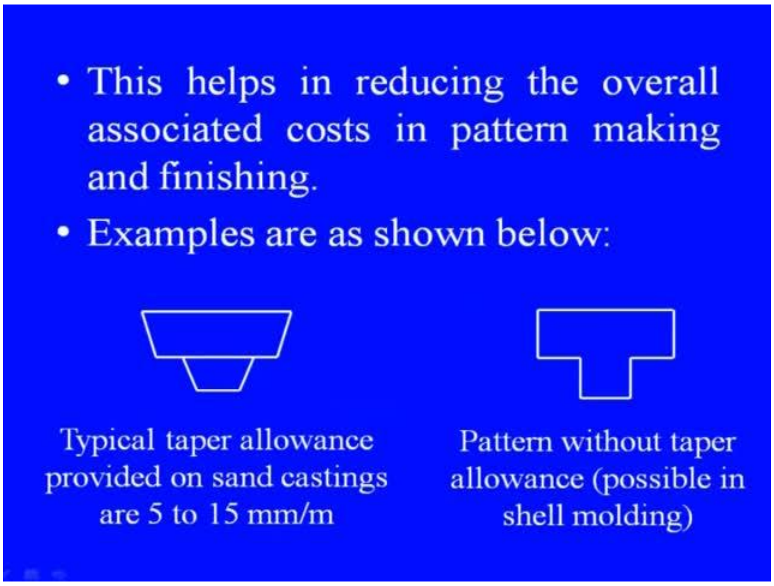

This helps in reducing the overall associated costs in pattern making and finishing. The examples are given here, this is a typical taper allowance, this is a pattern with taper allowance on sand sand castings which is 15 to 5 millimeter per minute, but here is a pattern without taper allowance which is possible in shell molding. Now, let us see little details about the sand used.

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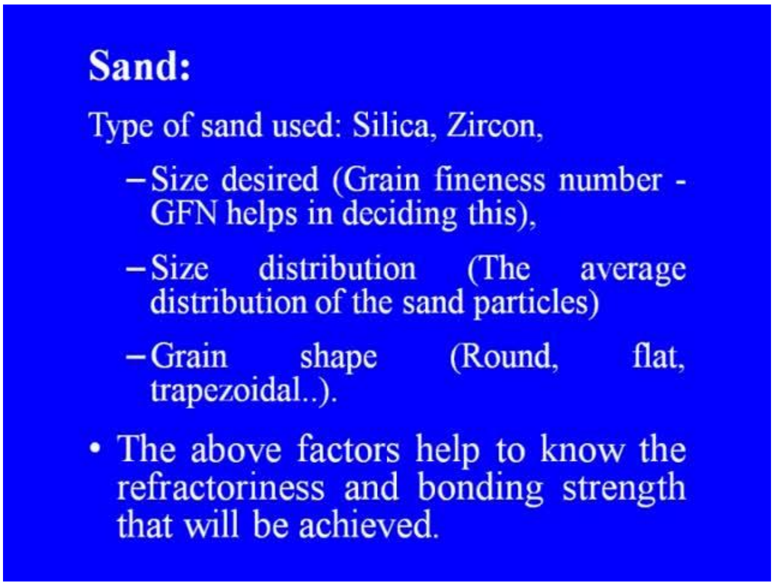

The type of sand used in shell molding are silica and zircon. So, they depend on the size desired then in this size the factor which is considered is GFN that is grain fineness number that helps in deciding the size. Then size distribution, the average distribution of the sand particles then the grain shape where they are round, flat or trapezoidal.

The above factors help to know the refractoriness and bonding strength that will be achieved. Sands of much smaller grain size than normal castings can be used in the shell molding process which nearly flat shapes it provides excellent surface finish. The shells have to be properly blended as a high volume of gas is evolved due to the resins and binders used.

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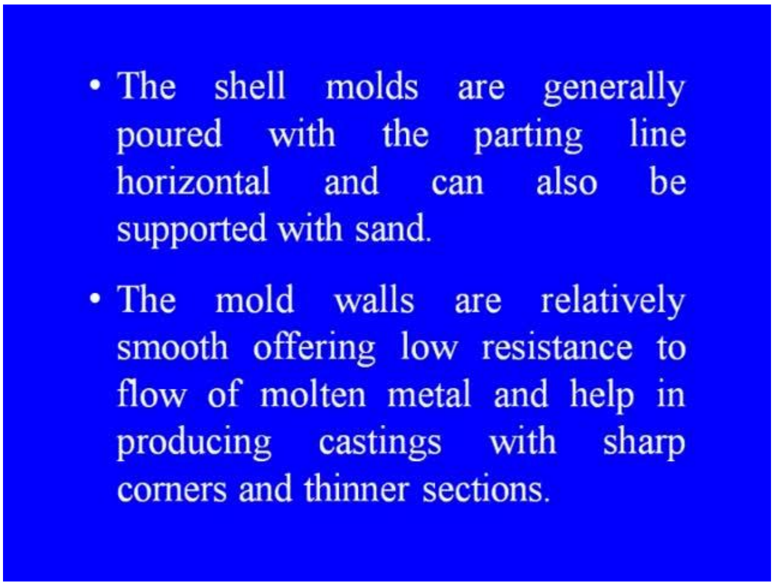

The shell molds are generally poured with the parting line horizontal and can also be supported with sand. The mold walls are relatively smooth offering low resistance to flow of molten metal and help in producing castings with sharp corners and thinner sections. Multiple gating systems can be used to produce several castings with a single mold. This can increase the economics of the process. Now, let us see some little details about resin and catalyst.

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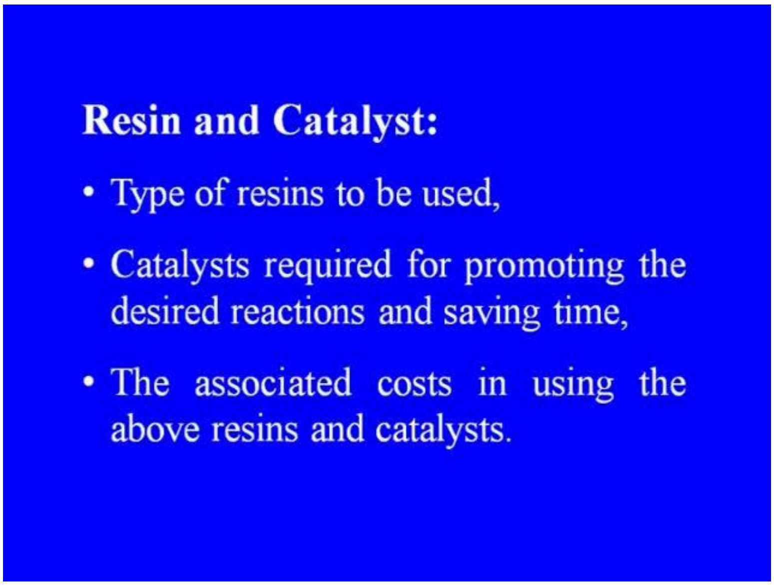

Catalysts required for promoting the desired reactions and saving time. The associated cost in using the above resins and catalysts are to be considered. The type of resins used should be considered.

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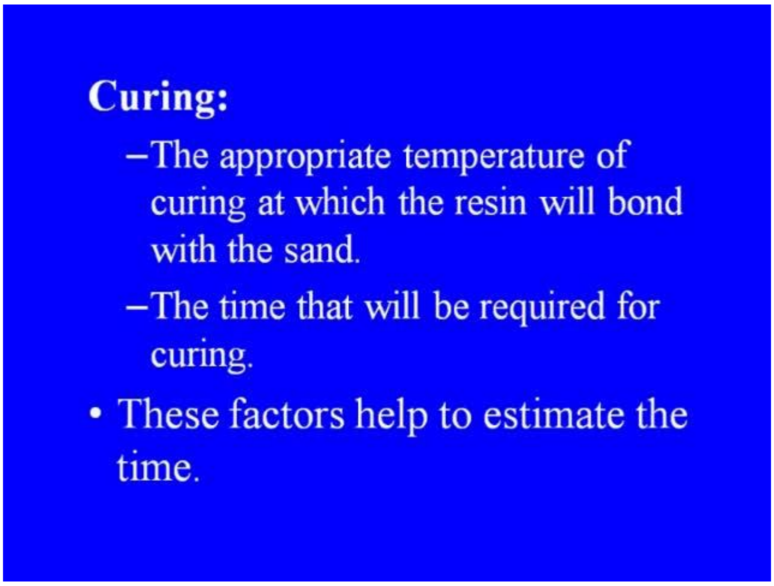

Then the importance of curing, the appropriate temperature of curing at which the shell will bond with the sand, the time that will be required for curing. These factors help to estimate the time. Now, let us look into the functions of additives. Additives may be added to the sand aggregate to further enhance the surface finish of the casting. It also improves the strength of the mold, and develops the resistance to thermal cracking and distortion.

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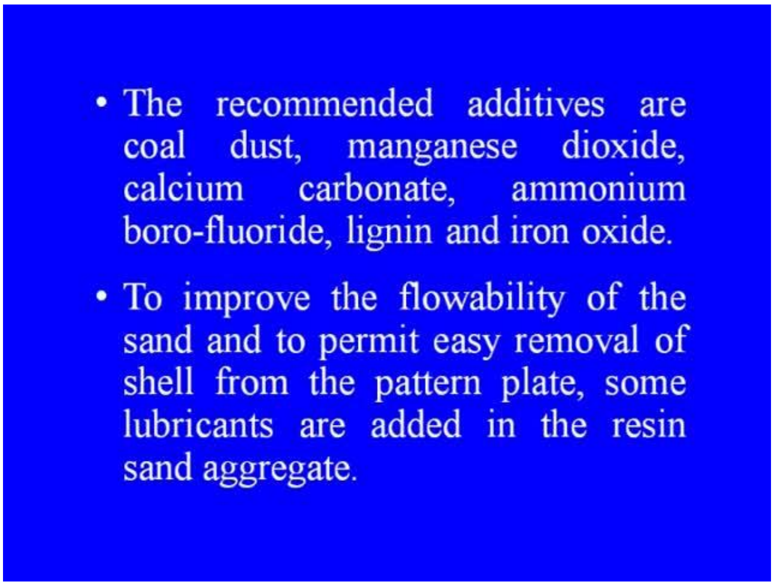

The recommended additives are coal dust, manganese dioxide, calcium carbonate, ammonium boro fluoride, lignin and iron oxide. To improve the flow ability of the sand and to permit easy removal of shell from the pattern plate, some lubricants are added in the resin sand aggregate. The common lubricants used for such processes are calcium or zinc stearate.

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Now, let us see composite shell molds using two or more different materials excellent shells can be made for the process of shell molding. In typical applications such as turbines and impellers some additional elements are desired to be added in the mold for getting special properties as desired. The normal ingredients in the shell molding include sand, binders, graphite and some metals.

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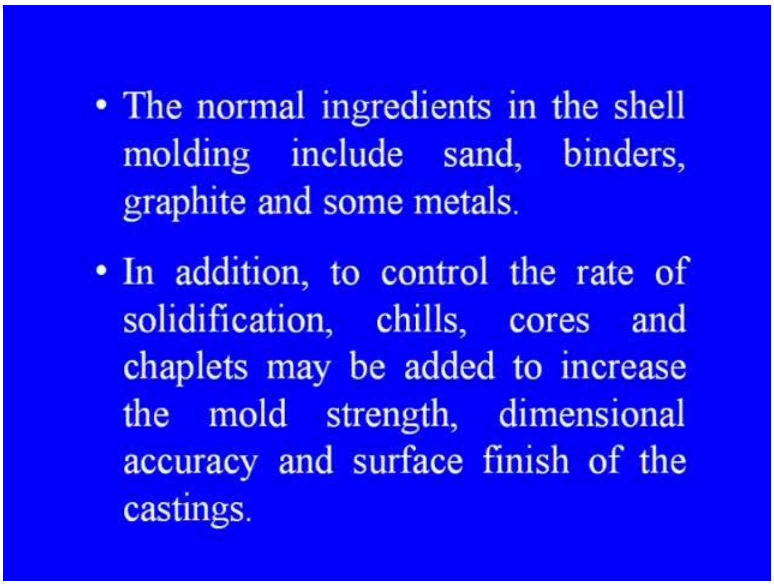

In addition to control the rate of solidification, chills, cores and chaplets may be added to increase the mold strength; dimensional accuracy and surface finish of the castings. Now, let us look into the key benefits from shell molding process.

The process gives higher permeability than any other casting process. Over permeability is a major issue in any casting process leading to defects in the castings such as blow holes, pin holes and porosity. The shell thickness being much smaller as compared to other molds, the permeability increases. As the thickness of shell is very small it allows the the escape of gases very easily to the atmosphere resulting casting which considerably less defects. Due to this the surface quality is also better. Now, let us quickly look into the applications of this process.

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The shell molding process has been widely accepted for producing castings where accuracy and surface finish are the prime requirements. They are mainly required in automobile and hydraulic applications. Small mechanical parts requiring high precision such as gear housings, cylinder heads and connecting rods, these components can be manufactured by the shell molding process.

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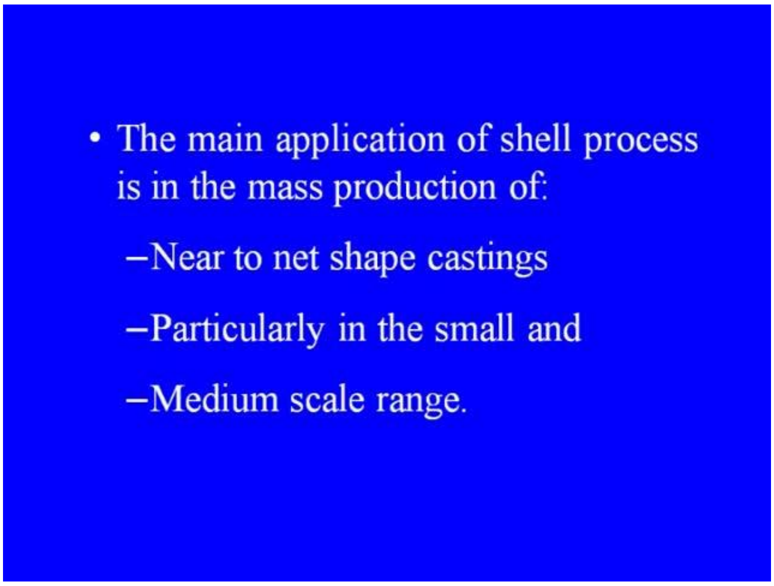

However, the main application of shell molding process is in the mass production of near to near net shape castings particularly in the small and medium scale range. The versatility of the process enables it to be used for all types of metals both ferrous and non ferrous. Examples are cast iron, (( )) cast iron, carbon steel, high alloys, stainless steel, manganese steel, aluminum and copper alloys. The shell molding is also used in making high precision molding cores. Nearly, any metal suited for sand casting can be cast by shell molding process. The relatively higher cost of metal patterns compensates as the production size increases. The process can also be easily automated.

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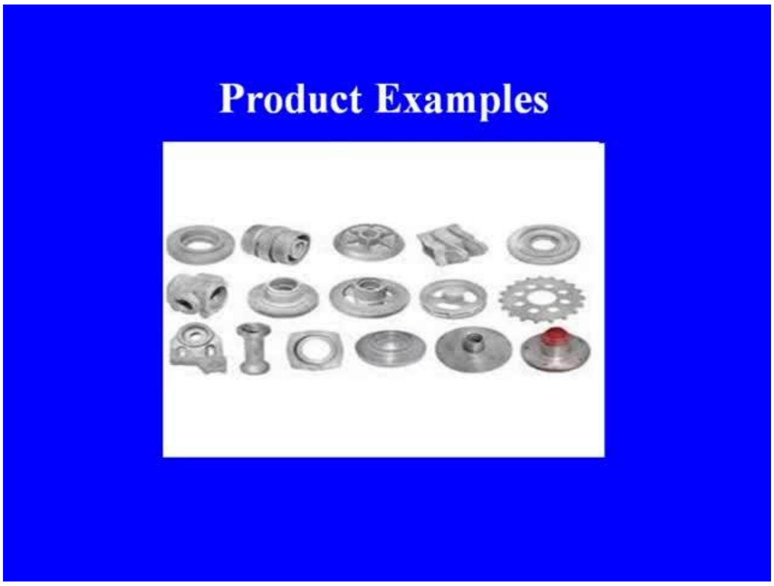

Here, are the few products. Some examples of the products manufactured by this process.

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Here, we can see easily even the complex sieves can be manufactured by this process. In the previous figure you have seen some of the parts that requires precision and very high surface quality can also be produced using this process.

Now, let us summarize what we have studied in this session. In this session we have discussed about the steps in shell molding process. We have also identified the key factors that affects the process quality in this casting. We have also discussed the advantages and limitations of the process.

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- Advantages and limitations of the process,
- The sands used, resin types along with their coating processes, and
- The major applications of the process.
- We hope, this session was knowledgeable and enjoyable.

The sands used, the resin types along with their coating processes have also been indicated. The major applications of the process have been mentioned and we have seen the working steps of this process. We hope this was an interesting session.

Thank you.