SHELL CASTS OUT AN ADVANCED MOULD TECHNOLOGY

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Shell molding process was invented by Dr. Croning in Germany, hence this process is also called as a croning process. The process was introduced in the German foundries in 1953 for making moulds & cores. At initial stage silica sand is mixed with powdered phenolic resin containing curing agent. The main disadvantages of this kind of simple mixing were segregation of resin & sand, particularly when cores were blown; low strength & heterogeneous mixture; slow curing rate & dust. To overcome this problem, the sand was warm coated with Novolak phenolic resin dissolved in alcohol. This helped for better strength at lower addition of resin, good curing characteristics & little or no dust problems.

A variety of coating methods for shell moulding sand have been introduced over the course of years; all of these contributed to the qualitative improvement of resin coated sand. E.g. warm coating to hot coating. Recently use of high speed mixtures with low monomer and reactive resins showed much better results. Also lot of work is done over the suitable shell sand having good disintegration properties for light metal alloys & cores like water jacket for cylinder heads & blocks.

In short, the development of sophisticated resin, better resin coating techniques & the evolution of automatic & semiautomatic production machines has helped the shell process to remain competitive in spite of competition from other processes. Shell is a process which is simple in many ways to operate than many competitive processes. The versatility of the process enable it to be used for all types of metals both ferrous & nonferrous e.g. cast iron, s.g. iron, carbon, steel high alloys., stainless steel, manganese steel, aluminum & copper alloys.

The main application of shell process is in the mass production of near net shape casting particularly in the small & medium range. Shell process has been widely accepted for producing the casting for automobile & hydraulic application, where accuracy, surface finish is the prime requirement.

The shell process has several unique properties which makes it an important process to the foundry. These properties can be briefed as:

- Dry free flowing mix
- Excellent Blow ability
- Can use very fine sand
- Excellent casting finishes
- Accurate dimensions of castings
- High thermal stability
- Hollow cores possible
- Low sand to metal ratio
- Cores have high humidity resistance
- Coated sand has indefinite shelf life.

Industry Trends of Shell Process

In past most of the foundries having Shell molding process use to make their own resin coated sand, but recent trend is the increased use of commercially available coated sand. Foundries of all sizes have realized the benefits of purchasing sand for their shell process. More & more foundries will convert to commercially coated sand in feature because of the following reasons:

- Capital expense is reduced
- Emission are reduced
- More floor space in made available
- Productivity is increased
- Customized formulation are available
- Latest technology is available

Recent Advantage in Shell Technology

- Application oriented special sand is available
- Faster curing resins are available
- Faster built-up
- Faster shakeout shell sand.

All these recent advantages have significant effect in terms of reducing casting cost & improving productivity in the following ways as follows:

- Improved de-coring for aluminum casting
- Accelerated cure speed
- Elimination of peal back
- Operational flexibility

One of the latest technologies in Shell sand is new formulation which offers greatly helps for better shakeout for aluminum casting. Many times the casting needs to be baked at 400-500^0 c to thermally break down the cores and remove them from the castings. This is a expensive process. The new shake out shell sand have greatly altered break down characteristic & reduced or eliminated these problems. With this new development, hollow shell cores may offer the best shake out of any binder system available.

Benefits of Shell Process

- **Excellent Surface Finish:** Shell sand process has ability to produce casting with excellent surface finish & capacity to produce fine detail.
- **Dimensional Accuracy:** The process has an ability to produce casting to tight dimensional tolerance. Due to this characteristic machining allowance can be reduced which ultimately helps for reduction in fettling and finishing cost.
- The shell process accommodates easily deep drawer patterns with less taper than conversional production processes.
- **Hollow Cores:** With the shell Sand hollow cores & thin profile moulds can be possible. This characteristic gives economics of Sand usage & ease of handling. Hollow cores increases the permeability hence usage of fine Sand is also possible.
- **Sand to Metal Ratio:** This is the only process which given hollow cores & thin walled mould, which results in substantial weight reduction and material saving. Normally sand to metal ration is 1:1 which is much lower than other processes.
- **Ease of Handling:** Shell Sand moulds and cores are exceptionally resistance to damage through handling and storage. This happens due to high resistance to humidly. The shell cores and moulds can be stored for month without difficulty.
- **Resistant to Moisture Pickup:** The shell process is resistant to moisture pick up. The shell cores and moulds can be stored for long period even in high humid conditions. The resin used for shell process is stable and moisture resistant.
- **Simple Process:** The shell sand is supplied in the form of ready to use & thus need not require sand mixers etc where as other processes requires precise measuring and mixing of binders and catalysts.
- **No Skill is Required:** Since every thing is ready to use, with minimum training any worker can produce, repeatedly, precision moulds and cores.
- **Excellent Flow-Ability:** Due to the dry coating on sand, it gives better flowing ability and blowing ability than processes based on wet sand mixes. This property of shell sand helps for the production of intricate cores and moulds, and cores to be blown to a greater density. Better flow ability of shell sand also helps for blowing coarser and high permeable sand which is may not be possible with other processes e.g. cores for water jacket.
- **High Out of Box Strength:** Shell sand after curing has very high out of box strength. This property of shell sand helps to produce ultrafine and intricate cores, which are required to suit the demands of modern advanced engine design and enable foundries to operate just in time production methods.
- **Less Inclusions & High Thermal Stability:** Shell sands are less prone to erosion by molten metal, because of high thermal stability of the phenolic resins, This characteristic of shell sand helps to reduce nonmetallic, burn in & scabs etc.
- **No Need of Refractory Wash:** Since cores or molds are cured in contact with pattern resulting is better surface finish of molds or cores. This helps for castings with accurate dimensions. But sometimes cores or molds may require refractory wash for specific purpose.
- **Little or No Pattern Wear:** Since patterns are made up of cast iron, very little or no wear is observed resulting longer pattern life. This helps to produce "N" number of casting without any dimensional problems.
- **Longer Shelf Life:** Shell sand has indefinite shelf life, if properly stored. Thus shell sand can be stored and used as needed by the foundry.
- **Low Capital Investments:** Molds and cores making equipments is of moderate cost and where necessary can be added as cells. In shell process, bases sand can be easily changed to suit specific requirement of the casting.
- **Economics:** Though the basic of shell sand is more than any other processes hollow cores, contoured shells, back up systems low fettling and cleaning, with good dimensional accuracy, makes process economically viable.

Disadvantages of Shell Process

- **High Cost of The Process:** Phenolic resins used for the shell process are costly & at the same time % usage of resins are high compared to other processes. Hence process requires a tight control of the shell thickness otherwise competitiveness of the process will be sacrificed.
- **High Tolling Cost:** Shell process is thermoset & requires high temperature to cure, hence patterns used are of cast iron with smooth surface have very low expansion coefficient. All these results in costly affair compared to other processes.
- **High Energy Cost:** Shell process operates at around 250^0 C toding temperature which requires energy either by the way of electricity or L.P.G. The cost of energy is very high, when compared with other processes.
- **Cycle Time:** Comparatively cycle time required for shell process in more than either cold box or CO_2 processes.
- **Limited Casting Weight:** Shell process in best for small intricate light weight casting. With shell process casting weight up to 80kg is produced.

Irrespective of all there limitation shell process finds a wide range of application are to be seen worldwide particularly in automotive & hydrolic casting. In Japan almost 90-95% of core making is in shell process.

Raw Materials Required for Shell Sand

For manufacturing shell sand, following inputs are necessary

- Silica Sand
- Zircon Sand
- Aluminum Silicate Sand
- Chromites Sand
- Phenol formaldehyde novolak resin
- Hexa catalyst with lubricant
- Various additives

The formulation and process of shell sand is decided by the need of particular casting. Sand suitable for the shell process vary over a comparatively narrow range of purity, grain size, grain structure & grain distribution in addition to this, chemical analysis, sintering point, thermal expansion & retained moisture vitally affect the performance of shell sand.

Common shell process foundry problems which arise from improper selection and handling of bulk sand may be defined as:

- Rough as cast surface finish due to poor packing characteristics of segregated natural sands.
- Rough as cost surface finish in deep pockets due to low sintering point of sand.
- Veining and run outs due to poor thermal shock resistance of the molds and cores.
- Dimensional variance in casting due to thermal expansion of sand
- Excessive binder requirement due to sand grain surface contaminants.

It is an experience of foundries that low cost, poor quality shell sands generally produce high cost, low quality casting.

Silica Sand

Silica sand is the basic material for making shell sand. In India variety of silica sands are available with various characteristic. The ideal silica sand for shell process should have following properties:

1. Grain Shape	Round to sub angular
2. Clay Content	0.2% max
3. Chlorides 0%	
4. Carbonates 0%	
5. acid demand Value	<6 ml of KOH/100 gm of sand
6. Silica Content	98% min
7. Loss on ignition	0.2% max
8. AFS No 50-80	
9. Sieve distribution	Min 80% retention on there consecutive sieve
10. Loose bulk density 1.4 gm/cc min	

In India silica sand from various source in used for shell sand e.g. Alahabad, Rajkot, Mangalore, Godur, Phonda etc. Some sand are from coastal belts & some are from mines. Normally coastal belts & some are from mines. Normally coastal sands are round to sub angular with good sieve distribution where as mine sands are angler with erratic sieve distribution.

distribution.

Effect of Grain Shape

For foundry terminology, sand grain shape is referred to as round sub angular and angular. Round grain sands required less binder for high cold strength, but less hot strength with high permeability. Where as angular sand results in lower cold strength and higher hot strength with low permeability. Sub angular sand grain exhibit the best compromise between low resin binder content medium cold strength & high hot strength. Shell moulds & cores made with sub angular sands show least tendency to washing and metal penetration.

Effect of Grain Size

Silica sand grains size has direct effect on the refractory properties of sand mass. The finer the grains are, the lesser the refractory mass is. But in case of shell sand, carbonaceous residue of burned out synthetic resin binder improves the refractory property of the mass. So that much finer silica sand can be used without any problem.

Sand grain size also decides the usage of binder to maintain the required cold and hot strength properties Surface area of the individual grains increase with decrease in fineness.

Zircon Sand

Zircon sand is very costlier than silica sand, but some of special applicators requires zircon sand. Zircon sand has following inherent advantages.

- Low thermal expansion i.e. only one third of silica sand resulting in greater dimensional accuracy
- High sintering point of 2150-2250^0 C hence no rough as-cast finish in deep pockets also

  High thermal conductivity which helps for eliminating veining and run-outs.

The blending of zircon with silica sand is not recommended for use in shell process. Zircon has twice the thermal conductivity and twice the density of silica sand i.e. zircon can absorb twice the amount of heat twice as fast, which also means it has about four times the cooling rate of silica sand. This fact should be borne is mind when light sections are being cast on zircon moulds and cores particularly in case of grey iron, undesirable hardness may be encountered.

Aluminum Silicate & Chromite Sand

Since zircon sand is costlier some times aluminum silicate of chromite sand may be used. Both the sands have high sintering point & low thermal expansion than silica sand.

Phenol-Formaldehyde Resins

For manufacture of shell san, phenol, formaldehyde novolak resin is used as a binder. The form of resin may be liquid or flake. Liquid resin is nothing but is a resin dissolved in alcohol. Liquid resin is used for manufacturing shell sand by either warm air process or by ignition process where as solid or flake resin is used for hot coating process. Most of Indian manufacturers of shell sand are using liquid resin, because of easiness of resins of the process.

Generally following properties of resins are checked as a acceptance criteria.

Liquid Resin

- Clarity
- Viscosity
- Sp. Gravity
- Solid content
- PH value
- Coated sand properties at certain % age of resin.

Solid Resin

- Softening point
- Flow rate
- Particle size

In a recent development, the reactivity of resins has been increased to reduce the curing time. Resins are made more thermo resistance to reduce the veining at the same time breakdown after casting has been improved. Low nitrogen & nitrogen free resins are also developed.

Hexa Catalyst

Since phenol formaldehyde novolak resins are thermoplastic in nature & required formaldehyde donor to cure at certain temperature. Thus after blend of resin & hexa catalyst process becomes thermo set & formation of shell moulds & cores becomes possible. Hexa catalyst is nothing but it is a blend of hexa methylene tetra amine (formaldehyde donor) & lubricant. Lubrication helps for the flow ability of shell sand. Hexa catalyst is supplied & used in the form of fine powder.

Additives

Shell moulds & cores mixtures are composed of sand, resin & additives. Sand provides the refractory property, the resin provides the adhesive property & additive provides the mould or core metal reaction inhibitor properties. While using additives their effect on permeability should be considered.

Research on various additives has resulted in the development of shell sand with unique properties which reduce fining, increases high temperature strength and minimum exothermic effect of resin decomposition.

Manufacturing of Shell Sand

Shell sand is manufactured by three processes i.e.

- Warm air process
- Hot coating process
- Ignition Process

Warm Air Coating Process

It is the widely accepted shell sand manufacturing process in India. The process requires special coating mixture with PLC controls for producing best quality of shell sand. The process can be briefly described as follows:

First, preweighed quantity of sand is charged into a mixer followed by hexa catalyst and mixed for 40-60 seconds. Phenolic novolak resin dissolved in alcohol (Liquid resin) is then charged & mixed for 2-3 minutes. After this alcohol solvent and water if any is driven off by flow of warm air for 4-6 minutes. During the coating process balling and builtup is observed followed by disintegration of lumps. At this stage coated sand is discharged coated sand temperature is maintained 60-65^{0}C, for ensuring complete evaporation of solvent/water. After disintegration and screening the coated sand is passed through cyclone where light non siliceous particles are removed & coated sand is cooled to room temperature. Cyclonised coated sand is stored in bunkers of bags.

Hot Coating Process

This process of manufacturing shell sand is adopted by most of developed countries. For this process most sophisticated coating plant is required. The process can be briefly described as follows:

The sand is heated to 120-150^{0}C. The resin in the form of flake or granulate is subsequently added to the mixer, melts and sand grains are coated. The hexamine is then added as an aqueous solution. A certain quantity of water is also added if required. The cooling effect produced prevents premature curing of binder. Lubricant like calcium separate is promotes collapse of the sand lumps in the mixture and serves as a partening agent in mould/core production. The water is driven off by a flow of warm air. After this, sand is discharged into disintegrator which is followed by vibratory screen for further lump braking and passed through a cyclone to remove fines & to cool coated sand to room temperature. Free flowing coated sand is stored either in bags or bunkers.

Process Control Procedures

The shell process is a science. Hence the control of finish product must be accomplished by constant checking, sampling & analyzing at every stage of the manufacturing process form raw material to finish product. This is required to produce precision cast part to consistently closed dimensional tolerances & rigid metallurgical specifications.

Phenolic Resin

Liquid resins are stable, but their solvents will evaporate when exposed to high ambient temperature. Thus errors in formulation can occur due to change in solid content. Solid resins are used since they are hygroscopic results in detoriation in strength.

As a process control every time one standard batch of shell sand should be produced & checked for all required parameters for consistency.

Formulation

All the steps in formulation must be carried out with great care, accuracy and cleanliness. Weigh scales used for binder & other ingredient must be check calibrated against dead weight at regular intervals & recorded in logbook.

The check test should simulate as near as possible the operation condition of the mixture on the production machine. If only standard test like tensile or transverse are carried out under ideal condition, it is difficult to correlate results with problems that arise from time to time on production line.

Pattern & Core Box Equipment

Once pattern and core box equipment has been designed and approved by the customer, it is necessary to have a rigid preventive maintenance as a part of the over all process control procedure. Before being placed in a storage, pattern and core boxes should be thoroughly cleaned with mild abrasive or cleaning chemicals, By means of soft metal scrapers and wire brushes, all build up of silicone release agent is carefully removed from reentrant corners, particularly when pattern in with base plate.

At the time of reuse of pattern or core box from storage, following precaution should be taken

- Heat to about 100^{0}C
- Spray with heavy coat of 5% water emulsion of silicon release agent
- Continue to heat up to 200-230^{0}C
- Allow to cool down to room temperature.

Operating Temperature

This is noting but at which pattern or core box operates determines the mechanical properties of shell molds & cores. Their temperature should be checked at regular intervals on the production line by means of surface pyrometer in several different areas in order to determine the thermal gradient that may exist between the high projection on the pattern & base plate. The check test figures are then compared with setting on the dial of machine's temperature controllers. If there is an appreciable difference the thermocouple probes inserted should be withdrawn, cleaned and replaced. The thermocouple and or controller should be changed if the indicated surface temperature still different forms the check test figures.

Dwell and Cure times

The time a pattern or core box is allowed to dwell for investment and cure has a effect on mechanical properties of the shell mold or core, also production rates are affected. For this reasons, the times set up on a production machines in accordance with the job card record should be carefully checked at regular intervals by mean of a stop watch.

Release Agent Spray

The release agent is used on the pattern or core boxes to emerge a smooth, stress free release of the mould or core. The main requirement of release agent is to insure that all vertical faces of core boxes or pattern receive an adequate amount spray without accumulating an excessive amount on horizontal surface.

Each times a mould or core in ejected, the spray deposited on the vertical faces is removed almost entirely by the sliding action of the ejected mould or core, but majority of the spray is used to apply the silicon emulsion.

Pattern & Core Box Sealing

On both moulding & core making machines, silicon rubber sealing strips or ring are used to prevent waste of shell sand. Badly worn or damaged silicon seals between dump box frame & pattern, between blow faces & blow plates & between parting faces of split mould or core boxes will result in dimensional errors of the casting.

Mould & Core Assembly

The skills with which mould halves & associated cores are cemented together determine the run of the shop dimensional tolerances. Obviously, those dimensions that cross the parting line of mould, or depend on the prints, which cross the parting line, will vary in accordance with the core. This is the point in the overall process where technical supervision is needed.

The mould closing machines for vertical & horizontal moulds must be periodically checked for spring pressure or negative pressure, where closing by vacuum.