

## **CHAPTER 2**

### **LITERATURE REVIEW**

This chapter discusses foundry processes and focusses on the Shell Mold Process. The aim of this review is to provide a background understanding of factors which influence the casting processes, molding materials and molding methods. Particular attention is paid to the production of resin-bonded sand and the properties of resin bonded sand molds and cores.

#### **2.1 Foundry Processes in General**

Casting is the formation of a solid body of predetermined size and shape (a casting) from a material in melt or molten state by a solidification in a mold. Foundry technology is the art and science of the processes and materials used in manufacturing casting of metals and alloys. Most metallic materials may be formed by the casting process. The process is particularly applicable to mass production of standard parts (Trager, 1985). Casting production begins with melting of metal. Molten metal is then tapped from the melting furnace into a ladle for pouring into the mold cavity, where it is allowed to solidify within the space defined by the sand mold and cores. Thus, the mold material and molding method must be selected with care if satisfactory castings are to be made. Most ferrous castings are made in sand molds because metallic molds can not withstand the higher pouring temperatures usually used and hence wear out too quickly to be economical for ferrous metals production. Permanent molds may be used many times and are usually made of metal. For low and medium production runs, in non-ferrous alloys the lower tooling costs of sand molding give it an overwhelming cost advantage over

permanent molds or die casting (Piwonka, 1988). In case of sand molds, which are used only once, patterns or templates are required. Sand is placed around the pattern, normally inside a molding box, and is hardened by compaction (as in clay bonded sands) or by chemical/thermal means (as in chemically bonded sands). Cores are parts made of sand and binder that are sufficiently hard and strong to be inserted in a mold. The cores shape the interior of a casting, which cannot be shaped by the pattern itself. Cores are produced in core boxes; these are filled with specially bonded core sand and hardened much like the mold itself. A schematic of the sequence of operations for a typical part made by sand casting is illustrated in Figure 2.1.

Binder systems can also be divided into inorganic and organic types. Inorganic binders, such as clay or cement, are used in green sand or cement processes. Most organic binders are resins which are used in No-bake, cold box or heat cured processes. In the literature, chemical bonded sands refer to both organic and inorganic chemically setting systems but these days the majority of chemical sands systems use organic resins. In the No-Bake and cold box processes, the binder is cured at room temperature. For Shell, hot box and oven-bake processes, heat curing is applied. The selection of the process and type of binder used depend on the size and number of cores and molds required, production rate, equipment, and type of metal. Properties of the various resin binder systems are described and compared in Table 2.1 (Archibald and Smith, 1988).

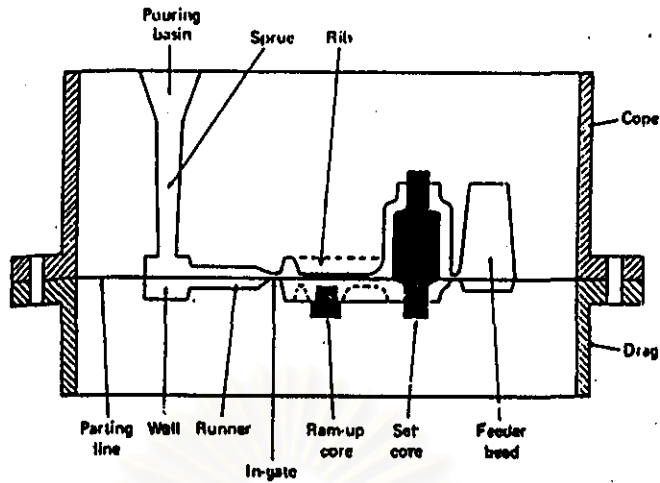


Figure 2.1 (a) Section through a typical mold

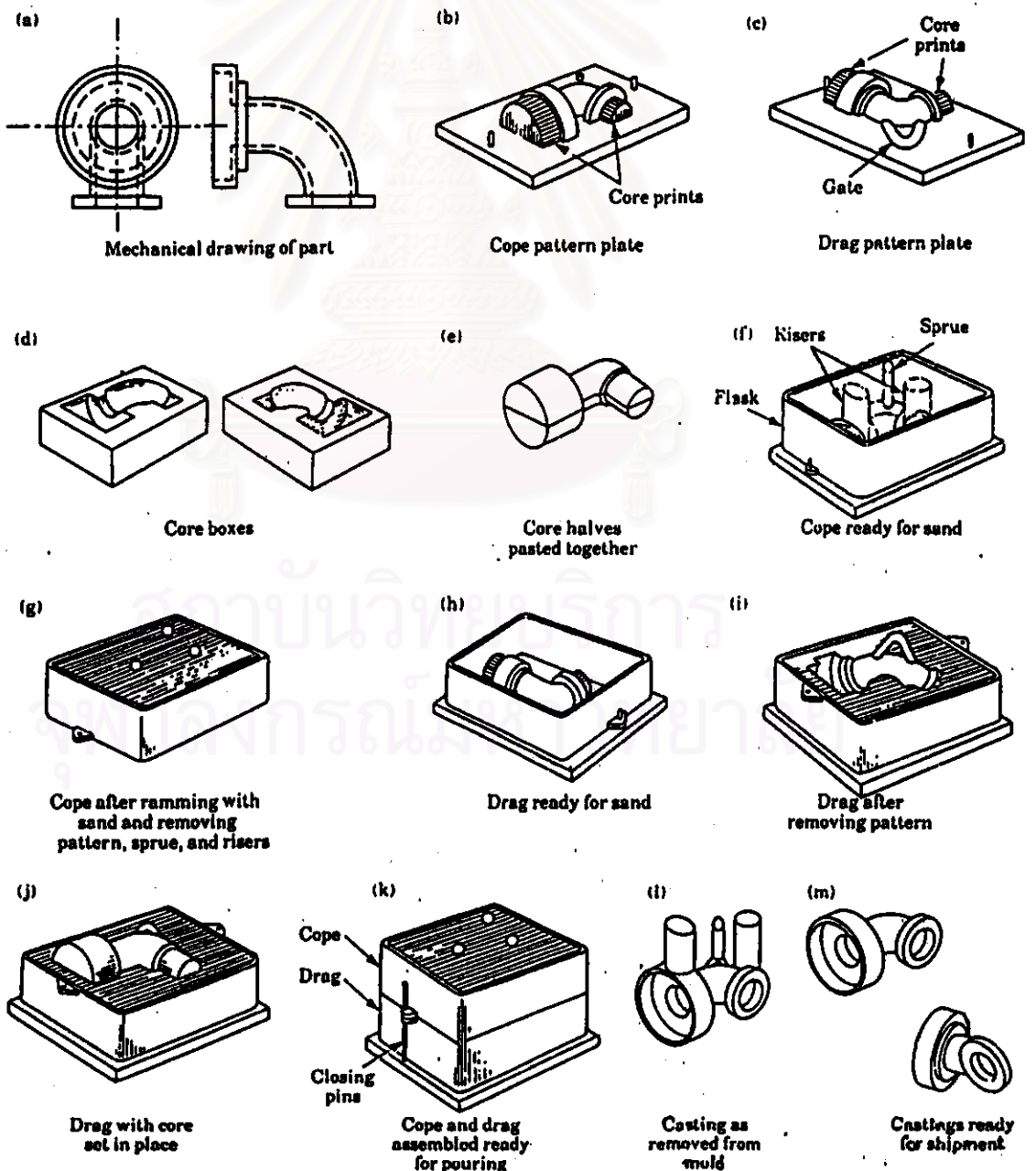


Figure 2.1 (b) Schematic illustration of the sequence of operations for a typical part

**Table 2.1 A variety of resin binder systems used in No-bake, Cold box and Heat-cured processes**

No-bake	Cold box	Heat-cured
Furan/acid	Phenolic urethane/amine	Shell process
Phenolic/acid	Furan/SO <sub>2</sub>	Furan process
Alkaline phenolic/ester	Silicate/CO <sub>2</sub>	Furan hot box
Silicate/ester	Phenolic/ester	Phenolic hot box
Oil urethane	Free radical cure (FRC)/ SO <sub>2</sub>	Warm box
Polyisocyanate		Core oil (oven-bake)
Aluminium phosphate		
Phenolic urethane		

No-bake processes and cold set processes are based on the ambient-temperature cure of two or more binder components after they are combined in contact with the sand in a sand mix.

Cold box processes involve the room temperature cure of a binder-sand mixture accelerated by a vapor or gas catalyst that is passed through the molded sand or core.

Heat-cured processes include hot box, warm box, oven-bake and Shell. In the hot box and warm box processes, the resin-sand mixture is wet. A liquid thermosetting binder and a latent acid catalyst are mixed with dry sand and blown into a heated core box. The curing temperature depends on the process. The oven-bake process is used in combination with linseed oil binder to produce a coated sand mixture. The wet sand mixture is then blown or hand rammed into a simple vented, relatively low-cost core box at room

temperature. In the Shell Process, the sand grains are coated with phenolic novolac resins and hexamine (curing reagent) and molds or cores are hardened thermally.

Cast iron is the most common casting; alloy steel, and nonferrous metals are used in smaller amounts. Most iron castings are made in "green" sand molds, which are uncured molds of sand, clay, and water. However, the use of shell moldings is growing, because this process permits reproducibility of castings with close dimensional accuracy. In addition, simplicity of equipment and procedures reduces costs.

## **2.2 Molding Materials**

Molding materials consist of the basic particulate material, a binder system and additive. The basic particulate materials, granular substances of adequate refractoriness, are mainly quartz ( $\text{SiO}_2$ ) either in form of clean silica sands or naturally bonded sands, and the non-siliceous materials such as Zircon, Chromite, and Olivine (Sarker, 1967). Silica sand is the most common sand used and constitutes 85% of aggregates used in the casting process. Zircon, Olivine, and Chromite sands are often referred to as specialty sands and are used for specific casting applications e.g. for steel castings. These sands have a much higher cost than the silica sand but offer specific advantages and, in some cases, disadvantages (Hoyt, 1995). Binder systems may be inorganic or organic, natural or synthetic. Sands must incorporate an appropriate amount of binder to give rise to the optimum degree of bond strength so that molds and cores may retain their rigidity. In general, several other properties of molding materials can be improved by additives. These are, for example, flowability, compactability, breakdown properties. Additives used include sawdust, calcium stearate, coal dust etc. The selection of a molding material and its bonding system depend on the type of metal being poured, the type of casting being

made, the availability of molding aggregates, the mold and core making equipment owned by the foundry, and the quality requirements of the customer (Trager, 1985 and Piwonka, 1988).

### **2.2.1 Sands**

Sands are sometimes referred to as natural or synthetic. Natural sands contain natural clay minerals and are "self-hardening" on compaction when tempered with the correct amount of water. Thus, the term "naturally bonded sand" is also used for sand molding. Synthetic sands have been washed to remove clay and other impurities to render sand suitable for bond strength development, carefully screened and classified to give a desired size distribution. Due to the demands of modern high pressure molding machines and necessary control of casting production, most foundries use synthetic green sands, in which clean silica sand is mixed with grinded clay binders and water to provide consistent molding characteristics.

Sands are described according to the method of deposition or formation such as sea, river, lake, glacial or wind-blown and according to the geological age or rock system in which the deposit occurs. Important properties of sand as basis molding materials are: 1) dimensional and thermal stability at elevated temperatures, 2) suitable particle size, shape, and distribution 3) chemically unreactive with molten metals, 4) free from volatile that produce gas upon heating 5) economical availability, 6) compatibility with binder systems, and 7) consistent cleanliness, composition and pH.

The size, size distribution, and shape of the sand grains are crucial in controlling the quality of the molds because they markedly affect the molds' performance with the

various binder systems. The grain shape contributes to the amount of sand surface area and that the grain size distribution controls the permeability of the mold. As the sand surface area increases, the amount of binder required must be increased.

The American Foundrymen's Society (AFS) has classified the grain shape of sands into four categories: 1) angular; 2) sub-angular; 3) compound; and 4) rounded, as shown in Figure 2.2 and 2.3. Angular sands have a low packing density and a high surface area and therefore requires significantly more binder and catalyst. The sub-angular to round classification is most commonly used, and it affords a compromise if shape becomes a factor in the sand system. Compound sands consist of multiple grain bonds into clusters. Their structures are the least desirable structure for foundry applications. Rounded sands have a low surface area and are preferred for making cores because they require the least amount of binder. These shape are also preferred to ensure the free flowing property desirable for the Shell Process (Elliott, 1988).

The distribution of grain size must be controlled to achieve good shell mold strength and density. Thus, control of grain size distribution is more important than control of grain shape. The grain size distribution including the base sand size distribution plus the distribution of broken grains and fines, controls both the surface area and the packing density or porosity of the mold. The porosity of the mold controls its permeability, which is the ability of the mold to allow gases generated during pouring to escape through the mold. If the porosity of the mold is too great, metal may penetrate the sand grains and cause penetration/burn-on defects. Therefore, it is necessary to balance the base sand distribution by adding fine sands. Most foundries in the United State use the American Foundrymen's Society (AFS) grain fineness number as a general indication of sand

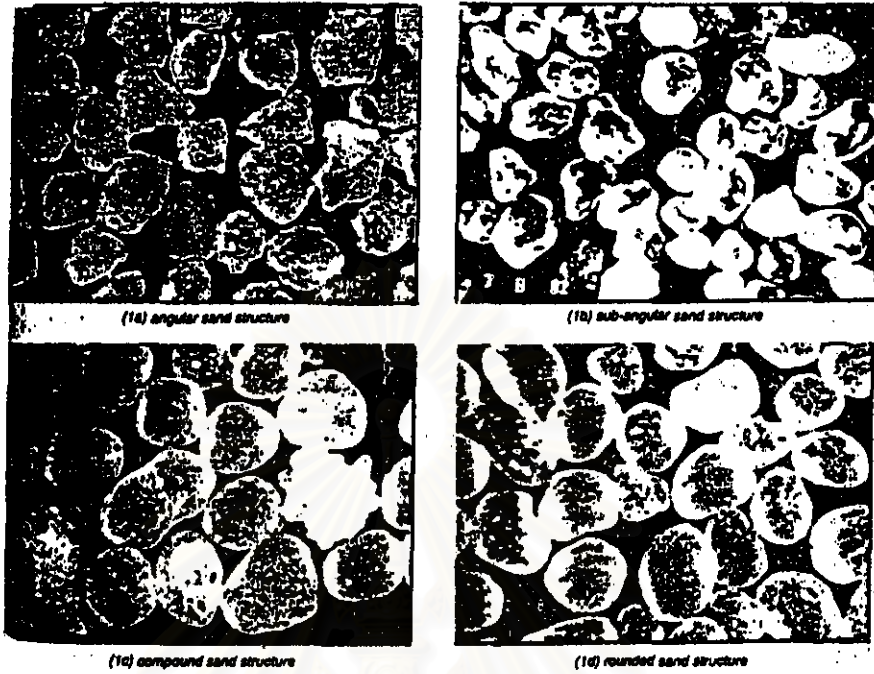


Figure 2.2 The grain shapes of silica sand (Hoyt, 1995)

						high sphericity	
							medium sphericity
							low sphericity
very angular	angular	sub-angular	sub-rounded	rounded	well-rounded		

Figure 2.3 Classification of grain shapes (Lemon, 1993)



fineness. The AFS grain fineness number of sand is approximately the number of openings per inch of a given sieve. It is important to understand that various grain distributions and grain shape classification can result in similar grain fineness numbers. Table 2.2 provides a sample sieve analysis demonstrating that two sands assigned the same AFS grain fineness number can have very different grain size distributions (Piwonka, 1988).

Table 2.2 Similarity in AFS grain fineness number of two sand samples with different grain size distributions (Piwonka, 1988)

USA sieve No.	Percentage retained	
	Sand A	Sand B
6.....	0.0	0.0
12.....	0.0	0.0
20.....	0.0	0.0
30.....	1.0	0.0
40.....	24.0	1.0
50.....	22.0	24.0
70.....	16.0	41.0
100.....	17.0	24.0
140.....	14.0	7.0
200.....	4.0	2.0
270.....	1.7	0.0
Pan.....	0.3	1.0
Total.....	100.0	100.0
AFS grain fineness No.....	60.0	60.0

Comprehensive studies on sand chemical composition were carried out by Lemon (1993). His important findings are that sand generally consists of the mineral quartz (specific gravity 2.6) which is a useful refractory material up to 1650°C. Sands of high silica content are essential to obtain good refractory properties in molding or core sand mixtures; this is especially important for steel and high temperature iron castings. If sands contain more than 0.5% potassium or sodium oxides (usually as feldspar and micas), burn-

on problems will occur on the surface about 0.1 mm. Calcium and magnesium oxides should not exceed about 1%. Sea sands, which often contain shell can also be troublesome as the calcium carbonate breaks down above  $800^{\circ}\text{C}$  to release calcium oxide, which can then reduce refractoriness.

Likewise, the quartz undergoes a series of crystallographic transitions upon heating. On heating at  $573^{\circ}\text{C}$  quartz expands due to the  $\alpha \rightarrow \beta$  inversion. Above  $870^{\circ}\text{C}$ , quartz transforms to tridymite, and this may result in contraction of the sand mold. At even higher temperatures of  $1470^{\circ}\text{C}$ , tridymite can transform to cristobalite. These volume changes in the sand mass can cause casting defects such as scabs and fins (Piwonka, 1988).

In Shell Process, the ideal base sand must have a consistently fine grading, narrow distribution, high silica content for good refractoriness, a round grain shape free from surface impurities and low fines content to enable minimum resin additions to be used. With modern sand processing plants the sand undergoes a complex treatment of wet attrition and acid treatment to produce the required grain surface conditions (Curtis, 1990).

Sand testing of the base sand (to be used with the binder system) has become increasingly more important to control casting procedures. The base sand comprises 98% of the mixed sand and clearly has a big effect upon binder performance and mixed sand properties. As mentioned earlier one common test for granulometry of the sand is a sieve analysis. This produces a grain size profile which is useful information for both characterization of sand and as a control test on the consistency of the sand. A grain fineness number or average grain size ( $\mu\text{m}$ ) can then be calculated on the basis of the sieve number or on the basis of the aperture size. In addition, control testing to assess the

surface condition of the sand is also important to ensure that the presence of contaminants is controlled to an acceptable level. This is particularly important where reclaimed sands are used. The usual tests for sand surface contaminants are loss on ignition (organics), pH (soluble contaminants), and acid demand (total alkaline contaminants) (Busby and Stancliffe, 1997).

The sand molds are used once only, therefore, the economics of a foundry operation require sand reclamation to reduce the costs and to reduce the problems with the control of environmentally undesirable contaminants in the discarded sand (Archibald and Smith, 1988). Nowadays reclaimed sand is the undeniable trend for foundry operations. The reclamation is frequently used to remove organic binders. Reclamation can be done by mechanical and/or thermal means. The properties of reclaimed sand have to be evaluated to determine the effect of residual binder, fines generated during reclamation processes and metal or metal oxide accumulated on sand surfaces. Temperature for thermal reclamation is also an important factor. High temperature equates to higher cost and may not improve the performance of reclaimed sand (Hwang; Liu; and Kesling, 1993).

### **2.2.2 Resins (Chemical Organic Binder Systems)**

Sand mixes must incorporate an amount of binder in order to impart an optimum degree of bond strength so that molds and cores may retain their rigidity while waiting to receive liquid metal and during casting. The four principle types of binders employed in the metal foundry are clays, oils and cereals, silicates and resins. In the last 30 years there has been an increasing tendency to replace oils, silicates, clays with resins for foundry binders. This is because resins enable in box curing, do not have the breakdown limitations of silicates and require less skill in the production of molds than when clay

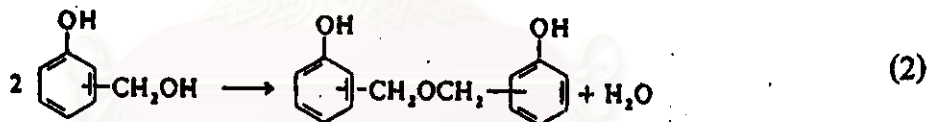
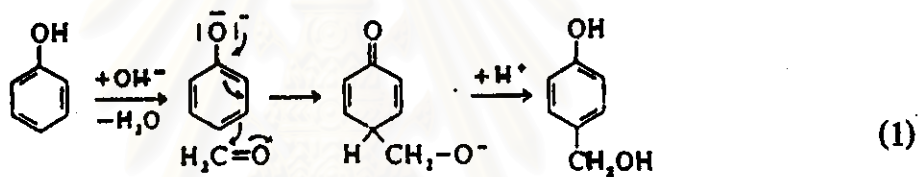
bonded hand rammed green sand is used. As seen in Table 2.1, there are a number of resins used as binders i.e., phenolics, urea, furans, polyols, etc. (Sarker, 1967 and Webster, 1980).

Parkes (1970) compared characteristics of organic with inorganic binders. The inorganic binders are thermally stable and show little or no change of state upon heating, whereas the organic binders burn out upon casting to produce gas and leave a carbonaceous residue on the sand grains. The characteristics of organic binders ensures these important practical advantages: 1) easy removal of the sand from the casting; 2) the evolution of gases ensures a reducing atmosphere in the mold and the formation of gas barrier between metal and mold leading to excellent surface finish; 3) possibility of reclaiming the sand for further use; and 4) all processes give a flowable sand and cores have excellent strength, and storage stability. Thus, for processes other than greensand most binders now used in foundries are organic.

#### **2.2.2.1 Phenolic Resins**

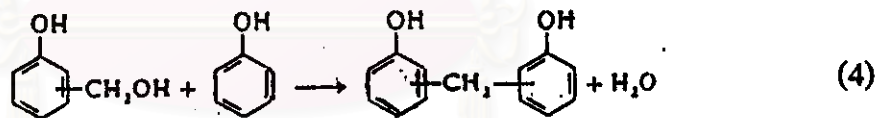
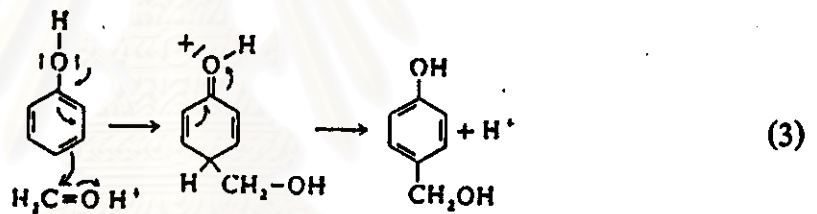
Phenolic resins have been used for many years as a general, unreinforced thermoset plastic in applications such as electrical switches, automotive mold parts, junction boxes, etc. Phenolic resins are quite brittle and have high shrinkage (Strong, 1989). They have also been used in several metal casting applications. Binding systems involve the interaction of a phenol or substituted phenol with an aldehyde, especially formaldehyde, in the presence of strong acid or base catalysts. Occasionally, weak or Lewis acids, such as Zinc acetate, are used for specialty resins.

Phenolic resins are classified as novolacs and resoles. In resoles the polycondensation is base-catalyzed with an excess of formaldehyde over phenol. Common base catalysts are NaOH, Ca(OH)<sub>2</sub>, and Ba(OH)<sub>2</sub>. The molar ratios of formaldehyde to phenol are between 1.2:1 to 3.0:1. Based on these ratios, the amount of the formaldehyde necessary for complete curing of the resin is present in the formulation. Characteristic functional groups of this resoles are the hydroxymethyl group and the dimethylene ether bridges which are reactive groups according to Equation 1 and 2. The initially formed product can be cured to a thermosetting polymer by heating and/or addition of catalyst. Thus, resoles can be self-cross-linking and the preparation of resoles is often referred to as a "one-stage" process.



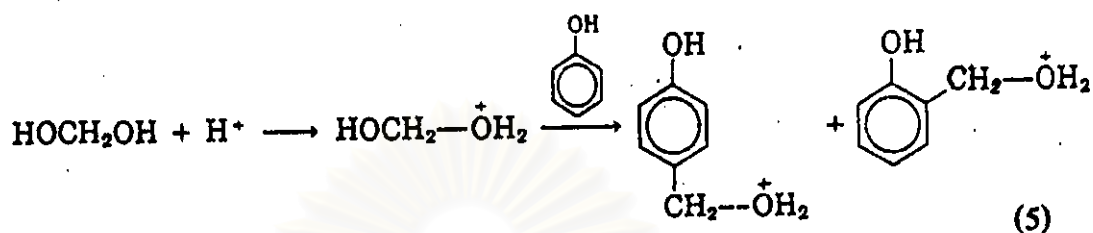
In the case of novolacs, the polycondensation is acid-catalyzed, strong-acid condition (below pH 2), with an excess of phenol over formaldehyde. The typical acid catalyst used such as sulfuric acid, sulfonic acid, oxalic acid or occasionally phosphoric acid. Hydrochloric acid has been abandoned because of the possible formation of toxic chloromethyl ether by products. Novolacs are considered thermoplastic resins with molecular weights of 500-5,000 and glass-transition temperature,  $T_g$  of 45-70°C. The formaldehyde-phenol molar ratios are between 0.5-0.8. The amount of formaldehyde present is insufficient to produce a complete cure and, therefore, more formaldehyde in the

form of curing agent must be added to produce thermosetting. In other words, novolacs can not cure on their own because of unstable hydroxymethyl compounds. The hydroxymethyl compounds can be formed but unstable in acidic condition and are rapidly converted into compounds linked by methylene bridges (Eq. 3 and 4). Therefore, crosslinking of novolacs can taken place by addition of curing agents, such as formaldehyde or hexamethylenetetramine (hexamine), to produce a thermosetting polymer. Cross-linking occurs at a sufficient rate at 140-160°C and can be carried out within a few minutes. Thus, the preparation of novolacs is often referred to as a “two stage” process (Hesse *et al.* 1985 and Kopf, 1988). The resulting thermosetting polymer which is used in production of shell molds and cores has a relatively high hardness, high stability, but a very low fracture strain.

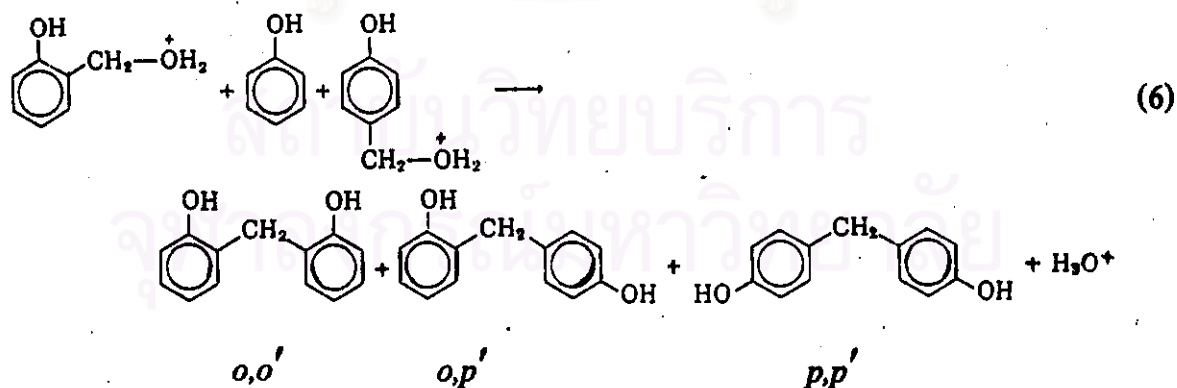


Novolacs enable sand grains to be readily coated with resin. On mixing resin with hot sand, the resin melts and coats onto the sand particles but suspends curing at this intermediate “B-stage”. At this stage, the phenolic resin is between the thermoplastic and thermosetting phase. During the subsequent molding stage, the higher temperature (200-250°C) remelts the resin and takes it up beyond the B-stage to achieve cross-linking and hence the resin cures. The resin does not cure on its own, a curing agent such as hexamine has to be added. Additives such as calcium stearate, improve flowability, crack resistance, and casting finish in certain conditions (Curtis, 1990). The generally accepted view of the

mechanism of the acid reaction is as an electrophilic substitution which depends on the protonation of formaldehyde or its methylene glycol form (Eq. 5).



Formaldehyde has a functionality of two. Phenol has a functionality of three and reactions take place at the position para (*p*-position) to the hydroxyl and at the two ortho positions (*o*-position) to the hydroxyl. The two meta position (*m*-position) will react only under severe condition not generally found in resin reactions, and can be considered inactive. Since virtually no substitution occurs at *m*-position. There are three possible forms of dihydroxydiphenylmethane, namely *o,o'*-, *o,p'*- and *p,p'*-dihydroxydiphenylmethane (Eq.6). The reactivity of these isomers varies over a wide range, the *o,o'* isomer having an exceptionally rapid rate (Keutgen, 1969).



Novolacs can be cross-linked by reaction with hexamine which is almost invariably used for the Shell Process. Hexamine is an infusible powder that sublimes

above 275°C. It is highly soluble in water, the aqueous solution is mildly alkaline at pH 8-8.5. Upon heating, at 200-230°C, it breaks down into ammonia which functions as the catalyst, and formaldehyde which takes part in the reaction to produce thermosetting (Behun, 1964). Unfortunately hexamine contains nitrogen and this can lead to nitrogen/hydrogen pinhole defects in the castings. To eliminate this defect novolacs can be modified during processing resulting in novolacs consisting mainly of ortho links. The "ortho linked" novolacs are more reactive, produce more rigid and stronger links, allowing the number of links to be reduced to get the same strength and thus the amount of hexamine can be reduced, giving a lower nitrogen shell sand (Webster, 1980).

Figure 2.4 shows the effect of hexamine on the cure rate of novolac resins. Hexamine content of 5, 10, and 15% was added to novolac resins. It was found that when higher hexamine content was used, viscosity increased with a higher rate as compared to that of lower hexamine content. Higher viscosities at gelation indicate a greater rigidity or degree of cross-linking.

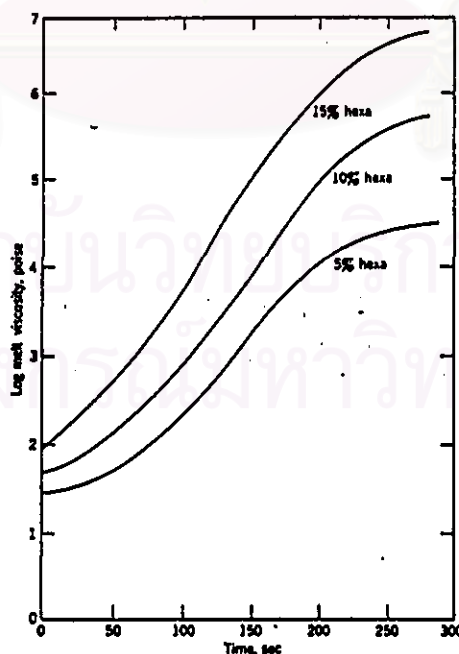


Figure 2.4 Effect of hexamine content on melt viscosity of novolac resin during cure at 130°C (Keutgen, 1969).



An approximate cure rate of phenolic resin is determined by measurement of the gel time. This is the time, taken from the addition of the curing agent, for a liquid resin to change to a gel. The gel time of novolac resin decreases as the hexamine content increased, see Figure 2.5.

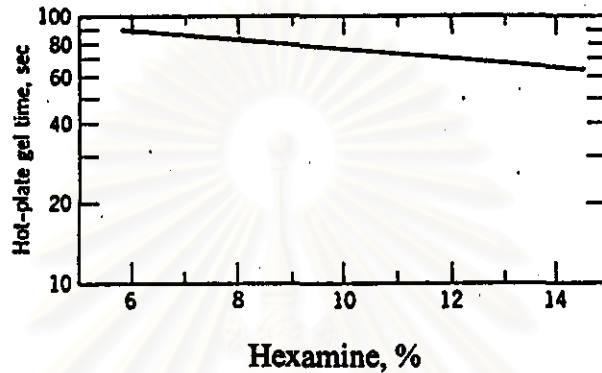


Figure 2.5 Effect of hexamine content on gel time at 150°C of novolac resin  
(Keutgen, 1969)

### 2.2.3 Additive

In shell process, additive is used in resin-sand mixtures to give easy release of molds and cores, especially on high-speed automatic machines, the normal additive is calcium stearate in powdered form. It improves the flowability of the sand and is said to give molds and cores with more uniform properties.

### 2.3. Shell Process

The Shell Process, developed in Germany during World War II by Johannes Croning, is still referred to as the "Croning process". The Shell Process gets its name from its thin-walled, hollow cores and thin, light weight molds that follow the contours of the core boxes or pattern (Roubitchek, 1993). This process makes use of sand precoated with synthetic resin. The "precoated" or "resin coated" sand is dry, free flowing, and has a particularly unlimited storage life (Trager, 1985). The resin coated sand is exposed to a heated metal core box or pattern and this causes the resin which is thermoplastic initially to convert to a thermosetting condition such that on removal from the core box or pattern, the shape is retained without distortion. This shape subsequently forms the basis for the Shell Process (Elliott, 1988). Thus, the use of Shell Process is growing because this process is unique in its ability to make excellent reproducible castings with a casting finish and dimensional tolerance better than most. Also, it is a process that in many ways is simpler to operate than many of its counterparts (Curtis, 1990).

The Shell Process is used extensively for mold and core making. Shell molds are made by the dump box method in Fig 2.6. The hot pattern ( $200-250^{\circ}\text{C}$ ) is placed face downwards upon a "dump box" or bucket containing the sand. This is then inverted, thereby causing the sand to drop on to the pattern. After a certain time in this position, the "investment" time depending on the thickness of shell required, the dump box is re-inverted, the unused sand falling back into the dump box and the pattern holding the sand removed. Further heating is used to cure completely about 2-3 minutes and it is then removed by means of ejector pins set in the plate. After removal, the two half shells are fixed together, usually by synthetic resin glue and the mold can then be stored or poured immediately (Parkes, 1970).

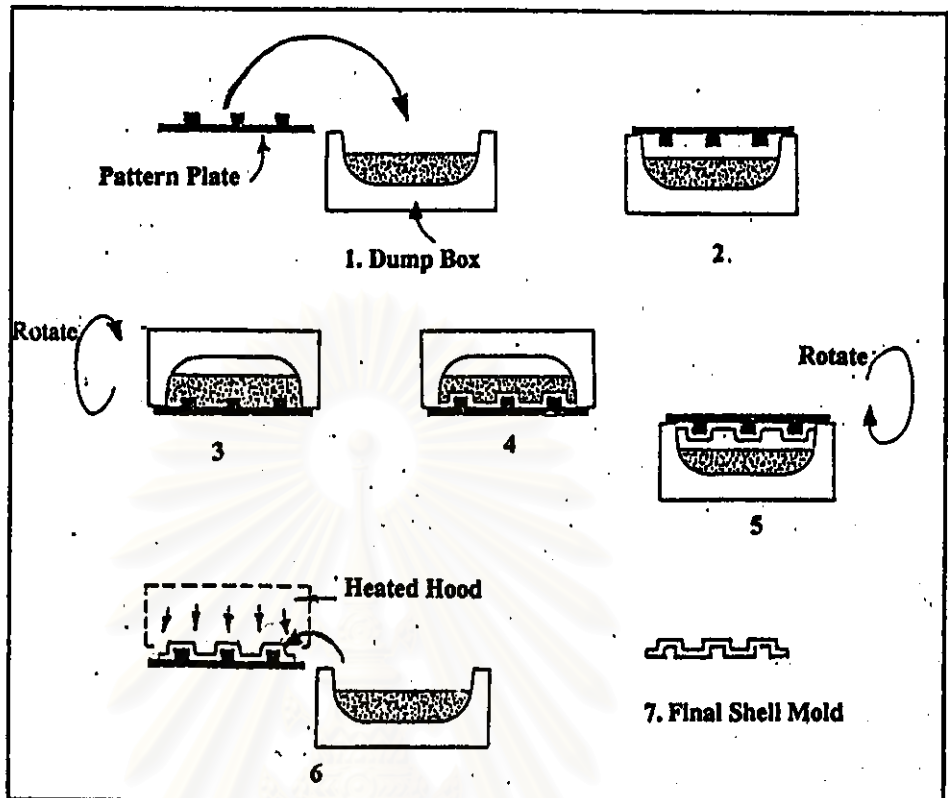


Figure 2.6 Operating sequence of typical Shell molding machine (Davies, 1996).

The Shell core process has become extremely popular in recent years for high volume repetition work, e.g. auto parts. The Shell core is made by the blowing method in Fig 2.7. The resin coated sand is blown by compressed air into a heated metal core box, which can be either the normal type of core box or a contoured mold box. The sand against the heated core box surface cures sufficiently for the core to be removed, usually in less than a minute. The uncured sand in the center can be removed and reused. After inspection and dressing, the core is ready for use in the mold. Shell cores have strength with superior finish and dimensional control to some other process (Elliott, 1988).

However, because core boxes and pattern plates are heated for curing there is opportunity for distortion (Campbell, 1991).

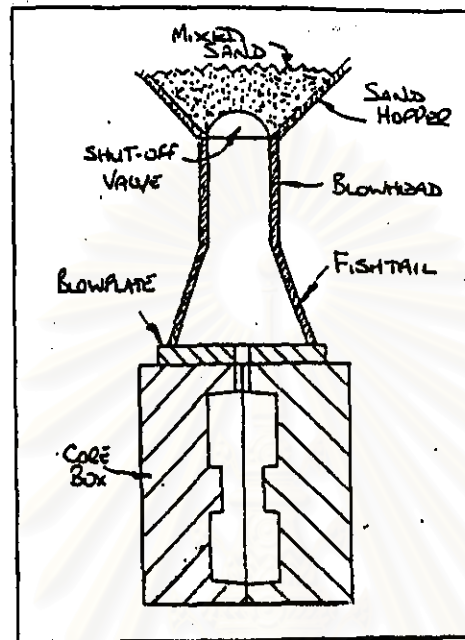


Figure 2.7 Components of a typical core machine (Davies, 1996)

The Shell Process has some other claimed advantages over other processes because the better blowability and superior flowability of the lubricant containing shell sand permits intricate cores to be blown and offers excellent surface reproduction in shell molding. The bench life of resin coated sand is indefinite and storage life of cured cores or molds excellent under normal conditions. High humidity, as in Thailand, may cause deterioration in storage. A variety of sands are usable with this process, and nearly all metals and alloys have been successfully cast (Archibald and Smith, 1988).

## 2.4. Resin Coated Sand

The technology applied to resin coated sand production has increased over the years to satisfy the demands of the modern foundry for shell that is consistent in properties and quality. In 1944, resin coated sand for Shell Process was originally prepared by mixing dry sand, powdered novolac resin and hexamine. This procedure has certain disadvantages such as the resin would segregate from the sand during the mold process, leaving resin-rich areas, resulting in sticking to the pattern plate. Likewise it proved difficult to utilize "blowing techniques" in making the core or mold because of the segregation of resin from sand. Because of the difficulty in obtaining a uniform mix, precoating methods were developed, in 1950, to make it feasible to supply a "ready-to use" resin coated sand thus avoiding the onerous foundry task of mixing sand and powdered resin (Curtis, 1990). The two most popular processes for precoating sands are "the warm coating and hot coating processes".

The warm coating technique, as the name implies uses the lower temperature. Hexamine and lubricant are milled together with the sand at a temperature in the range of 40-70°C in a mixer, which has a means of blowing warm air through the sand during mixing. The resin is solvent-based (novolac) and is introduced as a viscous liquid. General solvents used can be alcohol or a mixture of alcohol and water. The solvent is driven off by the warm air passing through the sand aggregate. As milling proceeds, the lumps of sand breakdown and the coated sand are finally discharged through screens into bags for storage until required for use or immediate usage.

The hot coating techniques uses a solid resin, in the form of granule, powder, or flake, which is added to hot sand. Sand is preheated to the temperature of about 125-130°C.

At this temperature resin melts and coats the sand grains. The hexamine addition is made as an aqueous solution. The water evaporates off rapidly and also serves to cool the system (mix). This causes the mixture to harden and to break down into free flowing sand, and then discharged from the mixer. A lubricant is added at this point. During this coating and mixing stage there is a partial reaction between the resin and hexamine. The reaction between resin and hexamine has been clearly described by Sarker (1967) and Kopf (1988). On mixing resin with hot sand, resin melts and is flowable. Molten resin coats on the sand grains. It is important to note that curing does not occur at this stage, but takes place at higher temperature during molding stage. It has also been reported by Sarker that sand temperatures during mixing stage should be carefully controlled. Very hot sand may cause complete reaction with hexamine and thermosetting is produced prior to the mold or core making stage.

The principal process used for foundry resins is the hot coating process because it is the less expensive, safe and fast. The total cycle time for most production batches is 2.2-3.5 min, which is considerably shorter than warm coating process. Thus, high production rates are possible because of the short cycle. In addition, the hot coating process will give more even shells which offer greater advantages in the manufacture of cores and molds. There are suggestion that the warm coating process will give more satisfactory results in the casting of heavier sections, but the reasons for this have not been clarified in the literature.

The advantages of resin coated sand are: 1) using low resin to sand ratios in mixtures and the lower gas evolution from the molds, 2) no segregation of resin from sand, and 3) enabling the coated sand to be used in core blowers in the application of automatic production methods with much improved flowability.

## 2.5. Sand Preparation and Sand Mixers

Sand preparation is to formulate the mixes to give properties adequate to produce a casting free from defects. The mixes must be economically feasible. Parkes (1970) stated that sand preparation technique is a vital link in the chain of sand technology. The actual mixing operation of the sand grains, binder and additive are carried out in a sand mixer. The function of the "mixer" is to distribute the bonding media around the sand grains and to discharge the sand in the correct condition for molding. The duty will depend on the characteristics of the sand mixes which it is desired to produce and these can be divided into two main classes: 1) medium to heavy bonded sand, such as molding sand, using clays as the principle bonding material, and 2) light to medium bonded sand, including sand for cores and molds utilizing the chemically hardened or gassing processes.

A mixture of the resin and hexamine is referred to as the bonding medium in shell molding mixes (Sarker, 1967). The bonding medium is important to consider from: 1) efficiency of coating of the sand grains because of the low percentage of binders used, 2) efficiency of mixing the sand without the development of excessive heat. This is important, particularly with resin-bonded sands, because of the very great effect of even a small amount of heat upon setting times and bench life. These conditions require the use of less energy input into the mixing because of kneading or rubbing the sand. Hence, the description of sand "mixer" rather than "mill" or "muller" commonly given to molding sand preparation machines.

The motor of the mixer must have sufficient power because as the resin melts partially the mass in the mixer becomes sticky and offers increasing resistance to the moving action of the impeller. At an appropriate stage when part of the resin has just

melted to retain the coating of the bonding medium around the sand grains a known quantity of water is sprayed on the sand-resin mix which lowers the temperature of the resin. Mixing is continued until the lumps of the sand-resin mixes break down which are discharged through a screen to be packed in bags or containers.

Sand mixer for resin coated sand production can be divided into two sections: batch and continuous processes. The foundry industry uses both roller mill and impeller mixer. A roller mill constitutes essentially a mixing pan together with one or more ploughs. The pan is filled with sand, clay, water and additive and the rollers are switched on to move inside the mixing pan in Figure 2.8. As the rollers rotate any lumpy matters are crushed down while the ploughs churn the mix over and over ensuring a through mixing. Once mixing is completed, the material is discharged through a door at the bottom of the mixing pan. This type of mixer is suitable for naturally bonded sands, such as green sand process, because necessary to break down any lumpy clay matter and then distribute it evenly in the material being mixed.

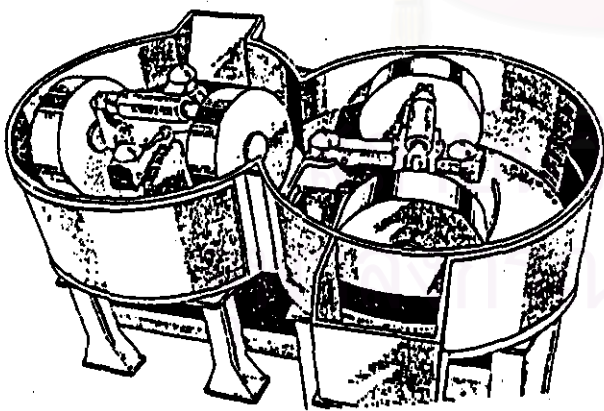


Figure 2.8 Roller mill (Sarker, 1967)  
(continuous mixer)

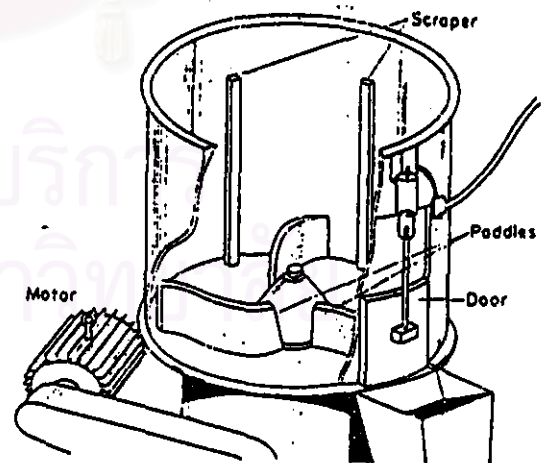


Figure 2.9 Impeller mixer (Sarker, 1967)



An impeller mixer is basically similar in construction to a roller mill with the difference that the rollers are replaced by double or three-blade paddle in Figure 2.9. In this case the action is a simple mixing and any lumpy materials will not be crushed. As the impeller rotates the mix climbs over the blades and hits two or more scrapers inside the mixer. This gives a churning action and ensures uniform mixing. The impeller mixer is normally employed for oil, silicate, and resin-bonded sands.

## **2.6 Resin bonded sands**

In recent years due to the increasing usage of resin bonded sands the foundry industry has recognised the need to understand the factors that influence the mechanical and other properties of resin bonded sands. Thus, a number of researchers have reported how the strengths of resin-bonded sand systems depend on processing variables, such as the type of sand and resin, the amount of resin, temperature, time and humidity. Several researchers using optical and scanning electron microscopy (SEM) have documented the various types of fracture, which can occur in resin-bonded sand systems. The types of fracture surfaces have been characterized as:

1) adhesive, wherein failure occurred at the resin-sand interface with the resin peeling or stripping from the sand particles, as shown in Figure 2.10.

2) cohesive, wherein failure occurred within the resin connecting adjacent sand particles (i.e. the resin remained adherent to both surfaces of the adjoining sand particles), as seen Figure 2.11.

3) combined or mixed adhesive-cohesive, in which a single failure site exhibited both of the two types, as shown in Figure 2.12.



Figure 2.10 Intact binder wedges after adhesive failure at sand-binder interface,  
a) 300x, b) 300x, c) 600x. (Toeniskoetter, 1970)



Figure 2.11 Binder wedges at grain-to-grain contact points , a) 330x, b) 840x, c) 300x  
(Toeniskoetter, 1970).

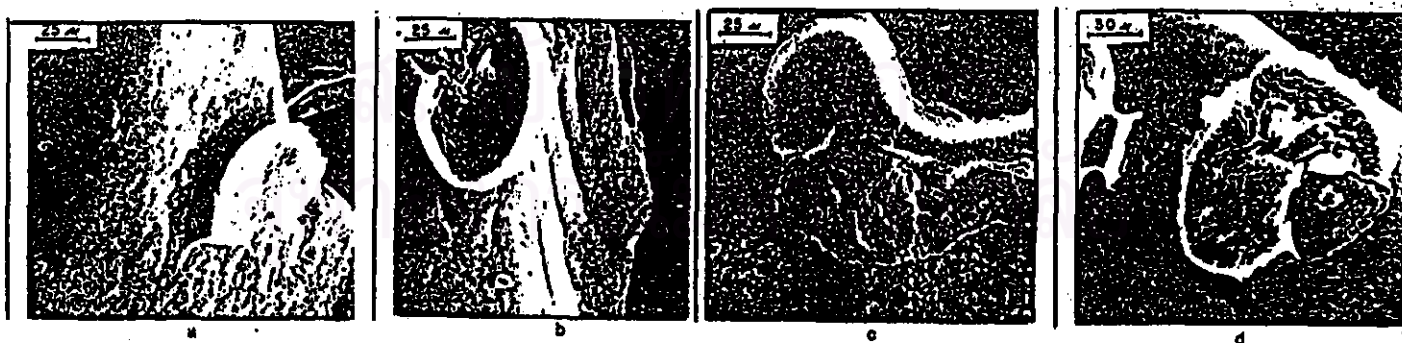


Figure 2.12 Fractured binder wedges after adhesive-cohesive failure,  
a) 600x, b) 600x, c) 600x, d) 500x (Toeniskoetter, 1970).

The mechanical properties of resin-bonded sand depends upon the strength of individual resin-sand joints. The strength of resin-bonded sand system and the predominant type of failure observed is expected to depend on a number of factors including:

- 1) The inherent strength of the resin (referred to as cohesive strength) is a function of the resin compositions, temperature, time and relative humidity.
- 2) The interfacial strength of the resin-sand surface (referred to as the adhesive strength) is also a function of the compositions of the resin and the sand, the cleanliness of the sand surface, temperature, time and relative humidity.
- 3) The stress state of an individual resin-sand joint is function of the resin film thickness and the relative configuration of the adjoining sand particles with respect to the direction of load or force application. The measured strength of the sample is also expected to depend on the sand surface area covered by the resin, the resin thickness and the number contact points per unit cross section.

There is very little published information on the fracture behavior of shell mold sands and on chemical bonded sands in general. Huang and Mobley (1983) studied the interrelations of tensile strengths of No-Bake resin-sand joints and types of failures as functions of time, resin thickness and sand surface condition. These variables influence the tensile strength and type of joint failure. Resin used was phenolic urethane and aluminium phosphate in no-bake processes. The effect of time (measured time at which the resin was cured) on the tensile strength is tensile strength increase to a maximum with increasing time and then remain constant or decrease slightly for longer times, as shown in Figure

2.13. For the types of failures, the sample tested after 12 hr exhibited a cohesive type of failure surface. The 48 hr sample exhibited on adhesive type of failure surface. These data suggest that both adhesive and cohesive types of failures can occur in a given resin bonded sand system depending on the changing strength of the resin as a function of time.

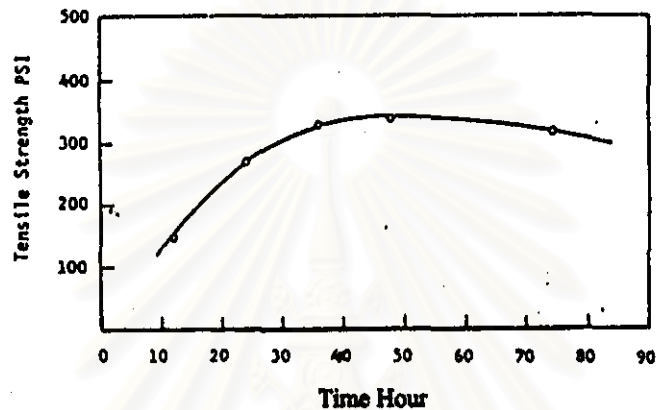


Figure 2.13 Influence of time on sand-aluminum phosphate joint tensile strength (Thickness 0.001 in) (Huang and Mobley, 1983)

The influence of gap or thickness of the resin bridge on the measured tensile strength for resin bonded sand is shown in Figure 2.14. Tensile strength decreases significantly, as gap thickness increase over the range of 0.002 to about 0.016 in and remain relatively constant for larger gaps. This result shows small average thickness of resin gives higher a strength. The type of failure is predominately adhesive for the thinner (0.002 in) joint and progressively becomes cohesive as the gap thickness increases.

The influence of various surface conditions on the tensile strength and type of failure in the No-Bake resin-sand system has been studied. Contamination of the sand surfaces with water or oil significantly reduced the tensile strength of the joints and also increased the occurrence of adhesive failures.

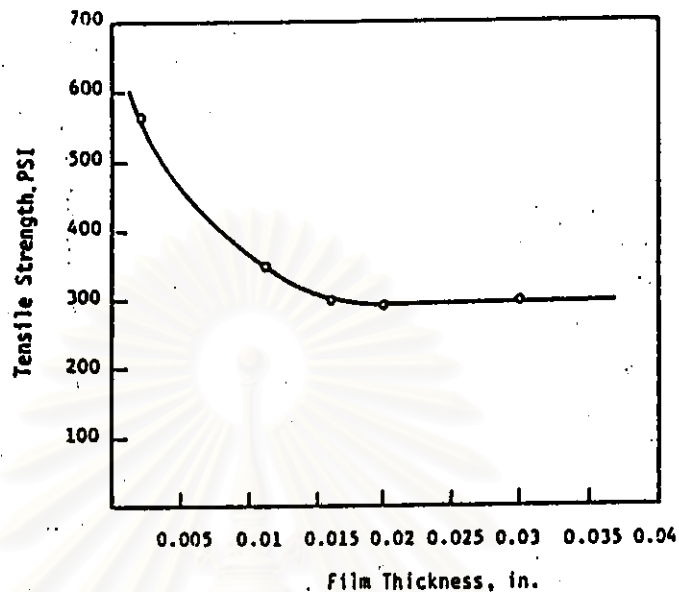


Figure 2.14 Influence of film thickness on resin-sand joint with tensile strength  
(Huang and Mobley, 1983)

They concluded from their experiments that the failure associated with resin-sand joints depend on the relative values of the cohesive and adhesive strengths of the system and the stress configuration in each part of the joint. If the cohesive strength of the resin is greater than the adhesive strength of the resin-sand interface, adhesive type failures should predominate. And if the adhesive strength is greater than the inherent strength of the resin, the cohesive type of failure should predominate. Such studies have not been done on shell sands.

Huang and Mobley (1986) also indicated that a number of qualitative or semi-quantitative relations have been reported on the bonding mechanism in clay-water or resin-bonded sands. Bonding mechanism is used herein to relate the macro- and microscopic

features and mechanisms which occur and lead to the adherence between the components and the resultant characteristic strengths of the resin-bonded sands. The strengths of the resin-bonded sands depends on the two principle factors: 1) the strength of the individual resin-bond joints, and 2) the contact area of the resin-bond joint which participates in the load carrying and fracture process. In addition, quantitative relations have been predicted the strengths of resin-bonded sands from knowledge of other variables, such as the percentage of a binder, the size and shape of the sand grains.

A number of researchers have indicated that the bulk mechanical properties, such as the tensile strength and bending strengths, of the clay-water bonded or resin-bonded sands depend on the strengths, dimensions, and number of the sand-binder-sand contact sites. Beeley (1972) states "The strength of bond is a function of the number and area of these contacts". The AFS Book Molding Methods and Materials also indicates that "increasing contact points between sands promotes better adhesion throughout a mass".

Ovestrund *et al.* (1971) carried out a limited study of Shell molds using SEM. They examined the effect of sand type on fracture behavior of Shell molded test pieces at a constant resin level by 3%. This study revealed that angular sand with flat prismatic faces which had rough surfaces gave poor resin-sand adhesion and resulted in lower cold tensile strengths. In contrast rounded sand with relatively smooth surfaces gave apparently much better adhesion resulting in much higher cold tensile strengths. They concluded from this study that surface texture of the sand was as important as grain size distribution. This work showed that the SEM was a valuable tool in examining fracture surfaces of bonded sands but surprisingly in reviewing the literature on the Shell Process, there appears to be no other subsequent published studies of SEM examination of shell sands.