

## Chapter 2

# Molds and Cores Systems in Foundry

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**Abstract** Sand binding systems can have a significant impact on the nature of the casting skin formation. In particular, the binder containing elements such as S, O and N may adversely affect the structure of the layer. As in the case of spheroidal graphite cast iron (SGI) and compacted graphite cast iron (CGI) main factor causing the degeneration of graphite in the surface layer of the casting is sulfur, therefore these binding systems (binder) which contain sulfur have been thoroughly discussed here. The following are sand mold technologies: furan, acid catalyzed, phenolic, acid catalyzed, hot box, warm box and Shell (Croning) process. Sand molding with the use of furfuryl resins technology is presented in detail due to their widespread use in casting both cast iron and cast steel. To reduce the thickness of the surface layer, which may be the adverse effect of sulfur on the degeneracy of the graphite, S content in molding sand should be less than 0.15 % mass, and even below 0.07 % mass. Sand binding systems can have a significant impact on the nature of casting skin formation. In the case of green sand, moisture promotes the formation of the ferritic rim (Reisener, Br Foundryman 55:362–369, 1962; Matijasevic et al. Trans AFS 82:571–622, 1974; Narasimha and Wallace, AFS Trans 83:531–550, 1975). Research carried out for sand mold with sodium silicate and phenolic urethane has shown that SGI and CGI castings made in the first sand mold is pearlitic rim occurred, and in the second sand mold this occurrence is not found (Boonmee and Stefanescu, Foundry Trade J 186:225–228, 2012). Regarding the effect of the molding sand on the nature of the casting skin formation, they can be divided into molding sand: with binders containing sulfur (i.e. furfuryl alcohol and urea-formaldehyde resin) and the molding sand that are not bound with binders not containing sulfur (i.e. phenol-urethane resin). From the point of view of the top layer the sulfur-containing molding sand is much more important, due to its adverse effect on the formation of spheroidal graphite.

## 2.1 The Influence of Sulfur on the Casting Skin Formation

Studies have shown that sulfur is a primary factor causing graphite degeneration at the metal-mold interface [1–7]. Sulfur originating from  $\text{SO}_2$  dissociation and from metal surface diffusion into molten metal form sulfides of the following reactive elements: Mg, rare earth elements (REE) and Mn without being suffice not time for new nodulizing elements to reach the surface by diffusion from adjoining metal layers. To reduce the thickness of the surface layer, which may be the adverse effect of sulfur on the degeneracy of the graphite, the sulfur content should not exceed 0.15 % mass for cold-setting resins using regenerated sand [7]. Therefore, among others, the reclaimed sand weight should be less than 70 % mass and should be used as an acid catalyst blend phosphoric acid with p-toluenesulfonic acid (PTSA). However, in this case, the phosphorus pick-up may take place and its segregation on the surface of ductile iron casting.

Similarly, the amount of sulfur in the lustrous carbon producer in clay sand molding material should be limited to 1 % mass, with a maximum of 0.1 % mass in the molding sand. In highly susceptible areas, such as the metal surrounding a thin corner of the sand, the limiting sulfur content may be lower, less than 0.07 % mass.

Generally, sulfur is considered to be a major contribution to the problem, but in many cases sulfur is not the only element in the mold causing flake graphite [7].

## 2.2 The Influence of Oxygen on the Casting Skin Formation

Existing or generated oxidizing gases in the mold cavity may be another important factor for graphite degeneration in the surface layer of the ductile iron castings. Dissolved oxygen will react with Mg or MgS to form MgO. Water bearing no-bake binder systems such as: ester-cured phenolic, furan no-bake and an inorganic no-bake binder exhibited a more prominent flake or vermicular graphite structure at the mold/metal interface versus the non water binder systems such as phenolic-urethane no bake (cold box) and alkyd oil [8, 9].

## 2.3 The Influence of Nitrogen on the Casting Skin Formation

Nitrogen is under suspicion as one of the elements promoting flake graphite. Nitrogen may derive from the metal or binder used for molding sand or core (e.g., furan resin). In treated ductile iron the effect of nitrogen is much less pronounced as it is purged from the system through Mg-treatment. Therefore, the main sources of nitrogen are binders containing a large amount of this element. Nitrogen has a profound effect on the frequency and severity of the pinholes. The influence of nitrogen on the structure is visible as matrix results (more pearlite or/and carbide

incidence), but disputed as the influence on graphite morphology. Nitrogen has a limited effect on the degeneration of graphite in the surface layer. Organic resins decompose below the liquid iron temperature to generate ammonia ( $\text{NH}_3$ ), which is an important source of both  $\text{N}_2$  and  $\text{H}_2$ .

**Molds may be classified in two large families**

- **lost molds** (single use molds): These are specially made for each casting and are destroyed after pouring. The molds are generally made of sand, and are chemically bonded, clay-bonded, or even unbonded. Investment casting can also be included in this family;
- **permanent molds** (multi use molds): These are used for gravity and low-pressure casting, pressure die-casting, and centrifugal casting. The molds are typically metallic.

## 2.4 Molding with Clay-Bonded Sand (Green Sand)

Green sand is the most common molding process. Green sand is generally not used to make cores. Green sand is the only process that uses a moist sand mix. The mixture is made up of about 85–95 % silica (or olivine or zircon) sand; 5–10 % bentonite clay; 3–9 % carbonaceous materials such as sea coal, petroleum products, corn starch or wood flour; and 2–5 % water [10, 11].

The clay and water act as a binder, holding the sand grains together. The carbonaceous materials burn off when molten metal is poured into the mold, creating a reducing atmosphere which prevents the metal from oxidizing as it solidifies. In the case of cast steel castings—the molding sand only contains bentonite, cereal binder and water. The introduction of carbonaceous materials could cause carburization of the surface layer of the casting. Most carriers of lustrous carbon (sea coal, lignite) contain sulfur, which may cause graphite degradation. Therefore, the sulfur content in carbonaceous materials should be limited [12].

## 2.5 Molding and Core-Making with Chemically-Bonded Sand

There are many different types of chemical binders. They are divided into two main types: organic and inorganic. Chemical binding systems are primarily used for core-making. Cores require different physical characteristics than molds; therefore, the binding systems used to make cores may be different from those used for molds. This means that the binding system used must produce strong, hard cores that will collapse to allow removal after the casting has hardened. Therefore, cores are typically formed from silica sand (and occasionally olivine, zircon or chromite sand), and strong chemical binders. The sand and binder mix is placed in a core-box

where it hardens into the desired shape and is removed. Hardening, or curing, is accomplished with a chemical or catalytic reaction or by heat.

Although a wide variety of resin binder processes are currently used, they can be classified into the three general categories:

- *Cold-setting processes (No-bake systems)* The curing of cold-setting sands is effective at ambient temperature. The process begins when the last component of the formulation has been introduced into the mix.
- *Gas-hardened processes (Cold-box system)* In these processes, curing takes place by injecting a catalyst or a hardener in a gaseous form.
- *Hot curing processes* In these processes, curing takes place by heating the sand-resin mix or, more often, by allowing it to come into contact with the heated pattern equipment.

The selection of the process and type of binder depends on the size and number of cores or molds required, production rates, and equipment.

**Cold-setting processes** include the following processes: phenolic-acid catalyzed, furan-acid catalyzed, polyurethane (phenolic isocyanate), resol-ester (alkaline phenolic ester hardened), alkyd oil-unbaked, ester silicate, cement.

**Gas-hardened processes** include the following processes: cold-box (amine hardened phenolic urethane), resol-ester (alkaline phenolics methyl formate hardened),  $\text{SO}_2$  hardened furan resins,  $\text{SO}_2$  hardened epoxy/acrylic (free radical curing),  $\text{CO}_2$  hardened sodium silicate (water glass),  $\text{CO}_2$  hardened alkaline phenolic.

**Hot curing processes** include the following processes: hot-box, phenolic and/or furan based, warm-box, Shell (Croning), linseed oil, alkyd oil-baked.

Another way to categorize binders is by the elementary classification of “organic” and “inorganic.”

The ester catalyzed silicate no-bake and the  $\text{CO}_2$ -gassed systems are classic foundry examples of inorganic core binders.

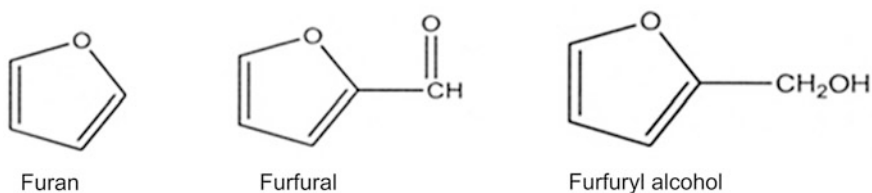
Due to the issues discussed in the monograph on the impact of developments on the border mold/metal in the performance of cast iron with spheroidal graphite and vermicular graphite, especially on the surface layer cast in terms of changes in the structure and the amount of graphite, only those sand mold technologies which may cause the greatest changes in the microstructure of the surface layer and yet are widely used in practice will be discussed in detail. These include:

- furan, acid catalyzed,
- phenolic, acid catalyzed,
- hot box,
- warm box,
- Shell (Croning) process.

### 2.5.1 Furan, Acid Catalyzed

Sulfonic acid cured furan no-bake (FNB) binders are based upon furfuryl alcohol (FA). Furan resins are made from furfuraldehyde or, more commonly, from furfuryl alcohol, both of which are obtained from agricultural waste products.

These binders are commonly used for the molding and core-making of medium and large sized parts, for small and medium batch production and for all alloy types. Only certain types are used for steel casting, as cracks, fins or pinholes may occur. The process allows for good flexibility in application and properties. FNB binders provide excellent mold and core strength, cure rapidly and allow the sand with which they are used to be reclaimed at fairly high yields.



It is a simple two-part binder system made up of an acid catalyst and a reactive furan-type resin. The addition of an acid catalyst to a furan resin causes an exothermic polycondensation, which hardens the binder. The FNB's condensation reaction produces water, which tends to slow the cure rate (dehydration). The bond producing reaction is the further polymerization of these chains with cross-linking.

The FNB curing mechanism is shown in Fig. 2.1.

In the presence of strong acids, prepolymers of furfural and furfuryl alcohol form polymer films that serve as binders. The curing rate is directly proportional to

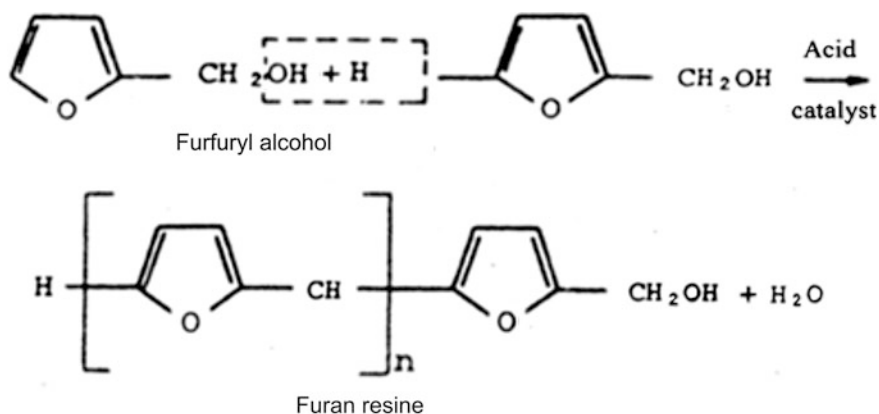
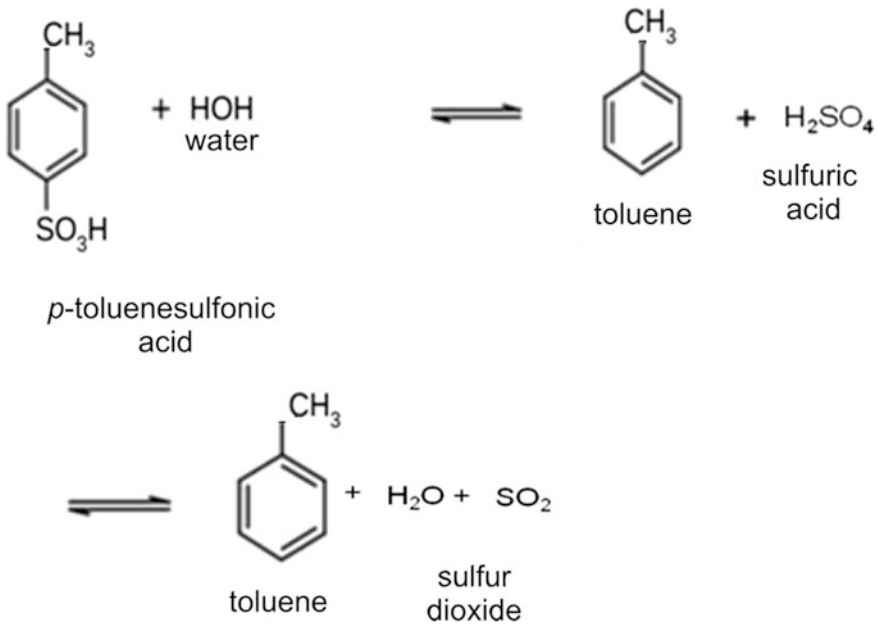


Fig. 2.1 The furan acid-catalyzed no-bake curing mechanism

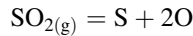


**Fig. 2.2** Decomposition of *p*-toluenesulfonic acid under the influence of temperature

the amount of acid and a two-part system can be formulated with a well-controlled curing time.

The conventional sulfonic acid hardener for no-bake furan resin contains toluenesulfonic acid, which decompose under the thermal effect of the liquid metal during pouring, according to the following equation [13] (Fig. 2.2):

The resulting  $\text{SO}_2$  adsorbs on the surface of the liquid metal, and decomposes to give a sulfur atom:



Sulfur atoms diffuse in the liquid metal causing the sulfidation of the surface layer of the casting. Sulfur may enter into a reaction with Mn, Fe, Mg to form sulfides of the S type (Fe, Mn, Mg) having low melting point. Therefore, much attention is paid to how to reduce the impact of  $\text{SO}_2$  gas released from the sand mold with furan resin on the quality of the castings.

Furan binders can be modified with urea, formaldehyde, phenol, and a variety of other reactive or non-reactive additives. In this way different furan resins, which are based on furfuryl alcohol are obtained [10]:

- furan resin (FA);
- urea-formaldehyde-furfuryl alcohol (UF-FA);
- phenol-formaldehyde-furfuryl alcohol (PF-FA);

- urea-formaldehyde-phenol-furfuryl alcohol (UF-PF-FA);
- resorcinol-furfuryl alcohol (R-FA).

Nitrogen content in furan resin varies from 0 to 2 %, i.e., zero, low, medium, and high nitrogen furan-types. Water content can range from 0 to 30 %. The lower the nitrogen and water content, the higher is the grade of furan binder [14].

UF resins contain about 17–18 % mass N. Nitrogen may cause defects in the cast steel and high quality cast iron castings, so that it is reasonable to use a resin with a high FA content (80–95 % mass FA, 3.5–1 % mass N) although they are more expensive than resins with a lower FA content. This is particularly advantageous when using high-quality sands for which the resin additive is a <1.0 %), and hence the nitrogen content is low.

There are also UF-PF resins available with a low content of nitrogen, which are the most commonly used sands of lower quality, when it is necessary to add more of the resin (>1.2 %).

A silane (0.1–0.3 % mass) is nearly always added to enhance the resin-sand bond (to significantly increase strength and to improve its moisture and humidity resistance).

The function of the FNB acid catalyst is to neutralize the alkaline contaminants (materials having a pH value greater than 7) in the sand. Then it initiates and sustains the FNB's condensation-type curing and cross linking reaction. The acid catalysts are in order of increasing reactivity, 75 % phosphoric, 85 % phosphoric, toluene sulfonic, xylene sulfonic, and benzene sulfonic sometimes with an addition of sulfuric or phosphoric or lactic acid, usually used in a diluted form [10]. All of the acid catalysts are carried in water, and the sulfonic-types usually contain various percentages of alcohol as well. The use of phosphoric acid may necessitate a lower reclaim rate.

The amount of FNB binders used ranges between 0.9 and 1.2 % based on sand weight. Acid catalyst levels vary between 30 and 50 % based on the weight of the binder and depend on the temperature of the sand and the necessary curing rate. The speed of the curing reaction can be adjusted by changing the catalyst type or percentage, given that the sand type and temperature are constant (the optimum temperature of the sand is 20–30 °C) [15–17].

The use of furan binders is, however, associated with a number of casting defects, the most serious being sulfur damage, which leads to a poor surface finish in some steel and destruction of near-surface graphite spheroids in ductile irons. The presence of urea-based resins in some types of furan binders may also lead to nitrogen damage [11].

The thermal decomposition products of the medium nitrogen furan binders are expected to include hydrogen, carbon monoxide, carbon dioxide and methane. The use of urea extenders may add nitrogen compounds to the effluent and the sulfur-bearing acids may introduce sulfur compounds, including sulfur dioxide and hydrogen sulfide to the effluent [18–22].

Since furfuryl alcohol was classified by the European Union as a compound with a probable carcinogenic influence in terms of its effect on the body, the EU directive (Regulation EC No. 1272/2008) requires that the content of free (monomer) furfuryl alcohol in resin be less than 25 % mass.

To limit the emissions of sulfur compounds during the pouring of molds with molten metal, new types of catalysts were developed, where part of the sulfonic acid was replaced with inorganic acids. The sulfur content of these catalysts is 20–50 % of that in traditional sulfonic acid [23, 24].

Molding sands hardened with sulfonic acids may be subjected to a reclamation process but the sulfur content in the molding sand is increased, which favors the occurrence of defects in castings from iron alloys, particularly ductile iron. This can also be a problem due to the environmental emissions generated during pouring  $\text{SO}_2$  gas.

Molding sands with furfuryl resins undergo mechanical reclamation well and it is often possible to reduce the addition of the resin when using reclaimed sand and matrix. The loss on the ignition of reclaimed sand should be less than 3 % mass. The content of sulfur and nitrogen in reclaimed sand should not exceed 0.15 % mass. The nitrogen content of 0.15 % mass or more in molding sand can cause defects in cast iron and steel castings. The sulfur content greater than 0.15 % in sand mold can cause degeneration of the nodular graphite into flake graphite in the surface layer of SGI castings.

*The calculation of the amount of sulfur by weight of molding derived from the acid catalyst (PTSA) (example)*

A binder component which introduces sulfur into the sand mold with furfuryl resins is the acid catalyst. This is generally a mixture of p-toluenesulfonic acid (PTSA) 65 % (MW 172.2, the sulfur content of 18.62 % mass) and sulfuric acid ( $\text{H}_2\text{SO}_4$ ), concentrated at 1 % mass (MW 98.08, a sulfur content of 32.68 % mass). Let's do the calculations for the weight of 1 kg sand, which contains 0.5 % mass of the catalyst, i.e. 5 g of acid catalyst/1 kg of molding sand (1 % mass using resin in sand mold).

### *Example*

Since the sulfuric acid in the acid catalyst is 1 % mass, so the content of inorganic sulfur in 5 g of catalyst:

$$S_{\text{H}_2\text{SO}_4} = 0.0163 \text{ g S}$$

The catalyst also contains 65 % mass of PTSA, then 5 g of catalyst contains organic sulfur in the amount of:

$$S_{\text{PTSA}} = 0.60 \text{ g S}$$

The total amount of sulfur contained in 5 g of catalyst:

$$0.0163 \text{ g} + 0.60 \text{ g} = 0.6163 \text{ g S}$$



**Hence the sulfur contained in the catalyst equals 12.33 %, whereas the sulfur coming from PTSA—12.00 % (organic sulfur) and sulfur coming from  $\text{H}_2\text{SO}_4$ , only 0.33 % (inorganic sulfur). Which means that PTSA brings 97.3 % of sulfur to the sand mold and sulfuric acid only 2.7 %.**

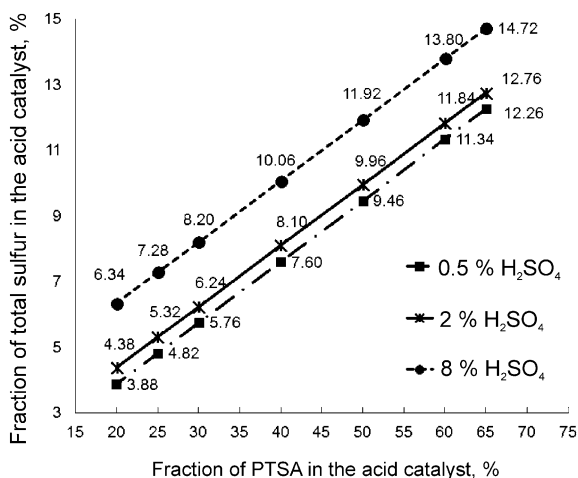
As we may see from the above calculations, the most effective way of reducing the quantity of sulfur introduced into the sand mold by the acid catalyst is to reduce the amount of sulfonic acids added or replace them with other compounds. Sulfur contained in sulfuric acid represents a small fraction of the total sulfur contained in the acid catalyst.

Figure 2.3 shows the dependence of the total amount of sulfur in the acid catalyst on the share of the PTSA in the acid catalyst, at a fixed concentration of sulfuric acid.

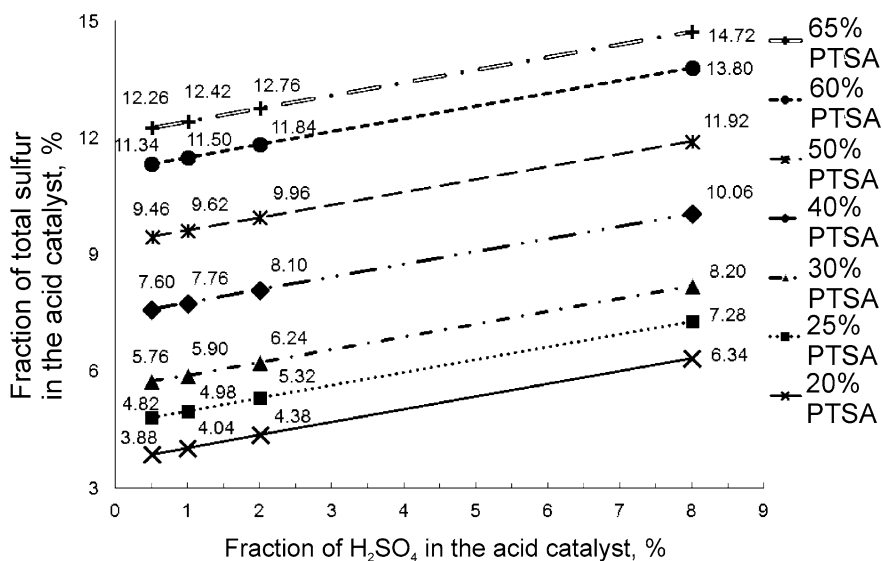
For example, at a fixed concentration of 8 %  $\text{H}_2\text{SO}_4$ , reduction of the PTS acid from 65 to 50 % will reduce the total amount of sulfur by 19 %. A similar effect could be achieved by reducing the share of sulfuric acid from 8 to 0.5 %.

Figure 2.4 shows the dependence of total sulfur in the acid catalyst on the share of the  $\text{H}_2\text{SO}_4$  in the acid catalyst, at a fixed concentration of the PTSA.

Both graphs show that the effective and efficient reduction of the total amount of sulfur in the acid catalyst should primarily be achieved by reducing the share of the PTS acid. However, to obtain an adequately strong hardener it is necessary to replace a portion of the sulfonic acid with a strong sulfur-free acid. In contrast, efforts to reduce the amount of sulfur by reducing the amount of sulfuric acid in the acid catalyst are not very effective. Binders developed by different manufacturers for foundry for low-sulfur catalysts composed of a mixture of non-sulfur strong organic acids and aliphatic or aromatic toluenesulfonic acid, and  $\text{H}_2\text{SO}_4$  are



**Fig. 2.3** Dependence of the total sulfur content on its share in the acid catalyst PTSA



**Fig. 2.4** The dependence of the amount of the proportion of the total sulfur acid  $H_2SO_4$  catalyst

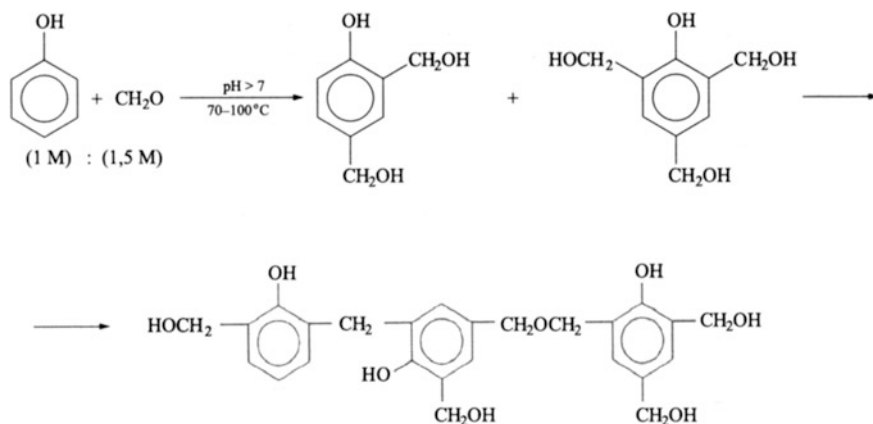
effective (possibility of reducing the sulfur content of the acid catalyst by about 50 %). A disadvantage of the acid catalyst is a higher price compared with a conventional acid catalyst based on the PTS acid.

New acid catalyst that contains only 0.25 % mass of free  $H_2SO_4$  and two times less S than conventional catalysts has been developed.

### 2.5.2 Phenolic, Acid Catalyzed

Acid-cured phenolic no-bake resins as the components are relatively cheap, it is mainly used for the production of large parts. It is applicable for all alloy types. The hardening of these resins is more difficult and less regular compared to the furan resins. Sand mixes made with these resins have adequate flowability for the filling of mold patterns or core boxes. The resins are either phenol-formaldehyde (PF), or urea-formaldehyde/phenol-formaldehyde copolymers (UF/PF). For example, phenol-formaldehyde resins (resins “resole”) are obtained by the reaction of phenol with excess formaldehyde in an alkaline environment (a formaldehyde/phenol ratio higher than one). They have a linear construction, and are soluble in organic solvents. Resole resins include methylene ( $-CH_2-$ ) and hydroxymethylene groups ( $-CH_2OH-$ ). One disadvantage of acid-cured phenolic no-bake resins is their relatively poor storage stability (Fig. 2.5).

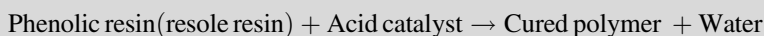
The catalysts for the phenolic no-bake resins are strong sulfonic acids, such as p-toluene, xylene or benzene-sulfonic, sometimes with the addition of sulfuric acid,



**Fig. 2.5** Reaction scheme of PF resole resin formation

usually used in a diluted form. Phosphoric acids will not cure phenolic resins at the rate required for most no-bake foundry applications.

The resole resin may be polymerized with a strong acid (sulfonic acid):



The catalyst initiates further condensation of the resin and advances the cross-linking reaction [25–27].

The condensation reactions produce water which results in a dilution effect on the acid catalyst that tends to slow the rate of cure. Due to this effect, it is necessary to use strong acid catalysts to ensure an acceptable rate of cure and good deep set properties.

Thermal decomposition products of phenolic resin include CO, CO<sub>2</sub>, phenol, benzene, toluene and PAHs. Use of a sulfur-containing organic acid produces SO<sub>2</sub> and H<sub>2</sub>S on the mold/metal interface [28–30].

### 2.5.3 Shell (Croning) Process

This process is the only one among all molding and core-making processes that can use pre-coated sand, directly available from suppliers and ready for use, although pre-coating the sand may also be performed at the foundry.

The sand is cured by heating it in a metallic pattern, producing a hardened surface layer. The cured sand forms a “shell”, which has given its name to the process. This process gives high dimensional accuracy and a good surface finish to

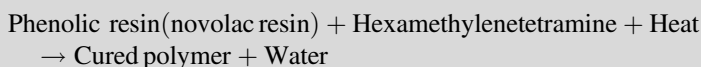
the castings, good shake out and de-coring properties and allows a nearly unlimited storage time for the pre-coated sand. Its use is restricted to the production of small or medium sized molds and cores in mass production.

The shell sand binder uses a novolac resin (phenol-formaldehyde) that requires formaldehyde to create the phenolic polymer that binds the sand. Novolac resins are obtained during the reaction of phenol with formaldehyde in acidic medium, using a slight insufficiency of formaldehyde (Fig. 2.6).

Since novolac resins contain only methylene groups ( $-\text{CH}_2-$ ) and do not contain methylol groups ( $-\text{CH}_2\text{OH}-$ ) such as resole resins, the same heating of these resins does not cause further cross-linking reactions and (they are thermoplastic). Only the addition of a formaldehyde-releasing compound causes end hardening.

This binder component is added to the sand in the form hexamethylenetetramine (as a hardener), that decomposes at  $160^\circ\text{C}$  into ammonia and formaldehyde when heated:

When pre-coated sand contacts the heated pattern, the hexamethylenetetramine decomposes and the formaldehyde cross-links the resin binder to form the characteristic strong bond. The presence of hexamethylenetetramine in sand mold does not cause bonding and the mixture needs to be heated to a predetermined temperature in order to harden it.



During the thermal decomposition of the binder  $\text{CO}$ ,  $\text{CO}_2$ , and various hydrocarbons will be emitted, in addition to traditional gas, and additionally nitrogen

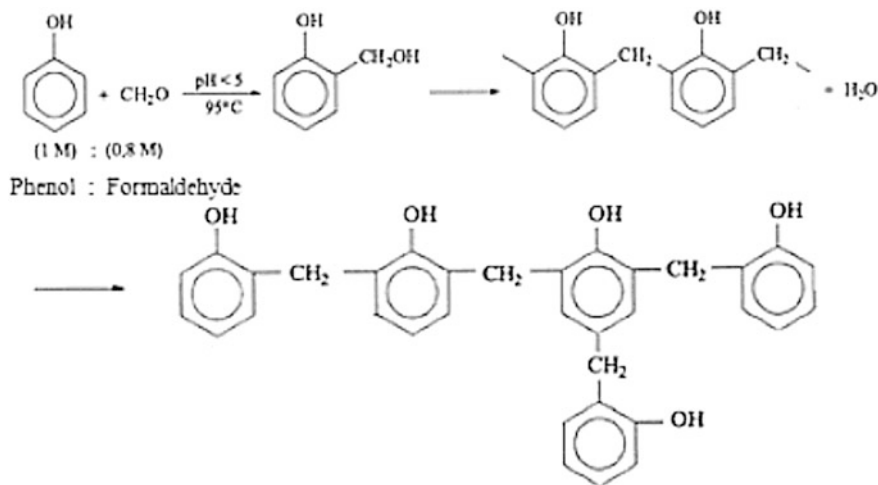


Fig. 2.6 Formation of a “novolac” phenol-formaldehyde resin

compounds in significant quantities. Also, when coated sands are heated, free formaldehyde may be released [31].

### 2.5.4 Furan Hot-Box

The hot box process is a development of a shell molding process, however it differs from it with three elements: it is only used for the preparation of cores, full cores are made (no shell) and the binding reaction is exothermic, which promotes the further hardening process after removing the heat source, namely, after removing the core of the core box.

The process can produce cores of a high dimensional accuracy and good mechanical strength. It provides a high dimensional accuracy, which can only be achieved by means of using high quality (metal) patterns, which can be very expensive. For this reason, the furan hot-box process is currently used in the manufacturing of small or medium sized cores in mass production.

Conventional hot box resins are classified simply as furan or phenolic types. The furan types contain furfuryl alcohol, the phenolic types are based on phenol, and the furan-modified phenolic has both. All conventional hot box binders contain urea and formaldehyde resin binder and a heat activated catalyst are pre-mixed with sand and the mixture is blown into a heated corebox, where it is cured. A wide range of resins: urea-formaldehyde, urea-formaldehyde–furfuryl alcohol, urea-formaldehyde-phenol are used. The catalysts are aqueous solutions of ammonium chloride or ammonium nitrate (acid salts), with urea additions to reduce the free formaldehyde. The typical amount of catalyst used varies from 10 to 25 % mass based on the resin weight. The addition ratio for the resin varies from 1.2 to 3.0 % mass based on the sand weight. The temperature used for the pattern ranges mostly from 230 to 290 °C.

The furan hot box resin has a fast cure compared to that of the phenolic-type system and can therefore be ejected faster from the core box. Furan resin also provides a superior shake out and presents fewer disposal problems due to the lack of phenol. Typical resin content is 1.5–2.0 % mass. A simplified hot box reaction mechanism is:



Hot curing processes are characterized by major emission problems: when heated, the resins and catalysts emit noxious chemicals including ammonia and formaldehyde that can be the source of odor nuisance. Ammonia is decomposed into nitrogen and hydrogen; the said gases dissolve in the melt casting and often cause pinholes in the cast steel and ductile iron casts. Therefore, resins with a lower content of nitrogen, formaldehyde and water are used for the casting from these materials.

### 2.5.5 Warm-Box

This process is very similar to the hot-box process and uses the same production techniques. Only the type of resin differs, which allows for curing at a lower temperature. However, this kind of resin is significantly more expensive compared to those used in the hot-box process. The binder is furfuryl alcohol-based, with a typical composition containing around 70 % mass furfuryl alcohol or a low polymer of furfuryl alcohol. Accordingly, the tool temperature can be held at around 180 °C, which leads to major energy savings of about 15–25 % mass compared to the hot-box. The warm box resin is a minimum-water (<3 %), furfuryl alcohol-type resin (furfuryl alcohol content: ~70 %) that is formulated for a nitrogen content of less than 2.5 % mass. Since the resin/sand mix exhibits a high degree of rigid thermoset properties when fully cured, little or no post strip distortion or sagging occurs.

The catalysts are copper salts derived from aromatic sulfonic acids, in water or an alcohol solution. The catalyst amount used is 20–35 % mass, based on the resin weight. These catalysts are unusual in that they impart an excellent latent property (unreactive at room temperature, reacting only upon heating) to the binder system, but still form strong acids when heated. They promote a thorough curing action at temperatures of approximately 65 °C or higher.

A simplified warm box curing reaction mechanism is:



The binder components remain stable when mixed together in the proper ratios in sand until activated by heat, which decomposes the catalyst and releases the acid that causes the resin to polymerize. The pattern temperatures used range from 150 to 230 °C. The optimum temperature of 190 °C is about 55 °C below the operating temperature for hot box binders. Warm box resins are low in nitrogen.

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