

Foundry Coating: Beyond Refractory & Binders

Vivek Kumar

Asst. Manager

Gargi Huttenes Albertus Pvt Ltd

Ritesh kumar Rituraj

Coating Section(Plant Head)

Feedchem Inc

ABSTRACT

The essentials of foundry refractory coating in improving the overall quality of castings cannot be over emphasized. The application of mould and core washes creates a high thermal integrity barrier between the metal and the mould resulting in the reduction of the thermal shock experienced by the sand system due to high pouring temperature. These thermal shocks lead to series of surface defects such as veining, cracking, metal penetration, burn-on/in, scab, rat tail, sand wash etc. The use of coatings reduces the tendency of occurrence of these defects, apart from this, surface quality of casting can be the reflection of mould/core finish, so maintaining quality casting with good surface finish can be achieved by good coating Practice.

1.Introduction

Refractory coatings are defined as fine particulate materials suspended in a liquid medium (in most cases) that is applied on the desired surface either by spraying or brushing to provide a thin layer covering the exposed surface. The liquid medium usually provides the bonding leaving a solid continuous surface that is supposed to provide protection by forming an impervious layer for the intended purpose. Refractory materials are used for coating on the working surface of the lining having a thin layer of thickness. Refractory coating materials may be used for different purposes depending on the requirement. They can be classified as follows.

1. As a parting material between two refractory layers so that the individual layers can react independently from thermal changes.
2. As a working layer in front of the lining to protect the main lining from direct exposure to the working conditions.
3. As a parting material between metal-metal contact or metal refractory contact.
4. As an impervious material on insulating blankets or modules so that the furnace gases cannot permeate through the insulation that can cause ineffective insulation as well as affect the supporting structure by corrosion from reactive gases.
5. As a sealant for gas leaks, such as coke oven roofs where the coatings help in preventing toxic gases from being released in the atmosphere.

6. As heat reflector providing heat emissivity where considerable heat can be saved by using the coatings when used inside the furnace up to a certain temperature limit.

7. As a protective layer for oxidation resistance of materials containing carbonaceous components.

8. As an inert, non-reactive, high temperature protection, lubrication and release. Since the refractory coating formulations and applications are widely diverse it is prudent to discuss the different types of coatings on the basis of their applications.

2. Components of coatings

A refractory coating on the mould or core should have the following characteristics:

- Sufficient refractory properties to cope with the metal being poured
- Good adhesion to the substrate to prevent spalling
- Be permeable to minimize air entrapment
- Be fast in drying
- No tendency to blistering, cracking or scaling on drying
- Good suspension and remixing properties
- Minimize core strength degradation
- Provide adequate protection against metal penetration
- Good stability in storage
- Good covering power
- Good application properties by the method chosen
- Leveling well and minimizing runs and tear drops For a coating to achieve these characteristics, the coating will consists of
- Refractory filler
- Liquid carrier
- Suspension agents (Rheology control system)
- Binder agents
- Additives

2.1. Refractory filler

Refractory materials are substances or minerals that have high melting points and are difficult to fuse except at very high temperatures. They are processed at high temperature and/or intended for high temperature applications. Refractoriness has been defined by Committee C-8 of the American Society for Testing and Materials (ASTM) as "...the capability of maintaining the desired degree of chemical and physical identity at high temperatures and in the environment and conditions of use." The melting temperature of refractory materials is an important characteristic showing the maximum temperature of use and represents fundamental point in phase diagrams used in high temperature chemistry, metallurgy, ceramics etc. In coatings, refractory materials are dispersed in the binder and constitute the skeleton of the coating film. They increase the density, viscosity and hardness of the coating film and reduce the permeability. There are characteristics other than resistance to high temperatures that refractory materials should exhibit. These include:-

- Suitable particle shape, particle size (PS) and particle size distribution (PSD),
- Chemically inert with molten metal,
- Not be readily wetted by molten metal,
- Not contain volatile elements that produce gas on heating,
- Have consistent cleanliness and pH
- Be compatible with new chemical binders as they are developed .

The significance of particle shape, PS and PSD are elaborated below in the following paragraphs. The other factors are readily understood. At a given refractory material loading, particle shape determines the mechanical properties of the coating matrix. The particle shape is usually described by a dimensionless parameter, the aspect ratio—this is the ratio between the average diameter and average thickness of the particle. The higher the aspect ratio of the particle of refractory material, the higher the reinforcing effect on the coating matrix will be. The particle size distribution (PSD) of a refractory material is usually given as a cumulative curve, indicating the amount per volume or weight of particles (%), which are smaller than a given size. PSD can be adjusted by grinding and classification. The coarsest particles act as points of highest stress concentration, where crack or fractures occur under loading. Impact strength is significantly improved by using finer particles. It is generally assumed that a sieve analysis sharply defines between the different sizes of particles comprising aggregate materials. On any particular sieve one finds particles ranging from those just able to pass through the preceding sieve to those just unable to pass through to the following sieve. As a result of this lack of sharp differentiation between the particle sizes on adjacent sieves, it is difficult to simply screen aggregate material and secure particles of uniform size on each of two successive sieves. From a practical aspect, the refractory material should be available in large quantities at reasonable prices. In foundry coatings, refractory materials determine the efficiency of the coating. The refractory filler may be

either a single material or a blend of materials selected for specific applications. They make up 50% to 70% of the coating. Fillers are chosen for their particle size and shape, density, sintering point, melting point, thermal conductivity, thermal expansion and reactivity towards the metal being cast and the mould or core material on which it is applied. These refractory materials include Plumbago, silica, graphite, coke, anthracite, zircon flour, magnesite, Chalmette, olivine, clays, talc, chromite, alumina, mica. The material of which sand moulds and cores are made generally exert influence upon the surface quality of the castings formed from these moulds and cores. This is because they have a high degree of porosity to the extent that the pores tend to be filled with molten metal causing high surface roughness on the castings. Therefore, with the application of refractory coatings on the surface of the moulds and cores that will be in contact with the molten metal, the refractory particles tend to fill these pores on drying, thereby creating a smooth inert surface on the moulds and cores. These refractory materials have different properties and are selected depending on the metal to be cast. The more common refractory materials are discussed below.

Plumbago is a finely ground blend of graphite containing 80% to 90% of particles that will pass through a 200-mesh (75 micron). The graphite may be amorphous (no definite crystal structure) or crystalline (having definite particle shape or flaky). Graphite will not melt at the highest foundry temperatures but its carbon is driven off by oxidation at these temperatures depending on the air (containing oxygen) available at the metal-mould interface. Amorphous graphite oxidizes easier than does crystalline graphite. Plumbago is applied dry only on green sand moulds.

Silica happens to be the major component of the earth's crust. It constitutes 60% of the crust's composition, occurring both independently and as silicates in combination with other oxides. The fusion point of silica flour is 1734°. At approximately 650°C (1100°F), silica refractory filler has an expansion of 1.6%. Silica fillers are well known for use as pigments, reinforcing agents etc. The silica used in monolithic refractories includes quartzite, silica sand, diatomaceous earth and fused silica glass. Silica sand was originally used for containment of molten iron and steel. Today, silica is often used as mortar and some kinds of special plastics such as tap-hole Monolithic Refractories. Fused silica is used in making castables and pumpables primarily for use in the coke oven. Fused silica containing low-cement castable shapes are now also used in repairing coke ovens. Pumpable fused silica compositions have better physical and thermal properties than silica bricks. They have better strength, lower thermal expansion and better load-bearing capacity than silica bricks. Finely ground silica (below 325 mesh) is used in various compositions, particularly coatings. The use of these fine silicas is somewhat restricted because of the associated health hazards (fine silica can cause silicosis after prolonged inhalation of the dust without appropriate protective safety gear).

Graphite is a form of carbon that occurs in nature. Graphite is generally described as grayish black in color with a lustrous black sheen. It crystallizes in the hexagonal system with rhombohedral symmetry. Natural graphite is usually described in three generic terms: amorphous, flake and high crystalline. Amorphous (which is a misnomer) graphite generally occurs in areas similar to coal

deposits and the carbon content varies between 75-90%. The base raw material for amorphous graphite is generally that of ordinary coal as determined by chemical analysis. Amorphous graphite is primarily found in Mexico, Korea, China and Austria. Natural flake graphite is a term also used to describe a naturally occurring graphitic mineral that has been homogeneously distributed through its host mineral. The flaky crystalline structure is easily identified when compared to amorphous graphite. Natural flake graphite is different from amorphous graphite; its properties are directional because of its high crystallinity. Natural flake graphite has a graphitization of 99.3%. The base material for high crystalline graphite is believed to consist of crude oil deposits that have been converted to a solid mass of graphite with time, temperature and pressure. High crystalline graphite occurs only in Sri Lanka and is usually used as a standard for comparison with all other graphites via X-ray diffraction. The other forms of graphites are artificial forms that are produced from calcined petroleum coke heat treated to $>2800^{\circ}\text{C}$. These materials are 99.3% graphite with usual carbon contents of 99.9%. The other artificial graphite is produced by the processing of graphite electrodes and has a graphite content of 85-95% and a carbon content of 98-99.5%.

Zircon flour is a highly refractory material and is primarily used for coatings in steel foundries. Good quality zircon flour suitable for foundry work should contain minimum 64% zircon oxide (ZrO_2), 30 to 35.5% silica and maximum of 0.5% $\text{TiO}_2 + \text{Fe}_2\text{O}_3$. Refractory uses of zircon require low interstitial water content. This translates into low loss on ignition. Excessive internal radiation damage to zircon crystals (metamict zircon) can cause an increase in the loss on ignition of a zircon product. The desire of the refractory market for a low loss on ignition implies that a low picocurie/gram requirement is placed on zircon products. It has a specific gravity of about 4.5 and a pH value of the water-based coating of not more than 9. The melting temperature is $2727 \pm 10^{\circ}\text{C}$. The high heat conductivity, about double that of silica, promotes quick formation of a solidified metal layer and helps in producing castings with a fine-grained structure. Its higher density than that of silica prevents metal penetration.

Magnesite although magnesite is a mineral (MgCO_3), in the refractories industries the term magnesite is identified with MgO (magnesia). Magnesite is produced either by calcining the mineral magnesite (MgCO_3) after appropriate beneficiation or by synthetically extracting it from sea water or brine. Naturally occurring magnesite is often associated with dolomite, talc, chlorite, serpentine, mica, pyrite and magnetite. Most deposits are mined selectively, and the ores are often beneficiated. The beneficiation method varies according to the location but usually includes crushing, screening, washing, magnetite separation, heavy media separation and froth floatation. The most important process in the production of magnesia from sea water and brines is the precipitation of magnesium hydroxide from solutions of magnesium salts by the addition of a strong base (calcined limestone or calcined dolomite). The magnesium hydroxide precipitate is then washed, thickened, filtered and calcined to produce magnesia. In another commercial process, concentrated magnesium chloride (MgCl_2) brine is sprayed into a thermal reactor where hot gases convert it to magnesia and hydrogen chloride. The magnesia is slurried forming

magnesium hydroxide that is washed, filtered and calcined to produce magnesia. For refractory applications, dead-burnt (>1400°C) magnesia is used. Naturally occurring dead burnt magnesite is often associated with higher quantities of silica and iron, while the synthetic magnesites are made by controlled chemistry with desired quantities of silica and calcia to attain higher density. Fused magnesia is produced at temperatures >2750°C by fusing magnesia in an electric arc furnace. The fused magnesite has much larger crystal size and is superior to dead-burnt magnesite in strength, abrasion resistance and chemical reactivity. In monolithic refractories the greatest use of magnesia is in the gunning maintenance of basic oxygen furnaces and electric furnaces. In recent years, the use of magnesite in the tundish working lining has become a regular practice and its consumption is increasing with time. The magnesite used in the tundish lining does not need to be of high quality since it is mixed with silicates and clay minerals to obtain the Monolithic Refractories.

Olivine was named after its olive-green color. It is a generic term used to indicate a group of orthosilicate minerals in a solid solution series, with forsterite ($2\text{MgO} \cdot \text{SiO}_2$) and fayalite ($2\text{FeO} \cdot \text{SiO}_2$) as end points. Olivine is a major constituent of earth-forming rocks. Therefore, it is found in varying quantities of alteration products, such as serpentine ($3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$). Dunite is an olivine-containing rock with about 90% olivine. Olivine has natural properties that support its use for a variety of applications, viz., melting point of 1800°C, low heat conductivity, good insulating values (60-80% less than magnesite), high refractoriness level (1760°C), no hydration, i.e., no calcination is required before use, inert nature, Mohr's hardness of 6.5-7.0, specific gravity of 3.27-3.37 and bulk density of 1.5-2.0 g/cm³. Moreover, it is environmentally friendly (contains no free silica), high chemical and mineralogical stability (due to strong forsterite mineralogical binding) and high resistance to metal penetration (to both basic and acidic iron oxide-rich slags, alkaline oxides, sulfates carbonates and halides). Because olivine is inexpensive, it competes favorably against higher-priced raw materials of similar chemistry. Olivine competes with magnesite as a refractory mineral as well as in castables and tundish liners. In refractory incinerators, olivine has technical advantage over other refractory materials including resistance to slag attack, temperature and spalling.

Andalucite is a naturally occurring alumina-silicate mineral that is isomorphic with sillimanite and kyanite. Andalucite occurs in nature as large orthorhombic single crystals and are found in gray, greenish, reddish or bluish colors. The main source of andalucite has been South Africa but it is also mined in the former USSR, France and Spain. The highest grade of andalucite is found in the western region of the Transvaal province of South Africa. Along with sillimanite and kyanite, it is an important mullite former used as raw material in Monolithic Refractories. It dissociates into mullite and silica at 1400°C and is associated with some expansion (about 6-7%). Andalucite has been a good source of alumina-silicate refractories for economic reasons and because of its high refractoriness particularly after conversion to mullite.

Sillimanite, the third isomorphous mineral, has a similar chemical composition but ranks between andalucite and kyanite in density. Monolithic Refractories converted to mullite and silica at a much higher temperature than the other isomorphism (1535-1545°C) with an associated expansion of 12-13%.

Kyanite has the same chemical composition as andalucite and sillimanite but differs in crystal structure and physical properties. It is the heaviest among the isomorphous minerals and has a sp.gr of 3.5- 3.7. It is found in India, Africa and the Appalachian region in the United States. Kyanite from India, the best quality available in the world, is different in character from American kyanite, with a native occurrence as surface boulders. Virginian kyanite is associated with quartz, from which it must be separated after grinding down to a workable mesh. Virginian kyanite is not available in grain sizes larger than 35 mesh while Indian kyanite can be calcined in lump form which makes an excellent grog. Indian kyanite often shows higher than theoretical amounts of alumina due to its association with corundum in the ore. The use of kyanite is quite extensive in both shaped and monolithic refractories particularly due its high thermal expansion (about 22-23%) during conversion to mullite. The expansion compensates for the shrinkage occurring from clay minerals used in a lot of monoliths. It is mostly used in low alumina and alumina-silicate compositions in all types of monolithic compositions.

Chemical compositions of andalucite, kyanite and sillimanite.

Composition%	Andalucite	Kyanite	Sillimanite
Al ₂ O ₃	54.0-61.3	56.1-61.3	61.1-71.1
SiO ₂	37.4-43.8	37.4-41.0	22.5-31.5
Fe ₂ O ₃	0.48-1.70	0.52-0.60	0.50-1.62
TiO ₂	0.25-0.30	0.10-1.30	0.90-3.00
CaO	0.10-0.20	0.10-0.20	0.06-0.10
MgO	0.11-0.20	0.20-0.25	0.05-0.08
K ₂ O	0.10-0.20	0.02-0.08	0.05-0.10
Na ₂ O	0.08-0.10	0.02-0.05	0.06-0.08
L.O.I	0.10-0.20	0.25-0.45	1.32-5.62

Table 1: Shown Chemical composition of andalucite, kyanite and sillimanite

Mica is a plate-like crystalline aluminosilicate and has been widely used as reinforcing filler in polymer matrix due to its excellent mechanical, electrical and thermal properties as well as lower cost than carbon or glass fibres. Chemically they contain complex silicate of aluminum and alkalis with hydroxyl. They crystallize in monoclinic system. Some varieties may contain iron, magnesium, lithium. There are seven important mica minerals: Muscovite or potassium mica, H₂KAl₃(SiO₄)₃; Paragonite or sodium mica, H₂NaAl₃(SiO₄)₃; Lepidolite or lithium mica, K·Li·Al(OH, F)₂Al(SiO₄)₃; Phlogopite or magnesium mica, H₂KMg₃Al(SiO₄)₃; Biotite or magnesium iron mica, (H₂K)(Mg, Fe)₃Al(SiO₄)₃; Zinnwaldite or lithium iron mica, Li₂K₂Fe₂Al₄Si₇O₂₄; and Lepidomelane or iron mica, (H, K)₂(Fe, Al)₄(SiO₄)₅. Muscovite is the commonest of all and

whenever the word mica is used it is understood to mean muscovite. No other natural substance has been found to possess the properties equal to those of mica. Of all the known varieties of mica only muscovite and phlogopite are of commercial importance. Muscovite finds the largest use while phlogopite has a limited application. On the other hand phlogopite is superior to muscovite in heat resistance. Muscovite can withstand temperatures up to 700°C, and phlogopite up to about 1000°C. Phlogopite is, therefore, preferred where a high temperature is required. Mica can be used as refractory filler in foundry core and mould coatings to eliminate or reduce finning defect in castings because of its lamellar plate-like nature.

Clays

Kaolinitic clays

Kaolinitic clays Kaolinitic clays include minerals like kaolinite, meta- and hydrated halloysite, nacrite and dicktite. These minerals have the same chemical formula $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ except halloycites that have more water molecules. When heated, kaolin changes into meta kaolin and finally converts into mullite at around 1200°C. The dehydration process of clays are endothermic reactions. From differential thermal analysis, different clays can be identified from the position, size and shape of their endothermic and exothermic peaks.

Bentonite

Montmorillonite is the principal constituent of bentonite. Like pyrophyllite, montmorillonite ($Al_2O_3 \cdot 4SiO_2 \cdot 6H_2O$) is a three-layer mineral in which part of the Al^{3+} ions are replaced by Mg^{2+} ions while Ca^{2+} and Na^{+} ions are absorbed between the layers. When dried, the water molecules between the layers are removed. When the mineral absorbs water again, water molecules get between the layers causing them to expand. Calcium bentonites absorb less water than sodium bentonites. Bentonite (montmorillonite-containing) clays are the most commonly used among the raw clays. The use of specific clays depends on the specific composition of each monolithic refractory. For plastic compositions, clays containing higher amounts of montmorillonite (bentonite and bentolite) are used because of their plastic behavior whereas, for gunning and ramming mixes, producers now use clays containing lower amounts of montmorillonite. Raw clays play an important role in the formulation of plastics, ramming, gunning and mortars. These clays offer workability, adhesion characteristics and refractoriness at higher temperatures by converting to mullite. The compositions are sometimes adjusted so that the shrinkage associated with the calcining of the clays is compensated by kyanite or similar materials.

Calcined clays

A wide variety of clays are now used in the composition of monolithic refractories varying from high-alumina kaolinitic clay to lower alumina plastic (bentonite) clays. Kaolinitic clays in the calcined form provide the major source for almost all categories of lower-alumina monolithic refractories. The kaolinitic clays are sometimes mixed with low-grade bauxitic clays and then calcined into high-grade dense grains that are widely used. These grains are dense and possess

low porosity and high refractoriness. The alumina content of these grains varies in the range of 47-70% with porosities in the range of 3-6%, thus providing a wide range of compositional varieties.

Mullite

Mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) has a specific gravity of 3.15. It softens at 1650°C and melts with dissociation into corundum and silica at 1810°C . Although a very stable compound, mullite is rarely found in nature except on the isle of Mull on the west coast of Scotland (from where it derives its name). Synthetic mullite is produced by sintering kyanite, bauxitic kaolin and bauxite (in the correct Al_2O_3 to SiO_2 ratio) and a mixture of kaolin and alumina in rotary kilns. Kyanite, andalucite and sillimanite convert to mullite upon heating in varying degrees of volume change. Most sintered mullites are not pure mullite, but a mixture of mullite, glass and cristobalite, the amount of each depending on the chemical and Monolithic. Pure synthetic sintered and fused mullite is produced in electric arc furnaces by fusing the right proportions of pure Al_2O_3 and SiO_2 . The extent of fusion determines the state of the sintered and fused mullite. Mullite is a unique refractory material with excellent thermal shock resistance, hot-load bearing characteristics, and high refractoriness. Mullite is formed in all alumina-silica refractory materials heated to sufficiently high temperatures. The amount of mullite formed depends on the chemical analysis and the heat treatment received. Relatively pure bauxite with 70% Al_2O_3 content converts to mullite at a temperature of around 1650°C whereas 60% Al_2O_3 containing bauxitic kaolin converts to mullite at around 1600°C . The associated volume shrinkages are 20% and 15% respectively. The mullite content of each is about 85-90% and 75-80% respectively while the remainder is glass. Both sintered and fused mullite are available on the market; but because of their higher cost in the pure form, neither of them is used in large quantities in monolithic compositions.

2.2. Liquid Carrier

The liquid carrier is the vehicle for the total coating composition and serves to transport the filler onto the sand substrate. It must be removed before casting takes place. The most commonly used carriers are water and isopropanol, although other solvents such as methanol, ethanol, hydrocarbons and chlorinated hydrocarbons have also been used. Water is cheap and readily available but drying in an oven is usually necessary to remove it before casting. Oven drying can be a problem on large moulds or cores. Isopropanol dries faster than water and can be removed quickly by burning so it is frequently used for large moulds and cores, but it is a more expensive carrier than water. Methanol and ethanol have higher vapour pressures at 20°C than isopropanol and dry faster still. Chlorinated hydrocarbons were at one time introduced for fast air drying, but they are now obsolete due to environmental concerns.

Properties of alcohols used as carrier liquids

	Methanol	Ethanol	Isopropanol
Flash Point	11	12	12
Boiling Point	65.2	78.5	82.3
Vapour Pressure at 20 oC mm Hg	94	43	32
Expansion limit(Vol%)	5.5-26.5	3.5-15	2.0-12
MAK value(ppm)	200	1000	400
Smell limit(ppm)	2000	350	100

Table2: Shown Properties of alcohols used as carrier liquids

The use of water-based coatings on cores and moulds made with chemically bonded sand can effect the strength of the bond, and may give rise to casting defects due to surface friability of the core or moulds. Silicate binders are particularly badly affected by water-based coatings and spirit-based coatings should be used instead. Cores made using phenolic-isocyanate resin processes can also be affected, and care must be taken to dry the cores quickly and immediately after coating.

2.3 Suspension Agents(The Rheology Control System)

There is no difficulty in keeping solid particles in permanent suspension in a liquid if both have the same specific gravity. This is not the case with foundry sand coatings. The maintenance of solid particles in suspension is achieved by addition of suspension agents. These agents provide the suspension system that prevents the filler particles from agglomerating and separating out during storage of the coating over extended periods. It ensures that the coating is homogeneous and ready for application with the minimum of agitation. It also controls the flow properties of the coating and is designed to suit the application method that is used . The suspension agent makes up 1 to 5% of the coating. When water is used as the carrier liquid, bentonite clay is used as a suspension agent. Bentonite swells and forms a gel when mixed with water. Time must be allowed for gelling to proceed to completion. Two kinds of bentonite are in common use, one linked with calcium and the other with sodium ions. As a suspension agent bentonite initially of the sodium type are preferred. Calcium bentonite is converted to sodium bentonite by treatment with sodium carbonate. This treatment affects the swelling power of the clay and makes control of the viscosity of the coating unpredictable. Apart from the difficulties with quality control of the bentonite, it has the disadvantage of tending to induce shrinkage cracks in the coating when dried. In view of the drawbacks associated with bentonite, substitutes are found in polysaccharide and certain forms of carboxymethyl cellulose. Polysaccharides require special mixers, which few foundries possess, to obtain optimum suspension. The cellulose type does not require this special mixers and do not induce shrinkage cracks as does dried bentonite. With organic solvent-based carrier systems, different suspension agents are used. Modified bentonite, known also as organic bentonite or bentone will gel and increase the viscosity of organic liquids such as alcohols and

solvents. Bentonites result from a base exchange of the inorganic Ca and Na cation for an organic one which is quaternary ammonium. Examples of suitable suspension agents for organic solvent-based carriers are hydrogenated castor oil and quaternary alkyl ammonium montmorillonite gel.

This provides the suspension system that prevents the filler from separating out during storage of the coating over extended periods. It ensures that the coating is homogeneous and ready for application with the minimum of agitation. It also controls the flow properties of the coating and is designed to suit the application method that is used. Coatings applied by dipping are different to those designed to be applied by brush, spray or overpouring and it is the rheology control system that affects whether the coating can be applied easily and evenly during use.

2.4 Binding Agents

The function of the binder is to bond together the filler particles and to provide adhesion to the mould or core. The binder often interacts with the whole of the coating composition and therefore cannot be considered in isolation.

Binding agents are various materials which act to hold the particles of refractories together and attach them to the sand surface. The quantity of binder required for this purpose increases a little as the particle size of the refractory decreases, thereby increasing the surface area for a given ratio in the coating. However, it makes up to 1 to 5% of the coating. It is important to determine the minimum quantity of the binding agent, because too little results in poor adhesion but, excess produces brittle coating which may crack on drying and spall off during casting. Furthermore, resins and similar organic binders evolve gas on heating. Thus, any undispersed binder collected in partially dried areas of moulds or cores will cause local concentration of gas generation. In this way, defects such as porosity and lapping can result. It is also worthy to note that most organic binders and many suspension agents used in water suspensions are subject to biological degradation. For longer storage of the coating, precautions must be taken to suppress these reactions. Such reactions do not occur with spirit-based coatings. Binders used for water suspensions include sulphite lye, various clays (bentonite and kaolin), dextrin, molasses, sugars, silica ester and resins (furan and phenol) soluble or miscible with water. For spirit-based suspensions, natural or synthetic resins are required. These include furan, phenol, urea formaldehyde, phenol formaldehyde, novolac and natural wood resins.

3. Coating Application Methods

Several variables dictate the choice of application method. Part geometry and size, appearance of the coating finish, and production rate, all influence the type of application method. Facility constraints will also determine the choice of application method. The configuration of the application equipment is dependent on space or climate. Systems can be manually or automatically controlled. Other systems may require extra equipment, such as holding tanks or outside air supply to operate properly. Similar application systems may operate at widely varying parameters. The viscosity of the coating material, the desired thickness of the final coating, and the complexity of the part will determine the best operating parameters for the application

method. Thus, part temperatures, dip times or number of coats are put into consideration. One factor that is important to all application methods is the transfer efficiency of coating material onto the part. Transfer efficiency is the percentage of solid coating material used that deposited on the surface of the part. The amount of solvent in the coating material is irrelevant. The higher the transfer efficiency, the better, as more coating material adheres to the part and less is wasted. Transfer efficiency ranges from 25% to 40% for conventional spray systems to almost 100% for dip and powder coating methods. Much of the pollution and waste created from organic finishing operations can be minimized or eliminated by improving the transfer efficiency of the application system. If the transfer efficiency cannot be improved, pollution control technology and waste handling measures must be employed.

The following are different methods of applying foundry coating on cores or moulds:-

- 1) Brushing and swabbing
- 2) Spraying
- 3) Dip coating
- 4) Flow coating

3.1. Brushing and Swabbing

This is a simple application technique and one or more layers may be applied. The correct flow behaviour needed is known as thixotropic rheology (well known to users of household paints). The viscosity decreases slowly upon the action of shear and regains more quickly, but not immediately, on shear removal. The coating can be of almost jelly-like consistency in the can but will flow readily when brushed. It gives extremely good suspension of the filler but allows brush marks to flow out after application, leaving a smooth, even layer of coating on the core or mould.

This is similar to brushing, except that the implement used has long, soft bristles which tend to adhere to each other. It is easier to penetrate reentrant areas of the mould with these long bristles and to apply a thick, smooth coating with the minimum of dripping. There is less tendency to mould damage or residual brush marks in the finished coating than with brush application. Both brushing and swabbing are rather slow and require a skilled operator to achieve the best results, but developments in coating rheology have significantly reduced the skill factor needed.

3.2 Spraying

This is a much faster technique than brushing but penetration and coverage of the sand is not as good as with brushing. Skill is required to ensure that deep pockets and re-entrant angles are fully coated. It is best used on moulds and cores having rather simple shapes. Generally, sprayed coatings are of much lower viscosity than brushing or dipping varieties. They are applied under pressure from a spray gun delivering a spray of finely divided droplets on to the surface to be coated. A degree of thixotropy is desirable to prevent the coating from sagging and tearing.

Correctly designed spray systems are available that give very good results, but older equipment may give problems as only very low viscosity coatings can be handled with these spray guns.

3.3 Deep Coating

This method involves submerging the core in the liquid coating, allowing it to pick up a suitable layer of the coating. It is the fastest method of application and is used by the majority of high production foundries. The core is dipped manually or mechanically and when it is removed from the coating bath, it must be allowed to drain to remove excess coating. The success of the operation depends on the consistency of the coating and its rheological properties. It is essential to ensure that a uniform thickness of coating is applied, that there is adequate wetting of the sand by the coating to give good adhesion and that excess coating drains freely from pockets in the core. Failure to do this will affect the dimensional accuracy of the resulting casting. The type of liquid flow that is suitable for dipping is known as a pseudoplastic rheology. A pseudoplastic liquid experiences an immediate decrease in viscosity upon the application of shear. The original viscosity is regained as soon as the shear is removed. As the core is submerged in the coating, the shear involved reduces the viscosity to a low level, thereby ensuring effective coating of all areas of the core. Coating viscosity increases rapidly on removal of the core and drainage of excess coating ceases when the downward coating film weight is counteracted by the upward resistance of the gel. With a correctly designed coating, the necessary thickness is deposited in a very even manner without sagging, excessive dripping or tear formation.

3.4 Flow Coating

Overpouring, also known as flow-coating, is particularly suitable for larger cores and moulds, it consists of a pumping system and a specially designed nozzle. The coating is continuously pumped through the nozzle which directs it over the core, the excess runs back into a reservoir to be recirculated through the nozzle once more. Overpouring also requires special equipment for handling large moulds and cores. The rheology of the coating must be designed to allow an even layer build-up independent of the amount of overpoured coating used. The gel system should allow an even deposition of coating without the risk of residual runs and tear marks.

4. Drying of Coating

After coating application, each coating must be 'dried', which means that the suspension agent (water, alcohol or volatile agents) must be completely removed. These substances do penetrate the moulds or core material and do not have any protective effect for the mould or core. On the contrary, it can cause severe problems of gas formation, blows, slag entrapment, porosity, blistering, and penetration and drastically reduce the strength of the mould or core. The methods of removal are different depending on the type of coating.

4.1 For Solvent Based Coating

In the past, foundries typically used solvent-based carriers because they dry quickly without external heating (air drying). They are also referred to as self-drying coatings. This takes a lot of time. Consequently, flame torching became the accepted means of drying coated cores and moulds. However, workplace environmental, health and safety concerns, as well as economic considerations emanating from the rapidly increasing cost of petrochemicals based solvent, continue to enhance the development and use of water-based coating technologies.

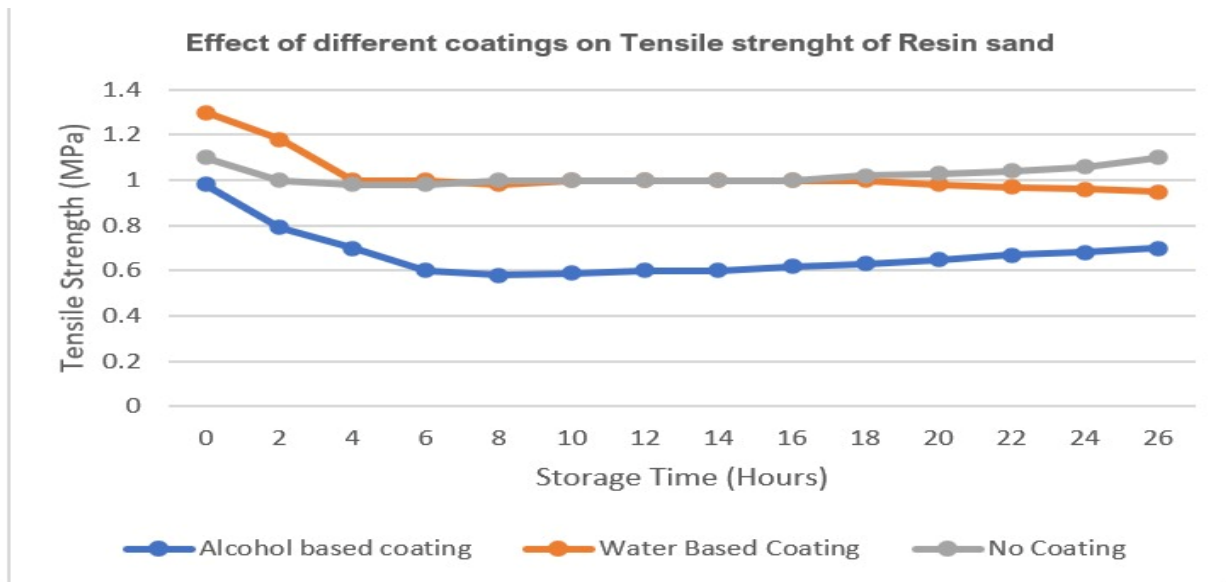
4.2 For Water Based Coating

The trend today is towards water-based coatings. But they require longer drying times using air drying and conventional ovens compared to organic solvent-based coatings. The drying temperature must exceed 100°C, but lower than the temperature at which the binder system is destroyed (mostly 250°C). Different drying techniques such as high intensity lights, microwave, drying tunnels and infrared ovens can be applied to water-based coatings. It was reported in [40] that the high intensity lights and drying tunnels did not dry fast enough as expected to prevent coatings from dripping and losing thickness uniformity. Microwave drying used non-selective heat that penetrated the sand cores and caused them to disintegrate. Infrared ovens, however, dry the coated cores or moulds quickly without damaging the sand bodies. Application of infrared heating for mould and core coating can reduce drying time by 85%. The energy saving comes from the controllability of the infrared unit, which brings the mould surface to the desired temperature and then cycles off in a predetermined time sequence. Less heat is dissipated to the surroundings. The infrared elements direct the heat more effectively at the mould and can dry deep cavities and mould pockets – thus contributing to better casting quality. The sub-surface of the mould is not affected. An additional advantage of using infrared heating is that only 25% of the floor space occupied by the resistance oven was required. A significant development in water-based coatings is the feature in which there is a distinctive colour change as the coating dries and transitions from the wet to the dry state as shown in Figure 7. This change in colour offers visual confirmation that the coating is dry. Not only that this shows when drying is complete, it can also serve as a quality control tool. When drying takes longer time than necessary it will mean that the moisture content is high and can be adjusted. This feature saves energy used in drying thereby saving cost.

5. The effect of coating on strength of resin sand

In order to compare the effect of water-based coating and alcohol-based coating on the strength of resin sand, we dipped coating single-side two kinds of coating (for 5s) in 8-shaped(dog bone) standard specimens (grain size is all 50/100 mesh) of acid self-hardening furan resin sand, after the coating was dried in a corresponding way (water-based self-drying coating was dried under the conditions of 23~30°C and 28~38%RH, began timing and testing after three hours; water-based coating began timing and testing after drying at 120°C for one hour and then cooled to room temperature; alcohol-based began timing and testing after immediate kindling and drying and then cooled to room temperature,) the tensile strength of 8-shaped(dog bone) standard

specimens of resin sand after different time intervals under the same conditions (9~12°C, 38~51%RH) were compared and tested, as shown in graphs:-



Graph 1: Shown effect of different coatings on Tensile strength of Resin Sand

From the analysis of the graph it can be known:-

1. Alcohol-based coating influences the strength of resin sand most and significantly reduces the strength of resin sand. After storing for 24 hours, strength loss rate of coated alcohol-based coating reaches 38% compared with the non-coated resin sand sample, the loss rate of curing initial strength of the alcohol-based coating also reaches 31% compared with the coated alcohol-based resin sand sample. The reason is that the solvent of the alcohol-based coating are methanol, ethanol and isopropanol, and they are all organic solvents; the residual organic solvent in resin sand is easy to make partial not fully cured resin film dissolved, meanwhile, the humidity resistance of the alcohol-based coating is poor, which leads to the significant decrease of the strength of resin sand.

2. Water-based coating is heated drying and curing, when the coating is heated and dried, it also makes the resin film of the resin sand which has not yet fully cured get further polymerization and strengthening, the strength of resin sand is significantly improved. But the binder of water-based coating is general water-soluble inorganic binder. It is easy to absorb moisture and lose strength during storage after curing, the hygroscopicity of coating is strong, it is difficult to prevent the moisture from penetrating the internal of resin sand, and leads to dramatic decline of strength of both coating and resin sand; after storing for 24 hours, strength loss rate of heating and curing initial strength reaches 41% compared with the coated water-based resin sand sample.

6. Characteristics of Coatings

In order to understand the behavior of coatings containing refractory materials, there is need for characterization of the coatings. The parameters that characterize foundry coatings are discussed below: -

6.1. Specific gravity

Specific gravity is the unit weight per unit volume. Specific gravity is a quick test that allows inferences to be drawn about the total solids and refractory components present in the coating. The knowledge of the specific gravity of the suspension agent and that of the refractory material is critical. There would be no difficulty in keeping the refractory material in permanent suspension in the suspension agent if they have similar specific gravity. The specific gravity also gives a fair idea of the refractory material content of the coating. Water has a lower specific gravity of 1. When it used to dilute a coating with relatively higher specific gravity component; the specific gravity of the coating is reduced. The suspension agents and rheology control agents used in coatings give the slurry some unusual properties which are difficult to measure in terms of simple viscosity. The viscosity of such slurries varies according to the shear forces applied. Users of household non-drip paints will be familiar with the way that the paint flows easily during brushing, then gels into a more viscous liquid as soon as the brush is removed. With coatings, a similar effect is seen. After shearing with a paddle mixer, for example, the slurry will take a little time (seconds or minutes) to recover its gel structure. This makes it difficult for the user, with only simple equipment, to check the consistency of the coating. The usual method of checking coating consistency is by means of a Baumé reading, but the Baumé hydrometer must be carefully used to give consistent, meaningful readings. The hydrometer must be clean. Allow the mixed coating to settle for 5 minutes after mixing. Gently immerse the hydrometer, supporting it manually until it finds the correct level (remembering that any shearing force on the slurry will alter its rheology). Wash the hydrometer immediately after use, since dried-on coating is difficult to remove. Always use the same type of hydrometer, coating suppliers will usually provide a suitable type.



Fig1: Shown measurement of Specific gravity (gm/cc)

6.2. Viscosity

Viscosity, a measurement of material flow properties, is the best test for evaluating coatings because of its high correlation with the dried deposit on the core. There are several different methods of measuring viscosity. The most commonly applied in foundries is the flow cup method as shown in Figure 8. The flow cup measure of viscosity requires the use of a cup with a specific size of hole in the bottom to match the material being used. A stopwatch is used as the cup is lowered into the coating and then taken from the surface of the coating after it has filled. The time it takes the coating to drain through the hole is the viscosity in number of seconds.



Fig 2: Shown measurement of Viscosity (Seconds)

6.3 Baume Parameters

The Baume test is the most common test used in foundries to control coating operations because it is both quick and easy. The test is performed with a hydrometer, which is a sealed glass tube that contains a calibrated scale in degrees Baume. The hydrometer should be clean and dry with a resolution of at least 0.5 degrees. The gauges reference the material they are to be used for and the temperature the material should be to achieve measurement accuracy. The Baume scale of numbers relates to the specific gravity and body of a coating. After mixing the coating sample thoroughly, the hydrometer is immediately floated into the coating slurry. When it stops sinking, the degrees Baume can be read directly from the hydrometer. This test requires that the coating be homogeneous, at the correct temperature have no air bubbles and be completely still.



Fig 3: Shown measurements of Baume (in Degree)

6.3.1 Baume Test Variation

Sources of Baume test variation can consume a foundry's operating range, with the magnitude of variation changing from coating to coating, as evidenced by the difference in numbers seen between the low and high solids coatings. There was less variability in the high solids coating Baume values for both hydrometer types. As suspected, there is a definitive difference in the amount of variation and resultant confidence levels between both types of hydrometers, with the glass models showing marked superiority. Variation between multiple operators was also demonstrated, as a reduction in variability occurred as dwell time increased. The percent solids and weight per gallon tests offer a higher degree of process control and are more reproducible. It is important to note that the tests performed were conducted under ideal laboratory conditions and not in a foundry environment. It is reasonable to assume that the data presented is a "best case" scenario. An attempt was made to cover many variables like multiple combinations of operators, delay to test start times, hydrometer types, dwell times and coating solids contents. Using Baume as an in-process control test requires extra cost to maintain casting quality. This additional cost manifests itself in engineering design to compensate for a wide fluctuation in percent solids, and is a burden on the casting designers, tooling designers and coating manufacturers.

A density measurement test, such as weight per gallon or percent solids, should be run in conjunction with Baume. However, if a foundry uses Baume as its principal refractory coating control tool, variability can be reduced by using a high resolutions hydrometer as well as specifying the lag time until the start of the test and the hydrometer dwell time.

6.4 Solid Content

The solids in the coating must be measured because they are the refractory materials that provide protection to the core or mould. The higher the percent solids, the more protection the coating offers. The solid content of a coating determines some other important parameters of the coating such as the density, viscosity, thickness, coverage etc . Therefore, the knowledge of the amount of solid in the coating is very important for reproducibility of these properties. The percent of solid content can be determined by dividing the weight of the dried coating by the original weight and multiplying by 100.

6.5 Coating Thickness

Coating thickness is usually measured using a destructive test. To date no reliable non-destructive test is being applied by the foundry industry to measure the consistency of the coating layer thickness applied on the cores or moulds. In some tests, the cores are sectioned, and the measurements were taken using a microscope. In some other methods, the coating is removed from a flat surface on a core and the difference in the cored surface and the coated surface is measured. The amount of surface deposit can be used as a reference for future comparisons and making decisions about coating allowance in casting design. There is a strong correlation between the viscosity of the coating and the coating thickness. However, coating dry thickness has proved difficult to measure, so what is generally done is to measure the wet coating layer thickness using the elcometer wet film “comb”. The elcometer wet film combs can be used in accordance with following standards; ISO 2808-7B, ASTM D 4414-A, BS 3900-C5-7B and NF T30-125. The film combs have various lengths on their sides. These standards specify that wet film comb be perpendicular to the substrate and the thickness of the coating lies between the biggest value wet tooth and the smallest value dry tooth values. The wet coating layer thickness will be correlated to the dry coating thickness, if the volume to solids ratio of the coating is known. As a rule of thumb dry coating thickness is 50% of the wet coating thickness. In dip coating, the coating thickness is mainly defined by the withdrawal speed, the solid content (density), the surface tension and the viscosity of the liquid.



Fig 4: Shown measurement of coating film thickness

6.6 Coating Permeability

Coating permeability is the amount of gas that can pass through the coating. The level of permeability is detected by both the type and amount refractory materials that are used in the coating formulation and the dry film thickness deposit on the core. The permeability of the coating on the core is measured using a laboratory permimeter. A coating with low permeability is desirable when directing evolved gases to vent through specific areas of the core. A high permeability coating is best when the goal is the evacuation of core gases through the coating. The permeability of the coating at the coating-metal interface may be different than that measured on the core. Some constituents of the coating may quickly thermally decompose leaving voids that result in higher permeability. Some may soften and flux resulting in lower permeability. High permeability coating will reduce the time required for removing the degradation products and will increase the metal fill velocity, often leading to blister and fold defects. Low permeability coating will slow down the metal velocity, which causes the molten metal to lose the adequate thermal energy required for complete pyrolysis, traps the degradation products and leads to misrun or partial fill. It has been reported that mould filling times decreased with permeability of the coatings.

6.7 Core Degradation

Core degradation varies from coating to coating. The longer a core stays wet, the more core degradation will take place. So, it is the best practice to put cores into an oven heat zone as quickly as possible after the core is coated. Most coatings use surfactants as wetting agents to allow the coating to penetrate the proper depth. These surfactants change the surface tension of the water, making it worse for core degradation. To evaluate the effect of refractory coating on core strength following steps were done & observed:-

1. Dipped one set of cores and kept the other set undipped.
2. Place both sets in the drying oven until dry and allow them to cool to ambient temperature approximately for 60-70 Mins.
3. Then, when cool, evaluation of both sets of cores were done for the strength.
4. The comparative loss in strength of coated cores will most likely be substantial. It was reported that the strength of core and mould material will decrease about 25-30% with alcohol-based coatings and 40-50% for water based coatings.

6.8 Coating Penetration Depth

The distance the coating penetrates the core is an important feature to a coating's success. A coating that lies entirely on the surface of the cores is not anchored well and will most likely spall away. A coating that penetrates too much will over degrade the core. Coating penetration is also a function of core density. A core that is blown too tightly resists coating penetration, while one blown softly acts like a sponge and absorbs much water. Therefore, any evaluation of coating penetration should be done on a core that is of normal production quality. It is also noteworthy that core release agents may waterproof the core and affect coating penetration. Coating penetration is evaluated by cutting a coated dried core and observing how far the coating penetrates the core. The usual reference is sand grain penetration. A normal level of penetration is 2 – 4 sand grains. It was reported in, that this is not the most precise methodology because sand grain sizes differ from one foundry to the other. Moreover, a batch of foundry sand has a known distribution of a variety of grain sizes within it, which also makes using sand grain count as a measuring system inadequate. Lower surface tension increases the depth of coating penetration. As coating penetration increases, the thickness of the proud layer decreases while the reverse is the case if the proud layer increases. Thermal expansion increases with the thickness of the proud coating layer (the layer on the surface of the substrate). Therefore, an optimum proud layer thickness is needed to reduce the expansion defects on the casting made with these cores. This requires that the coating penetration depth is controlled.

6.9 Wettability & Surface Tension

The deposition of a coating on a solid substrate generates new interface between dissimilar materials and involves considerations of wettability, spreading, interface evolution and adhesion. The wettability of a solid by a liquid is characterized in terms of the angle of contact that the liquid makes on the solid. The basic law governing the equilibrium of a liquid drop on a surface was formulated by Thomas Young σ . The drop is shaped by the resultant forces pulling at the three-phase contact line of the drop, where the solid/liquid, liquid/gas and solid/gas interfaces meet, in the plane of the solid. The forces (per unit length) acting at this line are the surface tensions and their balance yields the famous Young's equation.

$$\sigma_{SG} = \sigma_{SL} + \sigma_{LG} \cos \theta_c$$

where σ_{SG} , σ_{SL} and σ_{LG} are solid/gas, solid/liquid and liquid/gas surface tensions, respectively

According to Taylor’s depiction of liquid droplet shape on solid surface, the droplet height, $h = 2a \sin(\theta^*/2)$, where a is the capillary length ($a = (\sigma/\rho g)^{1/2}$, σ , the liquid surface tension and ρ , its density, $a = 2.7$ mm for water). It shows that gravity g can affect drop shape besides the three phase forces. Only if the drop is small enough that the effect of gravity is negligible, which typically is the case for drops of millimeter size down to micrometers, the drop will have the shape of a spherical cap and the liquid/gas interface meets the solid surface at an angle θ_c , which is called the contact angle of a flat surface. The condition $\theta < 90^\circ$ indicates that the solid is wetted by the liquid, such a surface is referred to as a hydrophilic surface and $\theta > 90^\circ$ indicates nonwetting, and the surface is called a hydrophobic surface. Wettability of a solid surface is governed by the chemical properties and the microstructure of the surface. Wettability is mainly determined by its interfacial free energy (σ_{SG}). The greater, the free surface energy, the easier, the liquid can spread upon and vice versa. Young’s equation applies to ideal surfaces that are Technology perfectly smooth and devoid of all chemical and structural inhomogeneities. The contact angle measured on a rough surface (called the Wenzel angle, θ_w) does not obey Young’s equation; it is related to the equilibrium (Young’s angle θ_y)

$$\cos\theta_w = r \cos\theta_y \dots\dots\dots(1)$$

where r is the ratio of true wetted area to the apparent area. Equation (1) is called the Wenzel equation. Wenzel’s equation applies to equilibrium angles on rough surfaces and not to advancing and receding angles of a droplet on a rough solid surface that give rise to contact-angle hysteresis. Hysteresis, H , is defined as the difference of the advancing and receding angles (i.e., $H = \theta_a - \theta_r$) and arises because the liquid-vapour interface does not retrace its original path when it recedes on the solid, so that spreading is thermodynamically irreversible. Because roughness hinders the contact line motion by creating energy barriers, the system can reside in any of the potential wells accessible to it the vibrational (or thermal) energy of the droplet In many industrial processes like that found in foundries, the substrate (core in foundries) is immersed in a liquid coating material, and then withdrawn to leave a liquid film on the substrate. The film (coating) thickness depends upon the surface tension, withdrawal speed, substrate geometry, roughness, and viscosity. The dispersion of fine, granular solids in a liquid vehicle is a basic step in preparing paints and other coating materials and involves particle transfer across a gas-liquid interface. The transfer of non-wettable solids into liquids requires the solid to overcome a surface energy barrier at the liquid-gas interface, and energy must be expended to assist the transfer of non-wettable solids. Once the solid enters the liquid, the capillary (attractive) forces and gas bridges between solids control such phenomena as agglomeration, dispersion, and air entrapment. The inter-particle forces between dispersed solids are due to liquid surface tension and pressure difference across the curved liquid-vapour boundary between contacting solids.

6.10 Potenz of Hydrogen(pH)

A pH meter is a scientific instrument that measures the hydrogen-ion activity in solutions, indicating its acidity or basicity (alkalinity) expressed as pH value. It works on potentiometric principle., by measuring the potential difference (voltage) or the minimum electrode voltages. between two electrodes, a reference electrode and a measurement electrode, that are sensitive to analytes. An acidic solution has more positive charge (H^+ ion) and greater potential to produce current than an alkaline solution. A pH meter displays the results directly in pH units on an analog or digital display. The pH range of solutions varies between 1 to 14, where 1 is the highest in acidic nature, and 14 is the highest in alkalinity. Potenz of Hydrogen(pH) test plays a vital role in the foundry coating, whether it may be water-based coating or it may be alcohol-based coating, coating acts as the barrier in between the metal & mould, it restricts the metal-mould reaction, in foundry the same coating may be used for the sand system of Acid-cured resin, Alkaline(ester)-cured resin, Green sand etc. So, generally we are maintaining pH in the range of 6-8 to avoid any sort of metal-mould reaction due to Acid/Alkaline nature of coating.



Fig 5: Shown measurement of pH

7. Conclusions

Foundry is considered to be the Mother Industry of the Manufacturing Sector, currently India has reached a remarkable height in the production of castings 11-12 million tonnes per year & expected a growth of 13-14% in the next couple of years. For foundry, coating is one among the vital raw materials to produce defect free castings with excellent surface finish, So having a wide knowledge about the coating it benefits both the users & the manufacturers. The information in this report will help foundries to identify the right parameters to enhance the performance of their coatings & its application to produce defect free castings with excellent surface finish. On the other hand it may be useful for the foundry coating manufacturers for the improvement of their various existing products.

8. Acknowledgements

The author wish to acknowledge the deep sense of gratitude and profound thanks to Mr. Ritesh Kumar Rituraj(Coating Plant Incharge) M/s Feedchem Inc. Rajkot & Mr. Sanjeev. B Phalke(Moulding Head), M/s WalchandNagar Industries Limited Foundry Division Satara, Maharashtra for their keen Interest, inspiring guidance, constant encouragement with my work during all stages to bring this research into fruition.

REFERENCES

1. T. A. Burns, "The Foseco Foundryman's Handbook," Pergamon Press, Staffordshire, 1986
2. AFS, "Moulding Methods and Materials," 1st Edition, The American Foundrymen's Society, Illinois, 1962.
3. J. Hlavac, "Melting Temperatures of Refractory Oxides," Pure and Applied Chemistry, Vol. 54, No. 3, 1982, pp. 681-688.
4. P. L. Jain, "Principle of Foundry Technology," 4th Edition, McGraw-Hill, New Delhi, 2006.
5. M. Yekeler, U. Ulusoy and C. Hicyilmaz, "Effect of Particle Shape and Roughness of Talc Mineral Around by Different Mills on the Wettability and Floatability," Powder Technology, Vol. 140, No. 12, 2004, pp. 68-78.
6. S. D. Chastain, "A Sand Casting Manual for the Small Foundry," Jacksonville Publishers, Florida, Vol. 1, 2004.
7. S. Banerjee, "Monolithic Refractories," World Scientific Publishing Co. Pte. Ltd, , Singapore 1998
8. U. C. Nwaogu, " Foundry Coating Technology: A Review Technical University of Denmark, Department of Mechanical Engineering", Lyngby, Denmark 2011.
9. Chunyi ZHAN, "Curing Properties of water-based self-drying/ Fast Drying Foundry Coating" School of mechanical and Electrical Engineering, Guangdong Institute of Science and Technology, Zhuhai, 519090, China, 2015.