



A COMPARATIVE STUDY FOR PROPERTY IMPROVEMENT OF MOULDING SAND USING SYNTHETIC BINDER

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Abstract : In the present investigation, the Rajmahal sand was selected as refractory raw material, and its various properties, such as AFS fineness number, specific surface area grain shape and texture base permeability, moisture, and clay content density for characterization, among the binder phenolic and alkyd no-bake resins, were characterized by testing its viscosity. Specific gravity, solid, and ash content. In the sand stage of investigation standard specimen was prepared with the characterized sand, and different proportions of resin constituents and composition of the mix were optimized for maximum strength. The standard specimen were made with optimum composition, and these were used for various room temperature test like strength development friability characteristics, working time pattern strip time as well as retained strength. The carbon dioxide sodium silicate process is one of the oldest processes. However, it is still in use due to the many advantages like no necessity of drying or baking, no carbon pick up from mould on casting surface and no smoke or gas evolution during pouring and shake out. Also the essential material and basic capital costs of this process lower than alternative process and it is relatively environmental safe. The cores and moulds prepared in foundry must have sufficient compressive strength for easy handling and also to avoid erosion of mould surface at corners during pouring of metal. The compressive strength of CO₂ silicate bonded sand is affected by parameters. In the present investigations the effect of certain variable such as binder per cent, flow rate of CO₂ gas, gassing time and holding time on compressive strength have been studied.

IndexTerms – Binder, Moulding, compressive, sand

I. INTRODUCTION

In recent years there has been a drive to increase the re-use of synthetic sands to limit the cost of new sand purchases and to minimize both the cost of dumping used sand and to limit environmental impact. Traditional synthetic sands systems are often based on silica sand, with specialty sands, such as chromites, being used in areas of the mold where higher refractoriness or thermal stability is required. However these additions of specialty sands (specifically chromites) can have a detrimental effect on the performance of the reclaimed sand reducing its refractoriness and increasing the potential of sand fusion and metal penetration, and should be effectively separated before re-use of both the reclaimed silica and chromites components.

Additionally the physical characteristics of silica sand such as grain shape, angularity and porosity can limit the effectiveness of mechanical reclamation processes by preventing the easy removal of the binder without damaging or fracturing the sand grain. High intensity scrubbing of the sand to effectively remove residual binder can lead to a reduction in the average grain size of the reclaimed sand. This will then require increased binder additions to subsequently re-bond the processed sand and increase dust levels that can, if not controlled, contribute to airborne particulates and an irrespirable silica dust hazard.

The use of synthetic sands offers the opportunity to eliminate the use of both silica and special refractory sands, and provide good yield during the reclamation process:

- Superior refractory properties compared with silica sand
- Low thermal expansion
- High strength, resistant to breakage during reclamation

2.1 Moulding Sand



Figure 1: Sample of moulding sand

Moulding sand, also known as foundry sand, is sand that when moistened and compressed or oiled or heated tends to pack well and hold its shape. It is used in the process of sand casting for preparing the mold cavity. In other words Foundry sand is clean, uniformly sized, high quality silica sand, used in foundry casting processes. The sand is bonded to form molds or patterns used for ferrous (iron and steel) and non-ferrous (copper, aluminum, brass) metal castings. Shake-out sand from completed metal casting is often reclaimed back into the foundry sand process.

It is a by-product of the ferrous and nonferrous metal casting industry, where sand has been used for centuries as a moulding material because of its unique engineering properties. In modern foundry practice, sand is typically recycled and reused through many production cycles. Industry estimates are that approximately 100 million tons of sand is used in production annually. Of that, four to seven million tons are discarded annually and are available to be recycled into other products and industries. Stringent physical and chemical properties must be met as poor quality sand can result in casting defects.

Foundries and sand producers invest significant resources in quality control of their sand systems, with extensive testing done to maintain consistency. As a result, FS from an individual facility will generally be very consistent in composition, which is an advantage for most end use applications. Although there are other casting methods including die casting, investment casting, and permanent mold casting, sand casting is by far the most prevalent casting technique. Sand is used in two different ways in metal casting: as a moulding material, which forms the external shape of the cast part, and as cores, which form internal void spaces in products such as engine blocks. Since sand grains do not naturally adhere to each other, binders must be introduced to cause the sand to stick together and hold its shape during the introduction of the molten metal into the mould and the cooling of the casting.

2.2 Classification of moulding sand (According to the amount of clayey matter they contain)

- Silica sand – It consist of up to 2% of clay.
- Lean or weak sand - It consist of up to 2 to 10% of clay.
- Moderately strong sand - It consist of up to 10 to 20% of clay.
- Strong sand - It consist of up to 30% of clay.
- Extra strong or loam sand - It consist of up to 50% of clay.

2.3 Properties of moulding sand

The success of the casting process depends to a large extent on the making of a satisfactory mould. For this, the moulding properties of the sand have to be controlled.

2.3.1 Porosity or Permeability

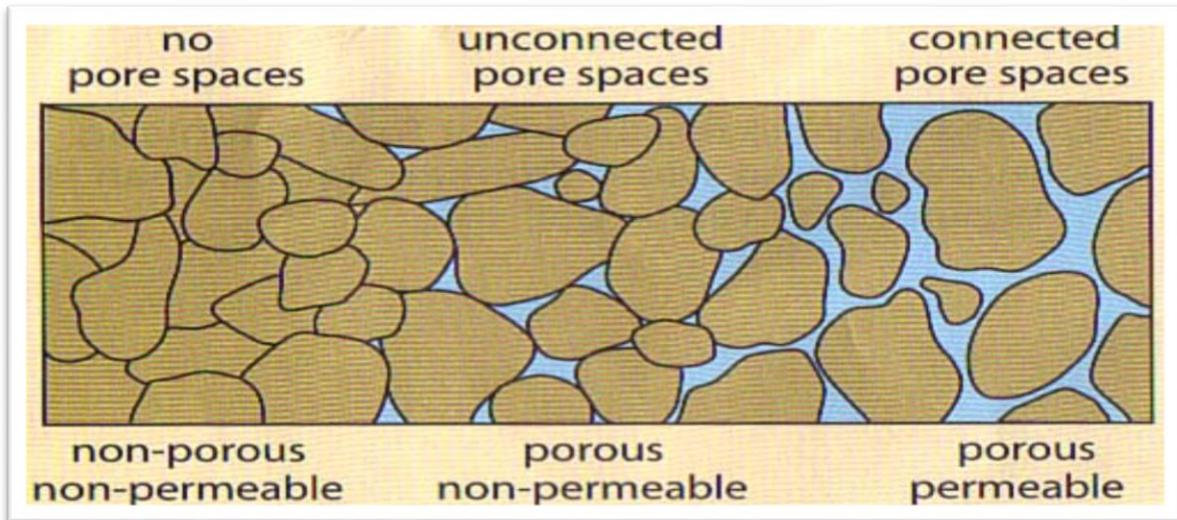


Figure 2: Space between sand particles

Permeability or porosity of the moulding sand is the measure of its ability to permit air to flow through it. It is also termed as porosity of the moulding sand in order to allow the escape of any air, gases or moisture present or generated in the mold when the molten metal is poured into it. All these gaseous generated during pouring and solidification process must escape otherwise the casting becomes defective i.e. If all these gases and vapours are not able to escape completely through the walls of the mould, they may penetrate the liquid metal where, after solidification, they form gas holes and pores. Again, higher the silt contents of sand, the lower its gas permeability. If the mould is rammed too hand, its permeability will decrease and vice versa. Permeability is a function of grain size, grain shape, and moisture and clay contents in the moulding sand. The extent of ramming of the sand directly affects the permeability of the mold. Permeability of mold can be further increased by venting using vent rods.

2.3.2 Strength or Cohesiveness



Figure 3: Sand holding its grain

It is defined as the property of holding together of sand grains. In other words **it** is property of molding sand by virtue which the sand grain particles interact and attract each other within the molding sand. Moulding sand should have ample strength so that the mould does not collapse or get partially destroyed during conveying, turning over or closing.

This property also enables the pattern to be removed without breaking the mould and to stand, the flow of molten metal when it rushes inside the mould.

The strength of the moulding sand grows with density, clay content of the mix and decreased size of sand grains. So, it is clear that as the strength of the moulding sand increases, its porosity decreases.

2.3.3 Refractoriness



Figure 4: Pouring of molten metal

Refractoriness is defined as the ability of molding sand to withstand high temperatures without breaking down or fusing thus facilitating to get sound casting. It is a highly important characteristic of molding sands. Refractoriness can only be increased to a limited extent. Molding sand with poor refractoriness may burn on to the casting surface and no smooth casting surface can be obtained. The degree of refractoriness depends on the SiO_2 , i.e. Quartz content, and the shape and grain size of the particle. The higher the SiO_2 content and the rougher the grain volumetric composition the higher is the refractoriness of the molding sand and core sand. Refractoriness is measured by the sinter point of the sand rather than its melting point.

2.3.4 Plasticity or flow-ability

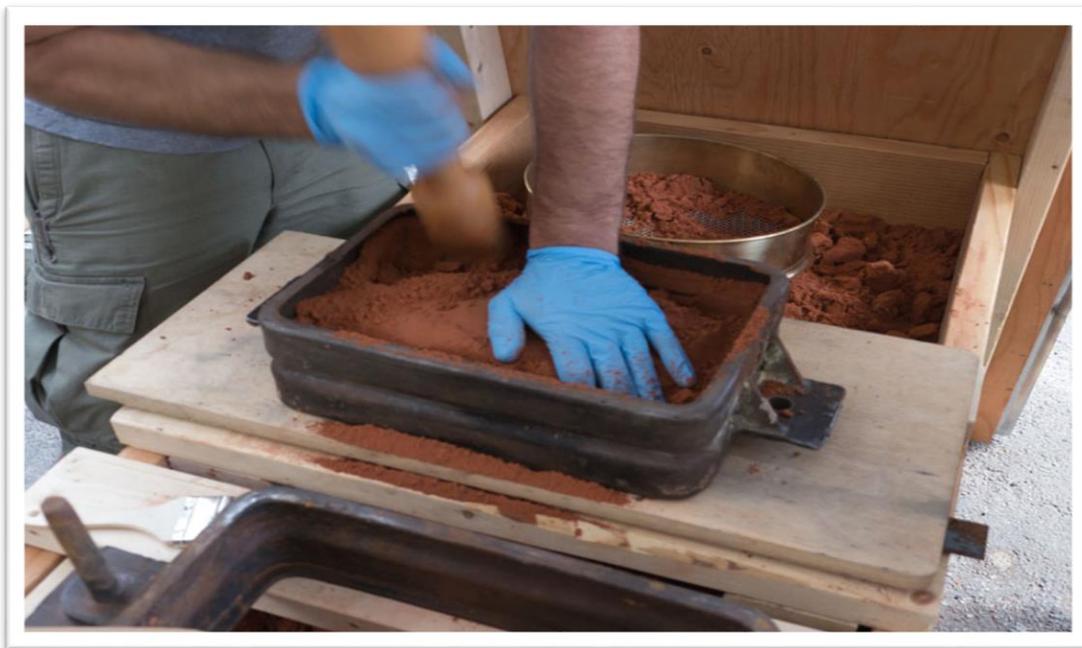


Figure 5: Filling of sand in sand moulding box.

Flow ability or plasticity is the ability of the sand to get compacted and behave like a fluid. It will flow uniformly to all portions of pattern when rammed and distribute the ramming pressure evenly all around in all directions. Generally sand particles resist moving around corners or projections. In general, flow ability increases with decrease in green strength and vice versa. Flow ability increases with decrease in grain size of sand. The flow ability also varies with moisture and clay content in sand.

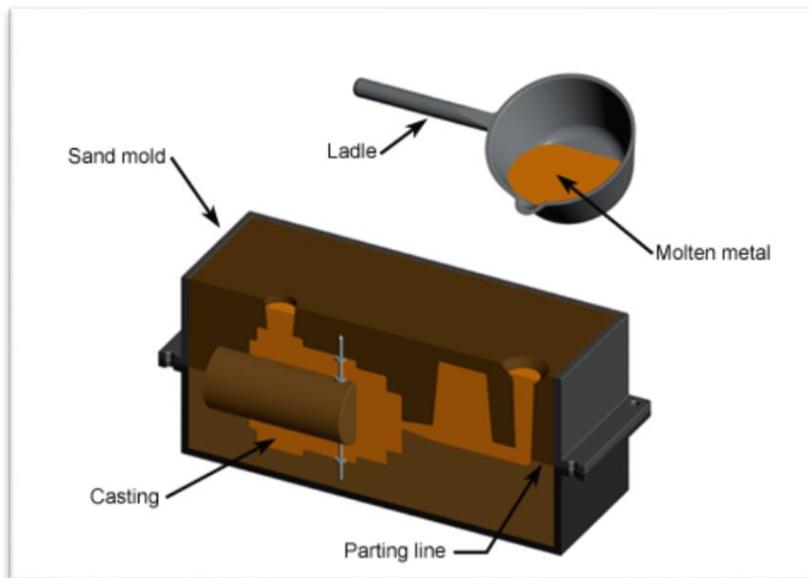


Figure 6: Process of sand casting

2.4 Sand Casting

Sand casting, or sand mold casting, is a popular method of producing non-ferrous alloy casts. Invented over 6,000 years ago, this process has undergone a number of changes and modernizations over the years, but the basic principals have remained the same. From small DIY operations to major commercial foundries, the technique has been replicated many times! One of the main differences between variations of this process is the type of sand used. Read on to learn more about the types of sand used in sand casting.

2.5 Sand Casting Methods

The process cycle for sand casting consists of six main stages, which are explained below.

2.5.1 Mold Making

The first step in the sand casting process is to create the mould for the casting. In an expendable mould process, this step must be performed for each casting. A sand mould is formed by packing sand into each half of the mould. The sand is packed around the pattern, which is a replica of the external shape of the casting. When the pattern is removed, the cavity that will form the casting remains. Any internal features of the casting that cannot be formed by the pattern are formed by separate cores which



Figure 7: Mould for casting

Further details on mould-making will be described in the next section. The mould-making time includes positioning the pattern, packing the sand, and removing the pattern. The mould-making time is affected by the size of the part, the number of cores, and the type of sand mould. If the mould type requires heating or baking time, the mould-making time is substantially increased. Also, lubrication is often applied to the surfaces of the mould cavity in order to facilitate removal of the casting. The use of a

lubricant also improves the flow the metal and can improve the surface finish of the casting. The lubricant that is used is chosen based upon the sand and molten metal temperature. [4]

2.5.2 Clamping

Once the mould has been made, it must be prepared for the molten metal to be poured. The surface of the mould cavity is first lubricated to facilitate the removal of the casting. Then, the cores are positioned and the mould halves are closed and securely clamped together. It is essential that the mould halves remain securely closed to prevent the loss of any material.

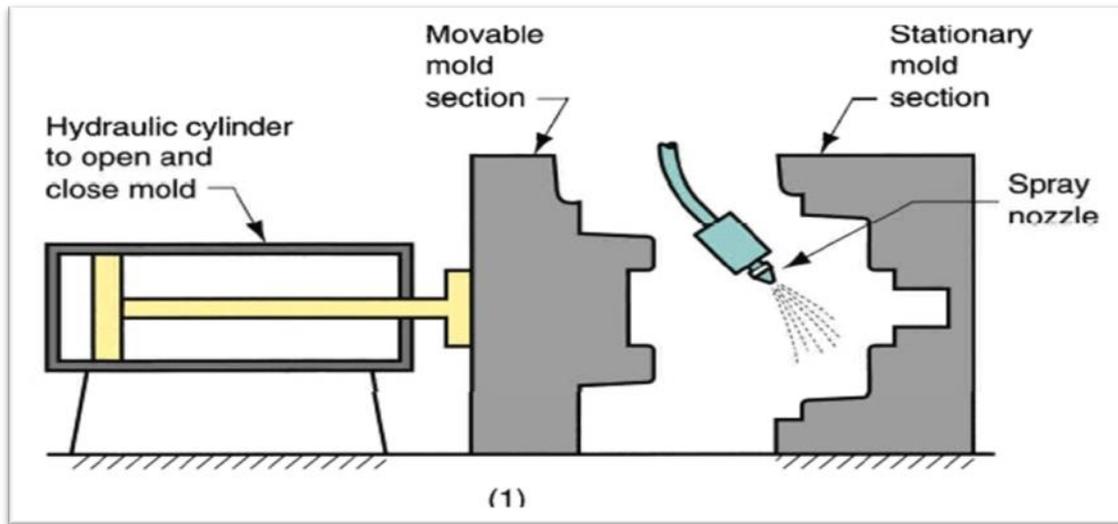


Figure 8: Process of clamping

2.5.3 Pouring



Figure 9: Pouring of liquid metal

The molten metal is maintained at a set temperature in a furnace. After the mould has been clamped, the molten metal can be ladled from its holding container in the furnace and poured into the mould. The pouring can be performed manually or by an automated machine. Enough molten metal must be poured to fill the entire cavity and all channels in the mould. The filling time is very short in order to prevent early solidification of any one part of the metal.

2.5.4 Cooling

The molten metal that is poured into the mould will begin to cool and solidify once it enters the cavity. When the entire cavity is filled and the molten metal solidifies, the final shape of the casting is formed. The mould cannot be opened until the cooling time has elapsed. The desired cooling time can be estimated based upon the wall thickness of the casting and the temperature of the metal. Most of the possible defects that can occur are a result of the solidification process. If some of the molten metal cools too quickly, the part may exhibit shrinkage, cracks, or incomplete sections. Preventative measures can be taken in designing both the part and the mould and will be explored in later sections.

2.5.5 Removal



Figure 10: Broken sand mould

After the predetermined solidification time has passed, the sand mould can simply be broken, and the casting removed. This step, sometimes called shakeout, is typically performed by a vibrating machine that shakes the sand and casting out of the flask. Once removed, the casting will likely have some sand and oxide layers adhered to the surface. Shot blasting is sometimes used to remove any remaining sand, especially from internal surfaces, and reduce the surface roughness.

2.5.6 Trimming

During cooling, the material from the channels in the mould solidifies attached to the part. This excess material must be trimmed from the casting either manually via cutting or sawing, or using a trimming press. The time required to trim the excess material can be estimated from the size of the casting's envelope. A larger casting will require a longer trimming time. The scrap material that results from this trimming is either discarded or reused in the sand casting process. However, the scrap material may need to be reconditioned to the proper chemical composition before it can be combined with non-re



Figure 11: Trimming of excess metal

2.6 Natural/Green sand for casting

Green Sand is also known as **tempered or natural sand**, which is silica sand with minor ingredient additives such as bentonite clay, water, and sea coal. It is a just prepared mixture of silica sand with 18 to 30% clay, having moisture content from 6 to 8%. The clay and water furnish the bond for green sand. It is fine, soft, light, and porous. Green sand is an aggregate of sand, bentonite clay, pulverized coal and water. Its principal use is in making moulds for metal casting.



Figure 12: Sample of natural sand

The largest portion of the aggregate is always sand, which can be either silica. Naturally bonded sand is less expensive but it includes organic impurities that reduce the fusion temperature of the sand mixture for the casting, lower the binding strength, and require higher moisture content.

Green sand is damp, when squeezed in the hand and it retains the shape and the impression to give to it under pressure. Molds prepared by this sand are not requiring backing and hence are known as green sand molds. Green sand is easily available and it possesses low cost. Green sand is commonly employed for production of ferrous and non-ferrous castings.

Not all Green sand is green in colour. But considered "green" as in the sense that it is used in a wet state (akin to green wood). According to the Cast Metals Federation website, an alternative casting method is to heat-dry the moulded sand before pouring the molten metal. This dry sand casting process results in a more rigid mould better suited to heavier castings.

This naturally occurring iron-potassium silicate (also called glauconitic) has the consistency of sand but is able to absorb 10 times more moisture, making it an exceptional soil conditioner for pastures, forage fields, lawns, orchards, small fruits, vegetables and greenhouse potting mixes.

Natural sand is the one which is available from natural deposits. Only additives and water need be added to it to make it satisfactory for moulding. Greensand was deposited millions of years ago when the area was still under water. It is mined primarily for water purification purposes but increasingly more and more people in agriculture and horticulture are requesting it to condition their soil. The clay content of most natural sands is slightly higher than desired so that new sand can be continuously.

Sand casting is one of the earliest forms of casting practiced due to the simplicity of materials involved. It still remains one of the cheapest ways to cast metals because of that same simplicity. Other methods of casting, such as those using coquille, boast higher quality of surface finish, but have higher cost.

2.7 Synthetic Sand



Figure 13: Sample of synthetic sand

A synthetic sand is prepared by mixing a relatively clay free sand having specified type of sand grain, with specified type of clay binder as well as water and other additives. synthetic molding sands are prepared artificially using basic sand molding constituents (silica sand in 85-91%, binder 6-11%, water or moisture content 2-8%) and other additives in proper proportion by weight with perfect mixing and mulling in suitable equipment's.

Synthetic sand is mixed in a manufacturing lab starting with a pure (SiO_2) sand base. In this case, the composition can be controlled more accurately, which imparts the casting sand mixture with higher green strength, more permeability, and greater refractory strength. For these reasons, synthetic sand is mostly preferred in sand casting manufacture.

2.8 Silica Sand



Figure 14: Sample of silica sand.

Silica sand is granular material that contains quartz and minute amounts of coal, clay and other minerals. It is also known as quartz sand and industrial sand, and is largely used in several construction applications. The presence of silica sand on metal materials can be a source of crevice corrosion on those metals.

Silica sand may also be known as silica sand abrasive when used for abrasive blasting. Silica sand is used for a variety of industrial applications depending on the grain size, refractoriness, texture and shape of the sample to be used. Applications can range from use as a building product and abrasive, to glass making and even in hydraulic fracturing of oil wells.

Silica Sand is quartz that over time, through the work of water and wind, has been broken down into tiny granules.

Commercial Silica Sand is widely used by companies involved in oil and natural gas recovery in conventional and unconventional resource plays. The resource is also used in industrial processing to make everyday items such as glass, construction materials, personal care products, electronics, and even renewable materials.^[8]

Silica (SiO_2) is the name given to a group of minerals composed solely of silicon and oxygen. Found most commonly in the crystalline state, it also occurs in an amorphous form resulting from weathering or plankton fossilization.

Silica sand deposits are most commonly surface-mined in open pit operations, but dredging and underground mining are also employed. Extracted ore undergoes considerable processing to increase the silica content by reducing impurities. It is then dried and sized to produce the optimum particle size distribution for the intended application.

For industrial and manufacturing applications, deposits of silica-yielding products of at least 95% SiO_2 are preferred. Silica is hard and chemically inert and has a high melting point, attributable to the strength of the bonds between the atoms. These are prized qualities in applications like foundries and filtration systems. Industrial sand's strength, silicon dioxide (SiO_2) contribution, and non-reactive properties make it an indispensable ingredient in the production of thousands of everyday products.

2.9 Binder

Binders can be either inorganic or organic substance. Binders included in the inorganic group are clay sodium silicate and port land cement etc. In foundry shop, the clay acts as binder which may be Kaolinite, Ball Clay, Fire Clay, Limonite, Fuller's earth and Bentonite. Binders included in the organic group are dextrin, molasses, cereal binders, linseed oil and resins like phenol formal



Figure 15: Mixing of binder in Moller machine

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2.9.1 Sodium Silicate

Sodium silicate is the common name for compounds with the formula $(\text{Na}_2\text{SiO}_2)_n\text{O}$. A well-known member of this series is sodium metasilicate, Na_2SiO_3 . Also known as waterglass or liquid glass, these materials are available in aqueous solution and in solid form. The pure compositions are colourless or white, but commercial samples are often greenish or blue owing to the presence of iron-containing impurities.

Sodium silicate [Na_2SiO_3 or $(\text{Na}_2\text{O})(\text{SiO}_2)$] is a high strength binder used with silica moulding sand. The advantage to this binder is that it can be used at room temperature and is fast. The disadvantage is that its high strength leads to shakeout difficulties and possibly hot tears in the casting

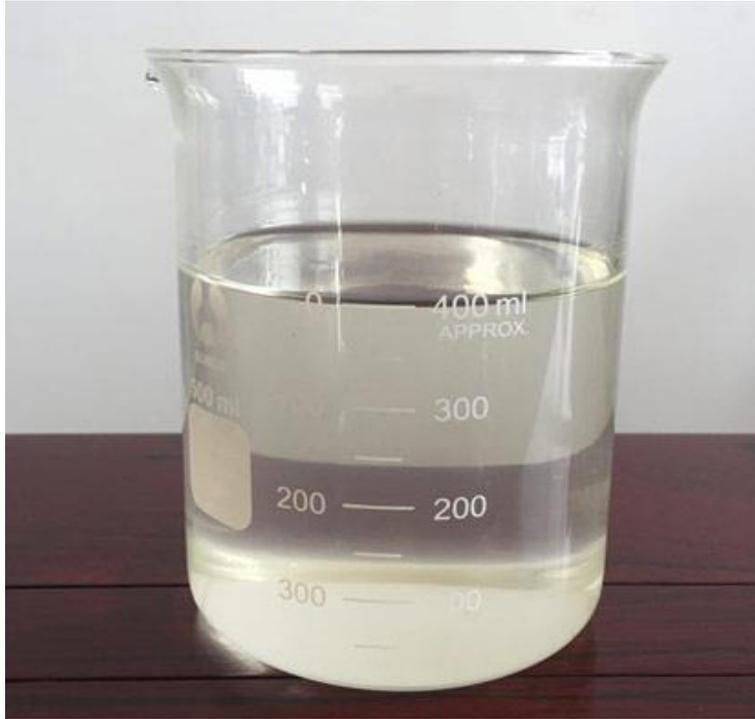


Figure 16: Sample of sodium silicate

Physical Test

- i) When test sample of CO₂ sand mice prepared by using 5% of sodium silicate mixed with high silica sand and gassed with CO₂ gas and tested then it should give a minimum shear strength of 3kg/sq.cm in each case and shall not exhibit friability.
- ii) Material shall show visibility clear thick liquid without suspended matter & shall bear translucent water white or slightly grey.

2.9.2 Phenolic Resin & Catalyst

Phenol formaldehyde resins (PF) or **phenolic resins** are synthetic polymers obtained by the reaction of phenol or substituted phenol with formaldehyde.

Resin binders are natural or synthetic high melting point gums. The two common types used are urea formaldehyde (UF) and phenol formaldehyde (PF) resins. PF resins have a higher heat resistance than UF resins and cost less. There are also cold-set resins, which use a catalyst instead of a heat to cure the binder. Resin binders are quite popular because different properties can be achieved by mixing with various additives. Other advantages include good collapsibility, low gassing, and they leave a good surface finish on the casting. MDI (methylene diphenyl diisocyanate) is also a commonly used binder resin in the foundry core process.



Figure 17: Catalyst in container



Figure 18: Resin in container

Resin binders are natural or synthetic high melting point gums. The two common types used are urea formaldehyde (UF) and phenol formaldehyde (PF) resins. PF resins have a higher heat resistance than UF resins and cost less. There are also cold-set resins, which use a catalyst instead of a heat to cure the binder. Resin binders are quite popular because different properties can be achieved by mixing with various additives. Other advantages include good collapsibility, low gassing, and they leave a good surface finish on the casting. MDI (methylene diphenyl diisocyanate) is also a commonly used binder resin in the foundry core process.

Chapter 2

LITERATURE REVIEW

St. M. Dobosz *, K. Major-Gabryś, A. Grabarczyk[4] The authors concentrated on the possibility of preparing new binders consisting of typical synthetic resins - commonly used in foundry practice - and biodegradable materials. According to own research it is presumed that using biodegradable materials as a part of new binders' compositions may cause not only lower toxicity and better ability to reclaim, but may also accelerate the biodegradation rate of used binders. What's more, using some kinds of biodegradable materials may improve flexibility of moulding sands with polymeric binder.

Xia Zhoua,*, Jinzong Yang b, Guohui Quc[5] In this paper, modified starch binder was synthesized using a new dry method with the aid of the compound catalysis of methanol and sodium hydroxide. The effects of various factors on the properties of the binder and its bonded core sand were discussed

Rasik A Upadhye and Dr. Ishwar P Keswani [7] has studied the sand casting process parameters of the castings manufactured in iron foundry by maximizing the signal to noise ratios and minimizing the noise factors using Taguchi method. The process parameters considered are moisture, sand particle size, green compression strength, mold hardness, permeability, pouring temperature, pouring time and pressure test. The results indicated that the selected process parameters significantly affect the casting defects in the foundry.

Jhon O. OJI et al. [9] has investigated the effect of mold temperature and pouring temperatures on ultimate tensile strength of aluminum alloy sand castings. The result shows that mold temperature is the significant factors which influence the casting quality. L. Ceschini et. al. [10] has investigated the relationships between ultimate tensile strength and micro structural parameters for the sand cast A357 aluminum alloy. Starting from the micro structural parameters and taking in to account the material hardness, a relationship able to predict the ultimate tensile strength of the alloy was found.

2.9.3 DEXTRINE POWDER



Figure 19: Sample of dextrin powder.

Yellow dextrin is manufactured by partially hydrolysing Starch, using the dry roasting method in the presence of a catalyst. Yellow dextrin has low viscosity and is very sticky and hygroscopic in nature. Yellow Dextrin Powder helps in increasing dry strength at the same time being completely soluble in water. Yellow Dextrin Powder is widely used as water soluble adhesives, testifiers and as binding agents in various industries. The adhesive industry uses large amounts of yellow Dextrin in the preparation of liquid and dry adhesives. Yellow Dextrin Powder is in the form of fine dry powder ranging from light to dark yellow and dark. Yellow dextrin is manufactured by partially hydrolyzing Starch, using the dry roasting method in the presence of a catalyst. Yellow dextrin has low viscosity and is very sticky and hygroscopic in nature.

2.9.4 Bentonite



Figure 20: Sample of bentonite

Bentonite has been widely used as a foundry-sand bond in iron and steel foundries. Sodium bentonite is most commonly used for large castings that use dry moulds, while calcium bentonite is more commonly used for smaller castings that use "green" or wet moulds.[2] Bentonite is also used as a binding agent in the manufacture of iron ore (taconite) pellets as used in the steelmaking industry. Bentonite, in small percentages, is used as an ingredient in commercially designed clay bodies and ceramic glazes.

The ionic surface of bentonite has a useful property in making a sticky coating on sand grains. When a small proportion of finely ground bentonite clay is added to hard sand and wetted, the clay binds the sand particles into a mouldable aggregate known as green sand used for making moulds in sand casting. Some river deltas naturally deposit just such a blend of clay silt

and sand, creating a natural source of excellent moulding sand that was critical to ancient metalworking technology. Modern chemical processes to modify the ionic surface of bentonite greatly intensify this stickiness, resulting in remarkably dough-like yet strong casting sand mixes that stand up to molten metal temperatures.

The same effluvial deposition of bentonite clay onto beaches accounts for the variety of plasticity of sand from place to place for building sand castles.^[18] Beach sand consisting of only silica and shell grains does not mould well compared to grains coated with bentonite clay. This is why some beaches are much better for building sand castles than others.

The self-stickiness of bentonite allows high-pressure ramming or pressing of the clay in moulds to produce hard, refractory shapes, such as model rocket nozzles.

Chapter 3

EXPERIMENTAL PROCEDURES

3.0 Experimental Procedures

Various tests are carried out for the characteristics of sand and binder. Besides this were also conducted on sand mix to optimise the properties. The present chapter deals with all experimental details.

3.1 Testing of Sand

AFS Fineness Number

The test was conducted on a standard sieve sifter (fig 22). The Sieve stack is connected to an electric vibrating arrangement having adjustment frequency. A stop watch control system is also provided in the instrument to make vibrate for a predetermined time.

50 g of representatives and sample was taken and placed on the coarsest sieve of sieve sifter. Sieve were arranged in such a way that finest sieve was at the bottom and the coarsest at the top. The lid of the top sieve was tightly closed. The set of sieve was placed on the sifter unit and clamped tightly with stay bars and fixing screws. The sifting time was kept 12 minutes. The ingredients retained on each sieve were weighed and AFS fineness number was calculated using standard formula.



Figure 21: Standard Sieve Shaker (sifter)

Compressive Strength Measurement

The compressive strength was determined for the entire test specimen with varying different parameters such as binder content, flow rate of CO₂ gas, different gassing times and setting times. The compressive strength of the prepared test specimen was measured by the universal sand strength testing machine. This is expressed in kg/cm².

Grain shape and texture

A small amount of representative sand sample was sprinkled over a black smooth surface and examined under microscope at magnification of 15X and 30X.

Base permeability of loose sand

The base permeability was conducted on a standard permeability meter with special tube. The test requires the use of two hundred mesh screen at each end of the specimen tube. The permeability screen placed with the sides of the cup upward, the

bottom of standard specimen tube representative sand sample was placed in the tube produce an AFS standard 2"x2" cylindrical test specimen.

Gassing Time

The properties of CO₂ silicate sand are tested for 8 different gassing times i.e. 0.5 min, 1 min, 1.5 min, 2 min, 3 min, 4 min, 5 min, and 6min.

CO₂ Gas flow rate

The flow rate of CO₂ gas was maintained at difference of 2.5 Lit. /min for different gassing times.

Setting time or Holding time

After the test specimen gassed with specified flow rate and gassing time, it has kept in open atmosphere for 0.5 hour, 1 hour and ½ hour and then the compressive strength has been determined. The compressive strength of a gassed passed experiment is also determined

Chapter 4

RESULTS AND DISCUSSION

4.0 Results and Discussion

4.2 Result for CO₂ process:

The compressive strength of prepared sand mix with different composition was studied. The effect of various parameters i.e. binder percent, flow rate of CO₂ gas, gassing time and holding time on compressive strength were discussed in subsequent details.

4.2.1 Effect of binder percent

The effect of binder percent on compressive strength (as gassed) for a fixed flow rate of 2.5 Litre/minute at different gassing time.

- With increase in gassing time, the compressive strength increases and reaches a maximum value. However, the strength decreases with further gassing.
- For given sand, increase in binder content increases the compressive strength.
- The compressive strength maximum occurs at a narrow gassing time between 3 and 4 minutes for varying binder contents.

The above factors predict the occurrence of maximum attainable strength at somewhat later stages of gassing. The initial increase in strength is due to the rapid silica hydro gel formation which contributes to the hardening phenomenon.

In the early stage of hardening with CO₂ gas, strength is developing a faster rate. The mixtures used contain low concentration of sodium silicate. As the quantity of sodium silicate increases the strength develop progressively more slowly, although an extended gassing very high strength is obtained. The reason for this is at low sodium silicate concentration, thin film of binder exists around with mixture containing high percentage sodium silicate on extended periods of gassing. It is clear that 5.5 % of sodium silicate yields maximum compressive strength for given sand at relatively increased gassing time (4 min). The sand mix with 5.5% binder for three minutes gassing at a flow rate of 10 litre/min is giving highest compressive strength. It is also observed that with increase in binder percentage the compressive strength also increases for fixed flow rate.

4.2.2 Effect of flow rate

The effect of flow rate on as-gassed compressive strength for 4.5% binder content and different gassing time as shown in the figure it is observed that with increase in binder strength is also increase.

The strength decreases with increase in flow rate. This is caused due to the following reason:-

1. At low rates an exothermic reaction occurs between sodium silicate and CO₂ gas with the formation of silica hydro gel, sodium carbonate and sodium bicarbonate.

2. As the gassing time is extended, the bond strength increases gradually, up to a maximum value.
3. At higher flow rate the exothermic reaction is replaced by endothermic reaction which results the removal of water from the aqueous sodium silicate binder, causes the bond to shrink. So the strength decreases. With higher binder percentage and high flow rate the as gassed compressive strength is high as compared to holding strength.

4.2.3 Effect of holding time

The effect of holding time on compressive strength for 5.5% sodium silicate and flow of 2.5% Litre/min at different gassing times. It is observed that as the holding time increases there are increase in compressive strength for less gassing times.

When the specimen kept in open air after gassing for long periods, the binder which is not reacted with CO₂ gas during gassing will react with CO₂ gas in atmosphere result in rise in strength. But as gassing time increases the entire silicate binder reacts completely with CO₂ gas.

METHODOLOGY

CORRELATION: in statistics, correlation or dependence is any statistical relationship, whether causal or not, between two random variables. Although in the broadest sense, "correlation" may indicate any type of association, in statistics it usually refers to the degree to which a pair of variables are linearly related

Pearson Correlation Coefficient Formula

The most common formula is the Pearson Correlation coefficient used for linear dependency between the data sets. The value of the coefficient lies between -1 to +1. When the coefficient comes down to zero, then the data is considered as not related. While, if we get the value of +1, then the data are positively correlated, and -1 has a negative correlation.

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}}$$

Where n = Quantity of Information

Σx = Total of the First Variable Value

Σy = Total of the Second Variable Value

Σxy = Sum of the Product of first & Second Value

Σx^2 = Sum of the Squares of the First Value

Σy^2 = Sum of the Squares of the Second Value

Linear Correlation Coefficient Formula

The formula for the linear correlation coefficient is given by;

$$r_{xy} = \frac{n \sum_{i=1}^n x_i y_i - \sum_{i=1}^n x_i \sum_{i=1}^n y_i}{\sqrt{n \sum_{i=1}^n x_i^2 - (\sum_{i=1}^n x_i)^2} \sqrt{n \sum_{i=1}^n y_i^2 - (\sum_{i=1}^n y_i)^2}}$$

Sample Correlation Coefficient Formula

The formula is given by:

$$r_{xy} = \mathbf{S_{xy}/S_x S_y}$$

Where S_x and S_y are the sample standard deviations, and S_{xy} is the sample covariance.

Population Correlation Coefficient Formula

The population correlation coefficient uses σ_x and σ_y as the population standard deviations and σ_{xy} as the population covariance.

$$r_{xy} = \sigma_{xy} / \sigma_x \sigma_y$$

Table 1: Compressive strength obtained for 3.5% binder, 2.5 litre/min flow rate at different gassing and holding time

GASSING TIME (min)	COMPRESSIVE STRENGTH (kg/cm ²)			
	As gassed	After holding ½ hours	After holding 1 hours	After holding 1½ hours
0.5	2.3	4.3	3.0	3.7
1	3.3	4.7	3.3	4.1
1.5	3.5	4.4	3.4	4.8
2	4.2	4.4	3.7	4.4
3	4.8	4.7	3.85	4.3
4	4.72	3.4	3.2	4.6
5	4.2	3.3	2.91	4.15
6	4.3	3.0	2.9	4.2

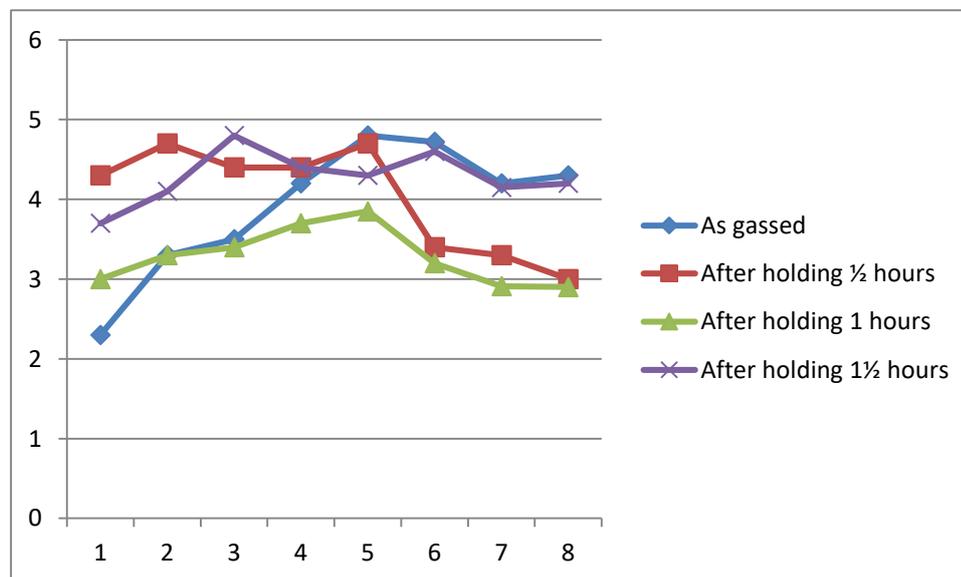
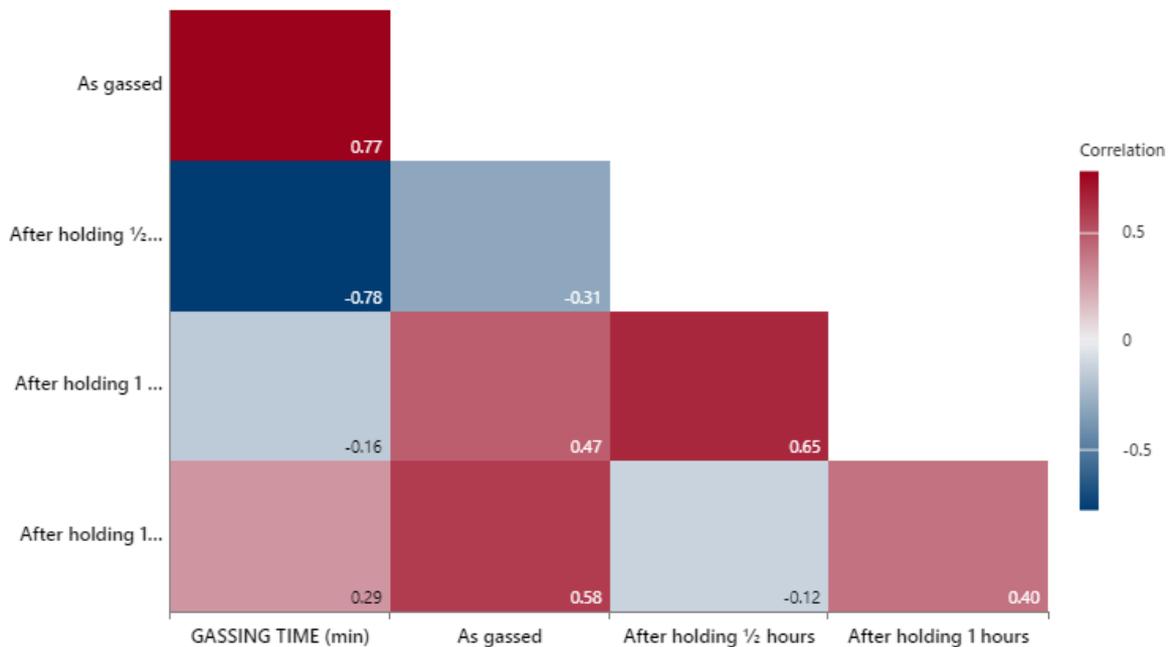


Figure 22: The effect of binder on compressive strength (as gassed) for a fixed flow rate (2.5 litre/min.) at different gassing time.

CORRELATION ANALYSIS OF THE OBSERVED DATA:

Table 2: Correlation table of synthetic sand prepared with 3.5% binder, 2.5 litre/min flow rate at different gassing and holding time

PREPARED SAND WITH 3.5% BINDER, 2.5 litre/min flow rate at different gassing time	
CORRELATION ANALYSIS OF GASSING TIME TO HARDNESS OF MOULD IMPARTED	
HARDNESS OF MOULD((kg/cm2))	GASSING TIME (min)
As gassed	0.702353685
After holding ½ hours	-0.863394272
After holding 1 hours	-0.386129961
After holding 1½ hours	0.158280907



INTERPRETATION OF TABLE 15:

From the above analysis, using 3.5% BINDER, 2.5 litre/min flow rate at different gassing time. It is seen that hardness of mould as gassed is highly related to gassing time. The hardness of gassing time after holding ½ hours is negatively correlated to gassing time which means that hardness of mould decreases with increase in gassing time.

Regression Analysis: As gassed versus GASSING TIME (min)

Regression Equation

$$\text{As gassed} = 2.847 + 0.417 \text{ GASSING TIME (min)}$$

Coefficients

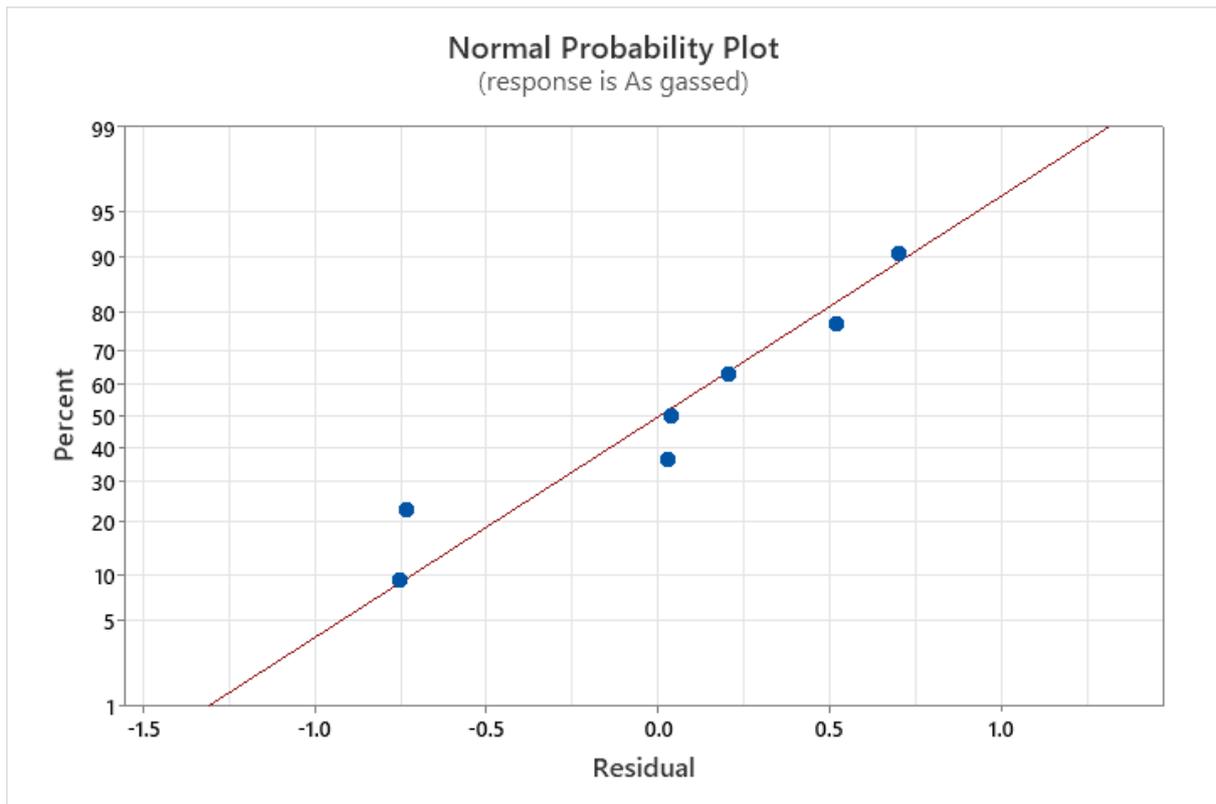
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.847	0.440	6.47	0.001	
GASSING TIME (min)	0.417	0.154	2.71	0.042	1.00

Model Summary

S	R-sq	sq(adj)	sq(pred)
0.618522	59.57%	51.48%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	2.818	2.8184	7.37	0.042
GASSING TIME (min)	1	2.818	2.8184	7.37	0.042
Error	5	1.913	0.3826		
Total	6	4.731			



Regression Analysis: After holding ½ hours versus GASSING TIME (min)

Regression Equation

After holding ½ hours = 4.840 - 0.2753 GASSING TIME (min)

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	4.840	0.286	16.95	0.000	

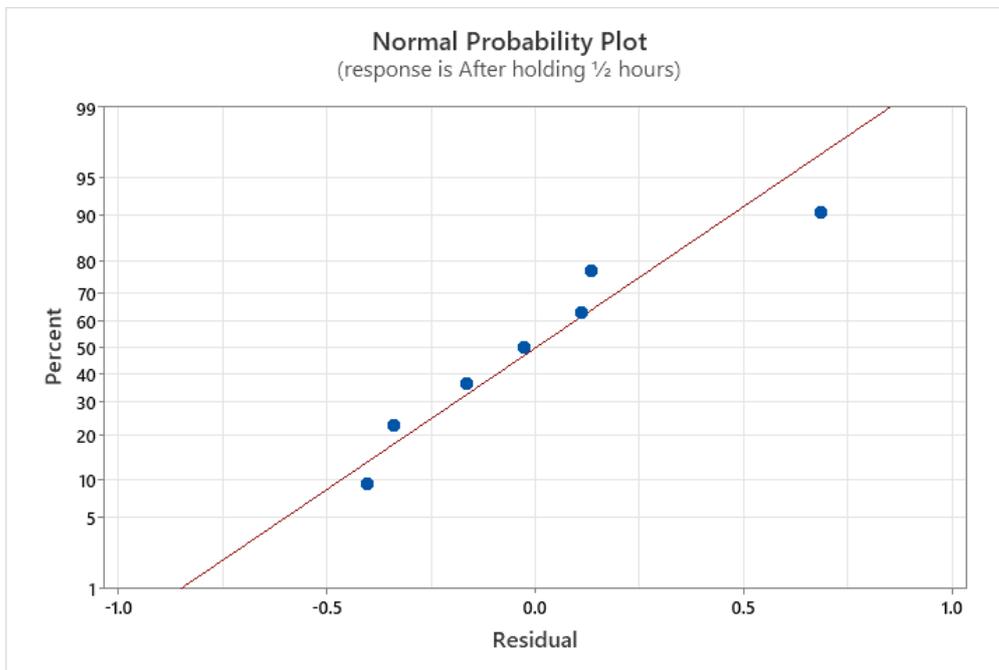
GASSING TIME - 0.0997 -2.76 0.040 1.00
(min) 0.2753

Model Summary

S	R-sq	sq(adj)	sq(pred)
0.401281	60.42%	52.51%	26.35%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	1.2292	1.2292	7.63	0.040
GASSING TIME (min)	1	1.2292	1.2292	7.63	0.040
Error	5	0.8051	0.1610		
Total	6	2.0343			



Regression Analysis: After holding 1 hours versus GASSING TIME (min)

Regression Equation

After holding 1 = 3.417 - 0.0328 GASSING TIME (min)
hours

Coefficients

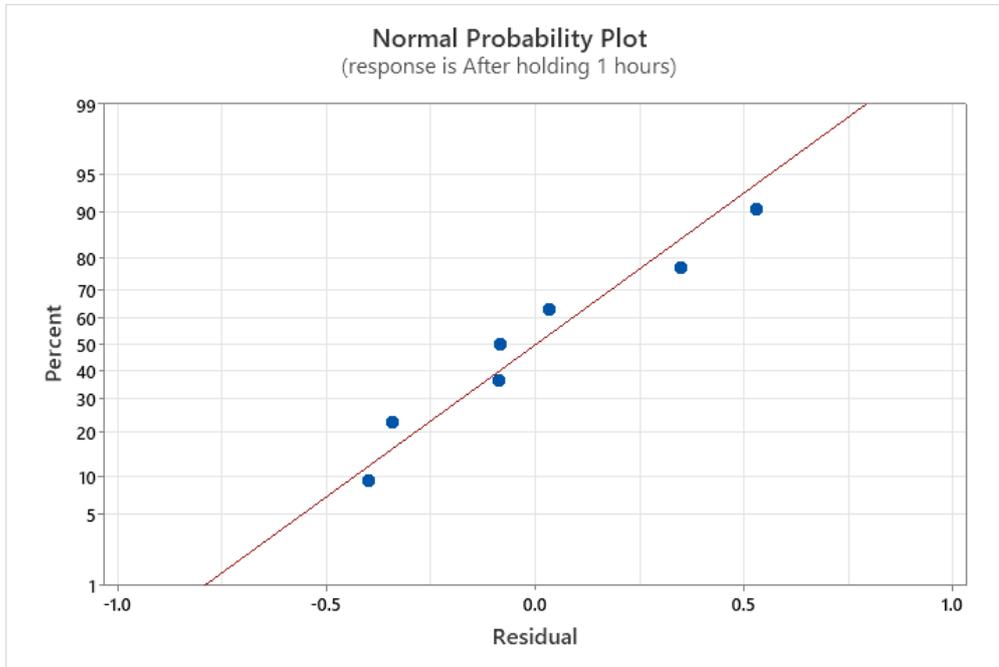
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	3.417	0.266	12.85	0.000	
GASSING TIME (min)	- 0.0928	0.0328	-0.35	0.738	1.00

Model Summary

S	R-sq	sq(adj)	sq(pred)
0.373504	2.44%	0.00%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	0.01742	0.01742	0.12	0.738
GASSING TIME (min)	1	0.01742	0.01742	0.12	0.738
Error	5	0.69753	0.13951		
Total	6	0.71494			



Regression Analysis: After holding 1½ hours versus GASSING TIME (min)

Regression Equation

$$\text{After holding 1½ hours} = 4.140 + 0.0630 \text{ GASSING TIME (min)}$$

Coefficients

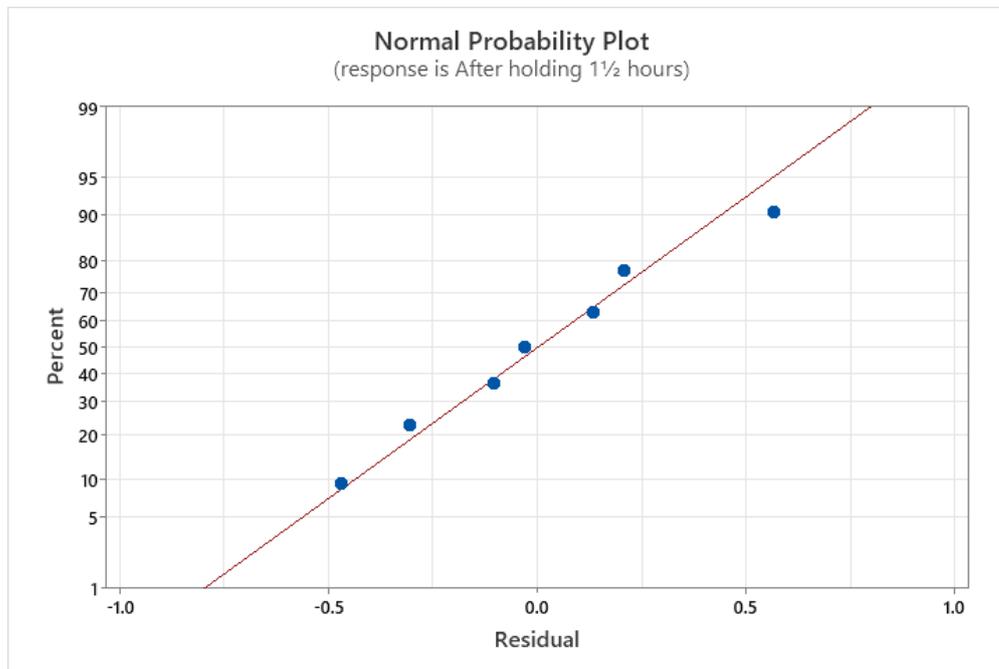
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	4.140	0.268	15.46	0.000	
GASSING TIME (min)	0.0630	0.0934	0.67	0.530	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.376244	8.33%	0.00%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	0.06435	0.06435	0.45	0.530
GASSING TIME (min)	1	0.06435	0.06435	0.45	0.530
Error	5	0.70780	0.14156		
Total	6	0.77214			



Binder 4.5%, 2.5 litre/min flow rate at different gassing and holding time

GASSING TIME (min)	COMPRESSIVE STRENGTH (kg/cm ²)			
	As gassed	After holding ½ hours	After holding 1 hours	After holding 1½ hours
0.5	1.6	3.65	3.55	2.5
1	4.25	4.35	4.3	3.2
1.5	4.22	5.2	4.9	3.45
2	4.82	5.2	5.4	3.75
3	5.4	5.3	4.75	4.35
4	5.75	4.8	4.49	3.85
5	5.65	4.72	4.30	3.85
6	4.42	4.35	4.15	3.7

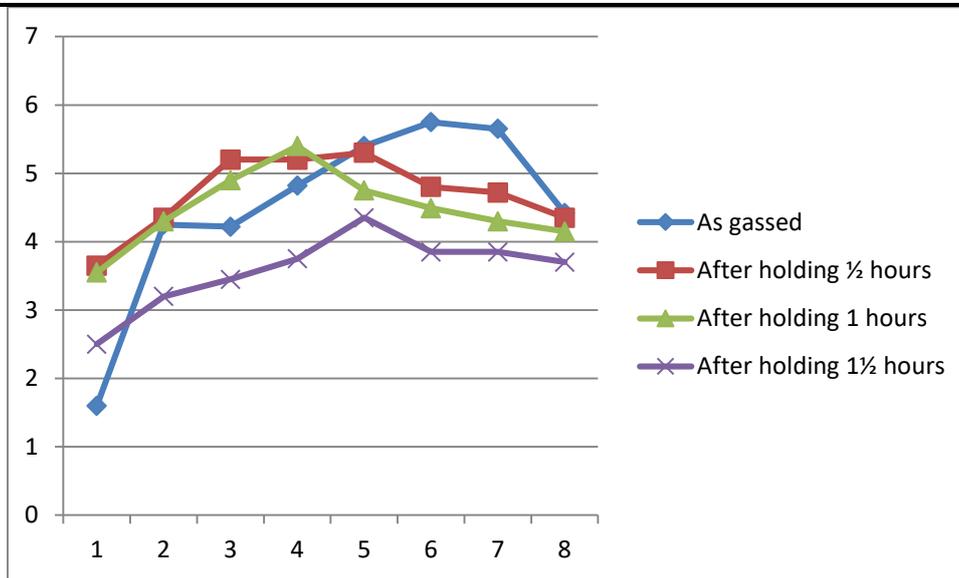
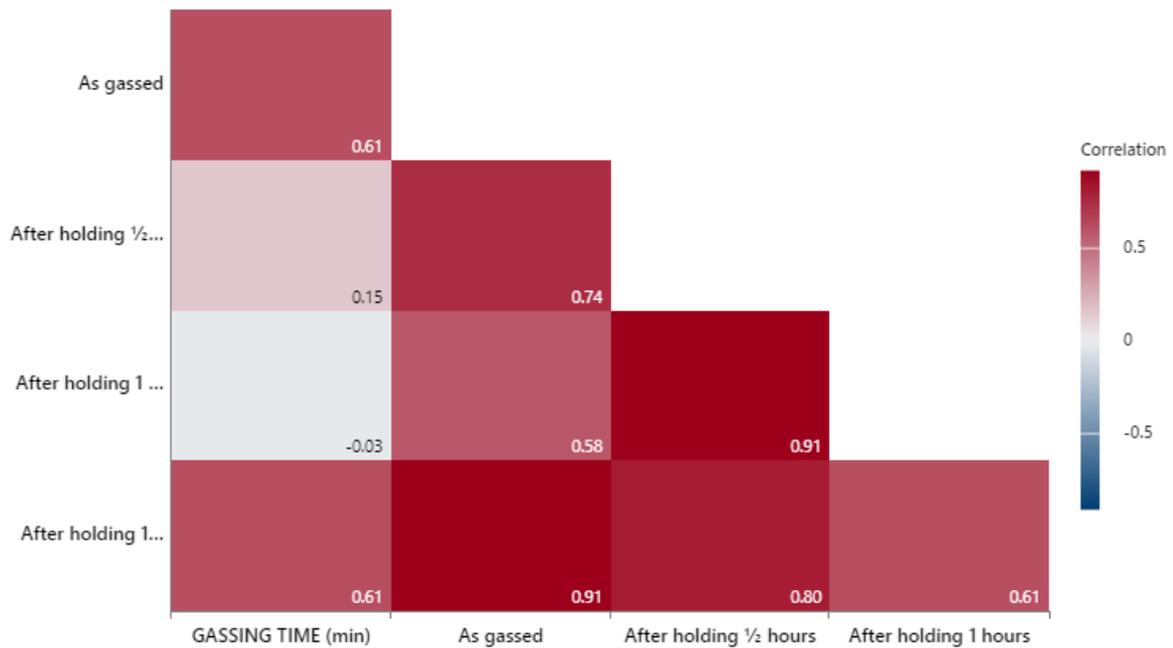


Figure 23; Compressive strength obtained for 4.5% binder, 2.5 litre/min flow rate at different gassing and holding time.

Table 3: Correlation table of synthetic sand prepared with 4.5% binder, 2.5 litre/min flow rate at different gassing and holding time

PREPARED SAND WITH 4.5% BINDER, 2.5 litre/min flow rate at different gassing time	
CORRELATION ANALYSIS OF GASSING TIME TO HARDNESS OF MOULD IMPARTED	
HARDNESS OF MOULD((kg/cm2))	GASSING TIME (min)
As gassed	0.61
After holding 1/2 hours	0.15
After holding 1 hours	-0.03
After holding 1 1/2 hours	0.61



INTERPRETATION OF TABLE 17:

From the above analysis, using 4.5% BINDER, 2.5 litre/min flow rate at different gassing time. It is seen that hardness of mould as gassed and after a holding time of 1½ hours, both show a good positive correlation to the gassing time.

Regression Analysis: As gassed versus GASSING TIME (min)

Regression Equation

$$\text{As gassed} = 3.340 + 0.408 \text{ GASSING TIME (min)}$$

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	3.340	0.745	4.49	0.004	
GASSING TIME (min)	0.408	0.218	1.87	0.110	1.00

Model Summary

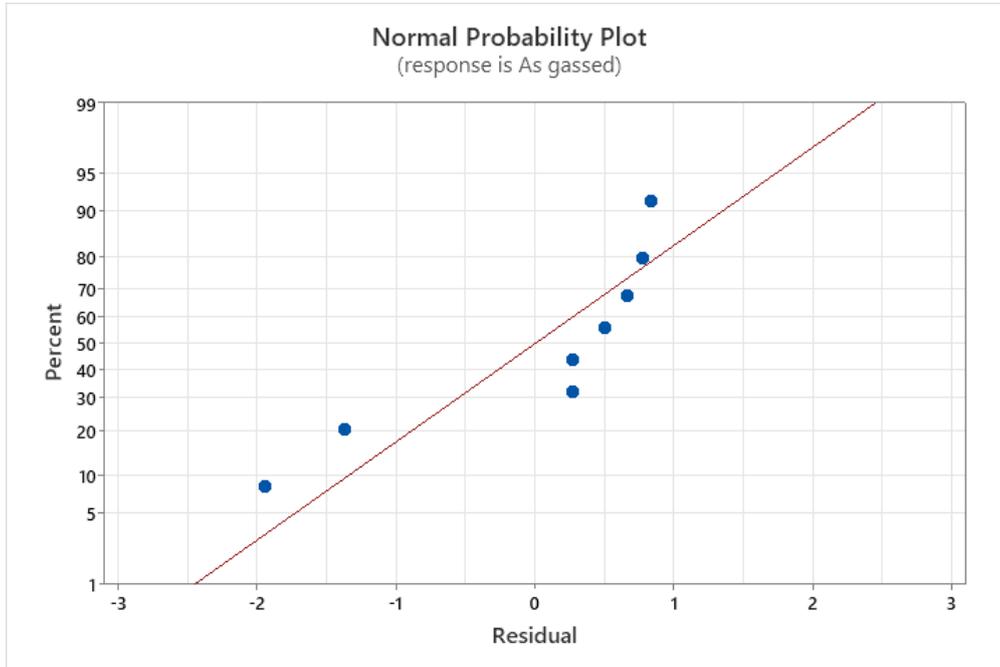
S	R-sq	R-sq(adj)	R-sq(pred)
1.13962	36.92%	26.41%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	4.561	4.561	3.51	0.110
GASSING TIME (min)	1	4.561	4.561	3.51	0.110
Error	6	7.792	1.299		
Total	7	12.353			

Fits and Diagnostics for Unusual Observations

Obs	As gassed	Fit	Resid	Std Resid
1	1.600	3.544	-	-2.09 R
				1.944



Regression Analysis: After holding ½ hours versus GASSING TIME (min)

Regression Equation

$$\text{After holding } \frac{1}{2} \text{ hours} = 4.574 + 0.042 \text{ GASSING TIME (min)}$$

Coefficients

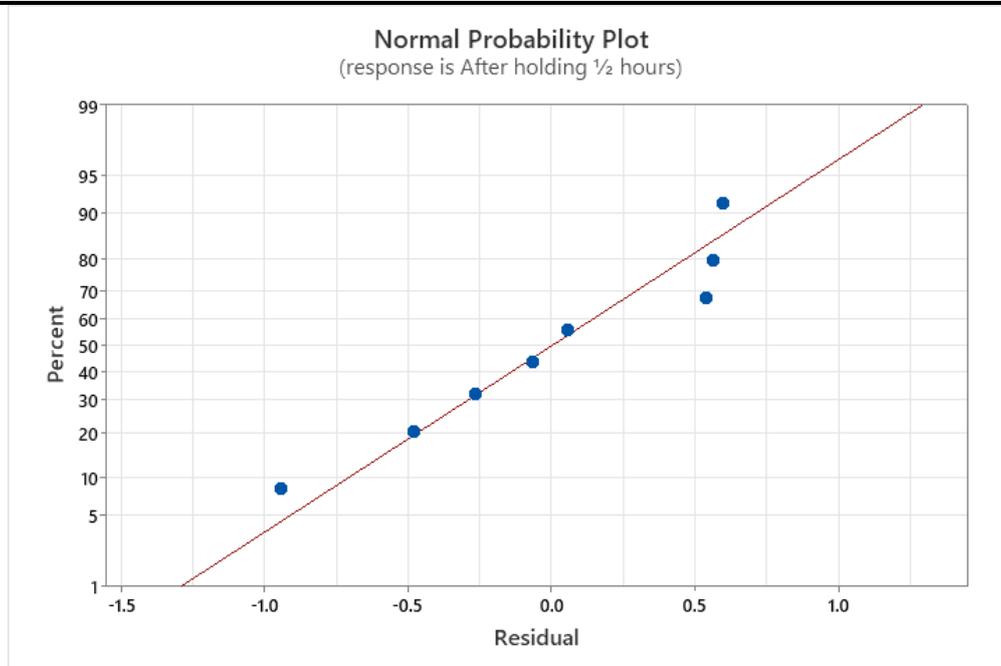
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	4.574	0.393	11.64	0.000	
GASSING TIME (min)	0.042	0.115	0.37	0.725	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.601183	2.22%	0.00%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	0.04926	0.04926	0.14	0.725
GASSING TIME (min)	1	0.04926	0.04926	0.14	0.725
Error	6	2.16853	0.36142		
Total	7	2.21779			



Regression Analysis: After holding 1 hours versus GASSING TIME (min)

Regression Equation

$$\text{After holding 1 hours} = 4.502 - 0.007 \text{ GASSING TIME (min)}$$

Coefficients

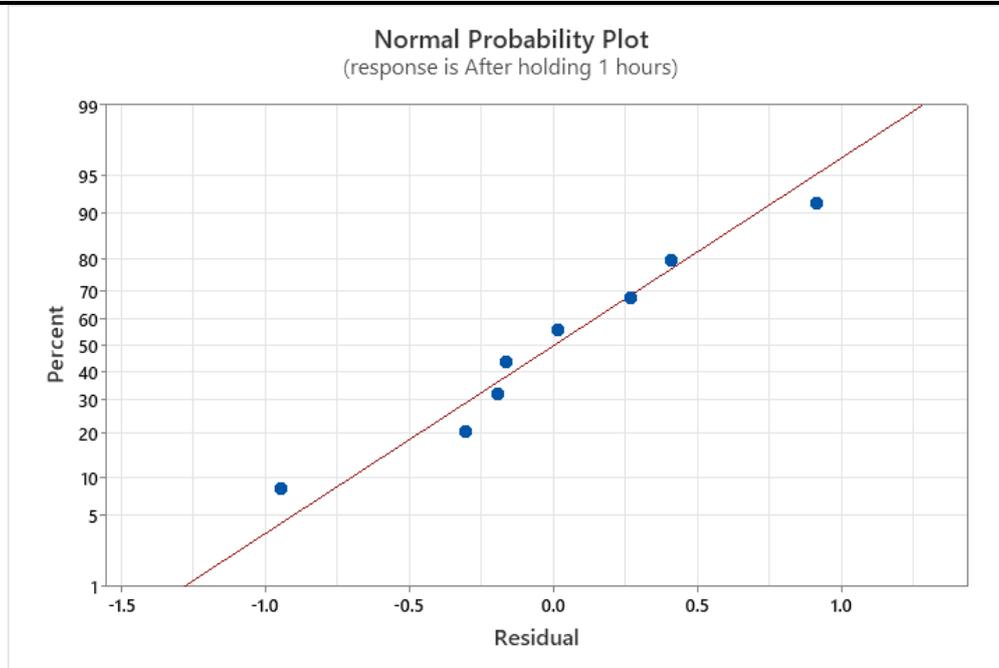
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	4.502	0.390	11.56	0.000	
GASSING TIME (min)	-0.007	0.114	-0.07	0.950	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.596219	0.07%	0.00%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	0.00154	0.001535	0.00	0.950
GASSING TIME (min)	1	0.00154	0.001535	0.00	0.950
Error	6	2.13286	0.355477		
Total	7	2.13440			



Regression Analysis: After holding 1½ hours versus GASSING TIME (min)

Regression Equation

$$\text{After holding 1½ hours} = 3.092 + 0.1701 \text{ GASSING TIME (min)}$$

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	3.092	0.306	10.10	0.000	
GASSING TIME (min)	0.1701	0.0896	1.90	0.106	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.468633	37.54%	27.13%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	0.7920	0.7920	3.61	0.106
GASSING TIME (min)	1	0.7920	0.7920	3.61	0.106
Error	6	1.3177	0.2196		
Total	7	2.1097			

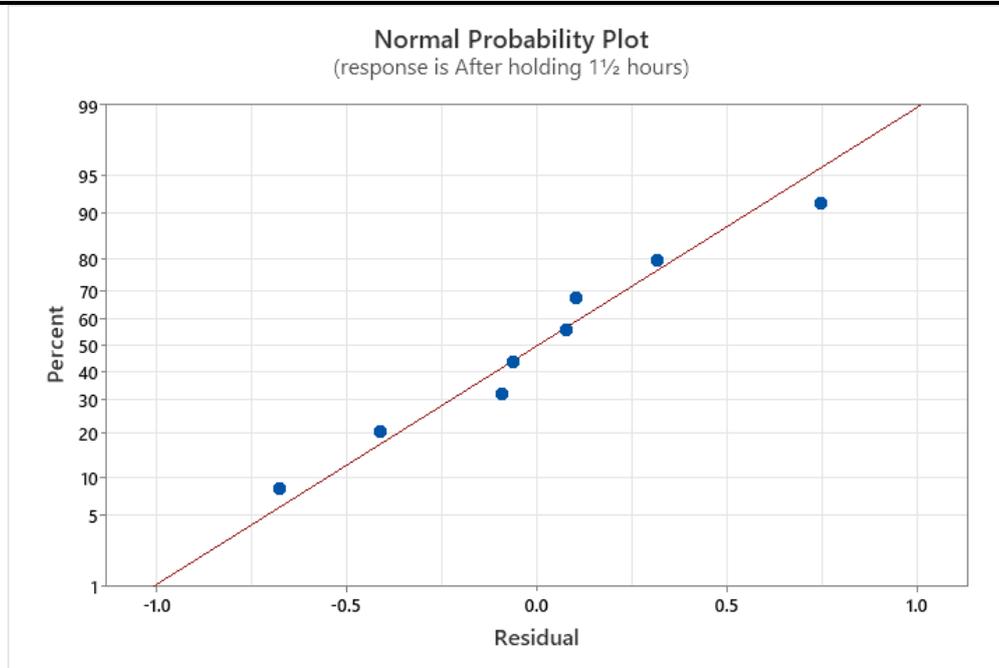


Table 4: Compressive strength obtained for 5.5% binder, 2.5 litre/min flow rate at different gassing and holding time

GASSING TIME (min)	COMPRESSIVE STRENGTH (kg/cm ²)			
	As gassed	After holding 1/2 hours	After holding 1 hours	After holding 1 1/2 hours
0.5	2.45	2.35	3.2	4.35
1	4.3	4.5	5.25	4.65
1.5	5.2	6.15	5.6	5.3
2	5.9	6.3	6.4	6.0
3	6.15	6.55	7.1	6.75
4	7.6	7.9	7.55	6.35
5	6.7	6.1	6.35	5.85
6	6.4	6.1	6.5	5.16

Table 5: Correlation table of synthetic sand prepared with 4.5% binder, 2.5 litre/min flow rate at different gassing and holding time

PREPARED SAND WITH 5.5% BINDER, 2.5 litre/min flow rate at different gassing time	
CORRELATION ANALYSIS OF GASSING TIME TO HARDNESS OF MOULD IMPARTED	
HARDNESS OF MOULD((kg/cm ²))	GASSING TIME (min)
As gassed	0.781867443
After holding 1/2 hours	0.601174204
After holding 1 hours	0.667189948

After holding 1½ hours	0.43070922
------------------------	------------

INTERPRETATION OF TABLE 19:

From the above analysis, using 5.5% BINDER, 2.5 litre/min flow rate at different gassing time. It is seen that hardness of mould as gassed, after a holding time of 1½ hours, After holding 1 hours all show a good positive correlation to the gassing time.

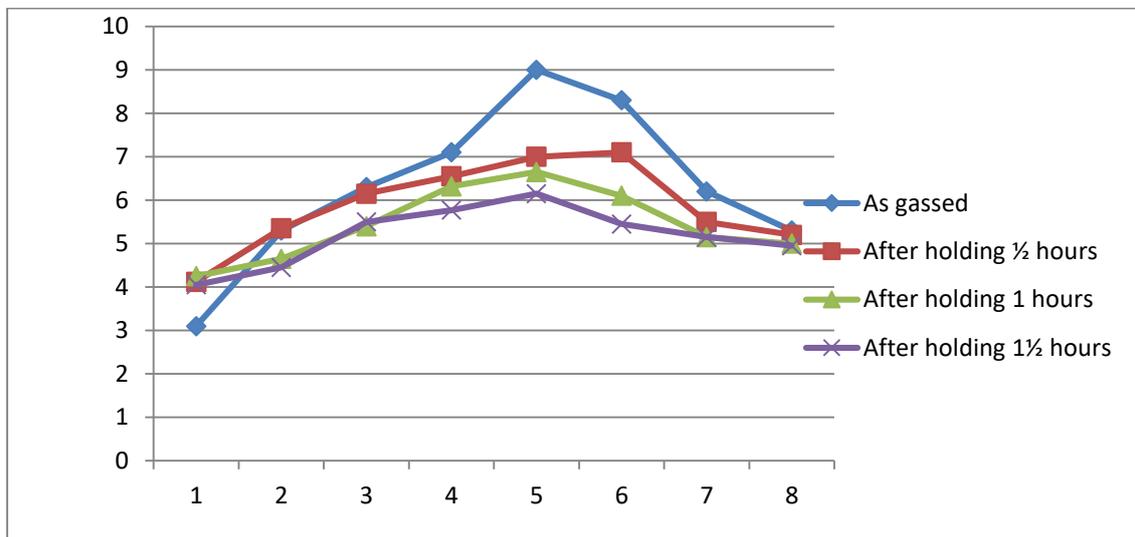


Figure 24; Compressive strength obtained for 5.5% binder, 2.5 litre/min flow rate at different gassing and holding time.

Regression Analysis: As gassed versus GASSING TIME (min)

Regression Equation

$$\text{As gassed} = 3.764 + 0.634 \text{ GASSING TIME (min)}$$

Coefficients

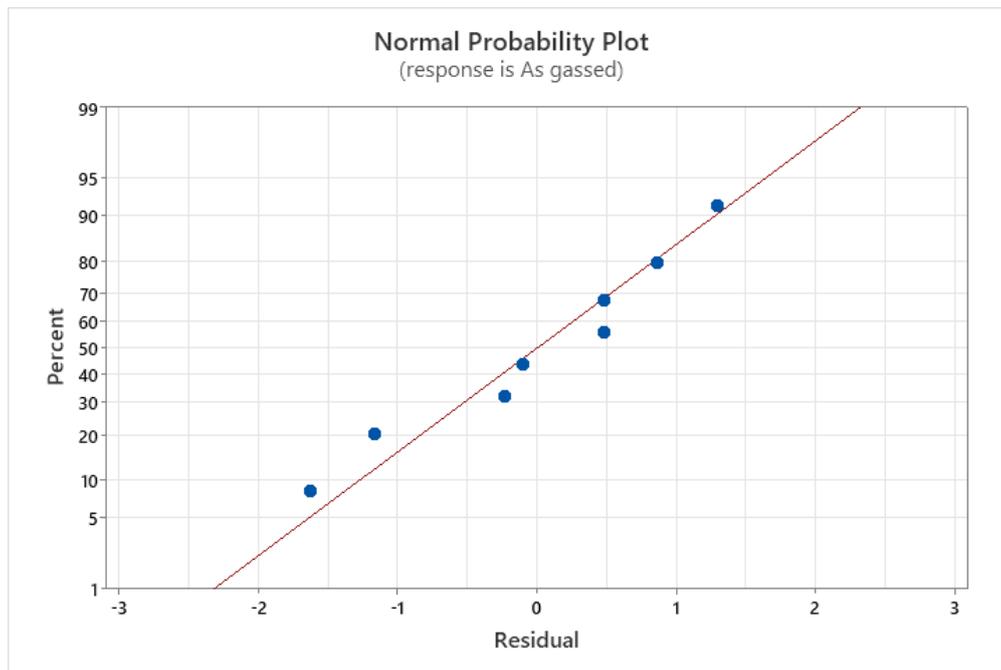
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	3.764	0.706	5.33	0.002	
GASSING TIME (min)	0.634	0.206	3.07	0.022	1.00

Model Summary

S	R-sq	sq(adj)	sq(pred)

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	11.012	11.012	9.44	0.022
GASSING TIME (min)	1	11.012	11.012	9.44	0.022
Error	6	7.002	1.167		
Total	7	18.014			



Regression Analysis: After holding ½ hours versus GASSING TIME (min)

Regression Equation

$$\text{After holding } \frac{1}{2} \text{ hours} = 4.300 + 0.502 \text{ GASSING TIME (min)}$$

Coefficients

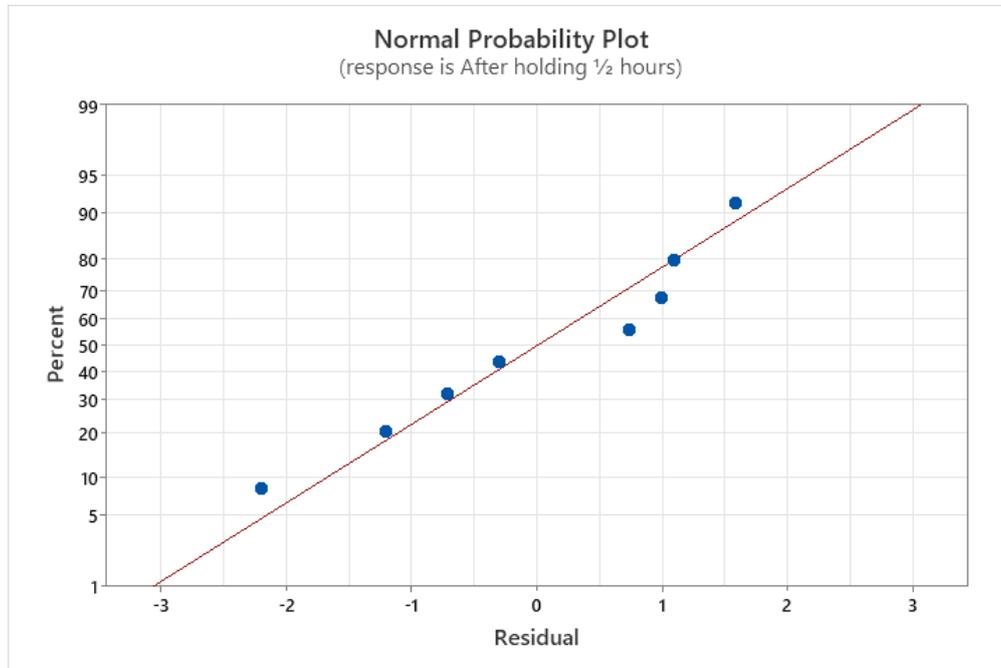
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	4.300	0.931	4.62	0.004	
GASSING TIME (min)	0.502	0.272	1.84	0.115	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.42549	36.14%	25.50%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	6.900	6.900	3.40	0.115
GASSING TIME (min)	1	6.900	6.900	3.40	0.115
Error	6	12.192	2.032		
Total	7	19.092			



Regression Analysis: After holding 1 hours versus GASSING TIME (min)

Regression Equation

$$\text{After holding 1 hours} = 4.687 + 0.455 \text{ GASSING TIME (min)}$$

Coefficients

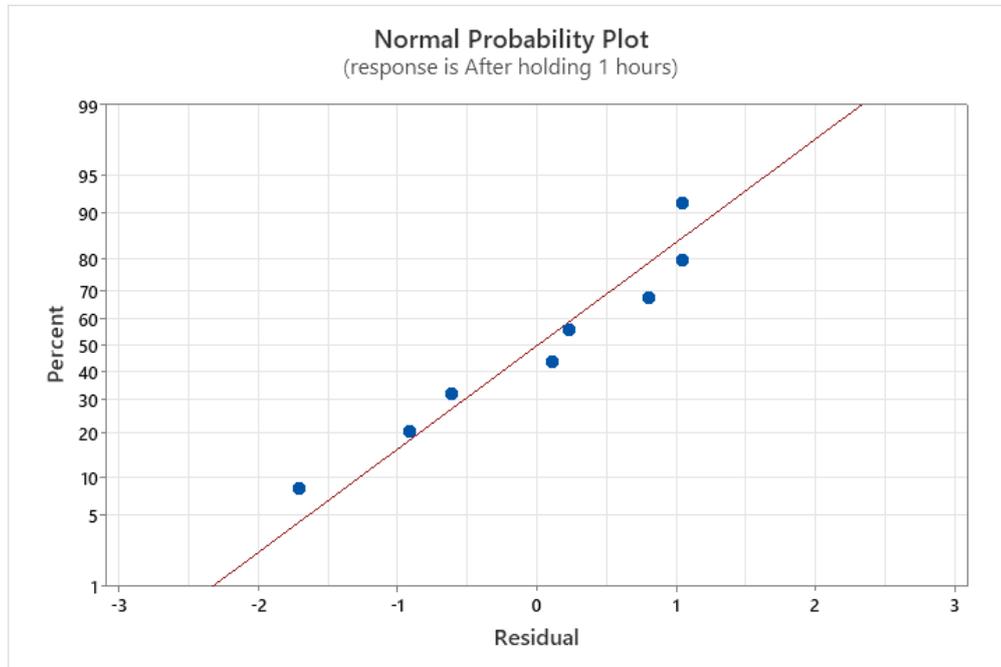
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	4.687	0.708	6.62	0.001	
GASSING TIME (min)	0.455	0.207	2.19	0.071	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.08403	44.51%	35.27%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	5.657	5.657	4.81	0.071
GASSING TIME (min)	1	5.657	5.657	4.81	0.071
Error	6	7.051	1.175		
Total	7	12.707			



Regression Analysis: After holding 1½ hours versus GASSING TIME (min)

Regression Equation

$$\text{After holding 1½ hours} = 5.031 + 0.181 \text{ GASSING TIME (min)}$$

Coefficients

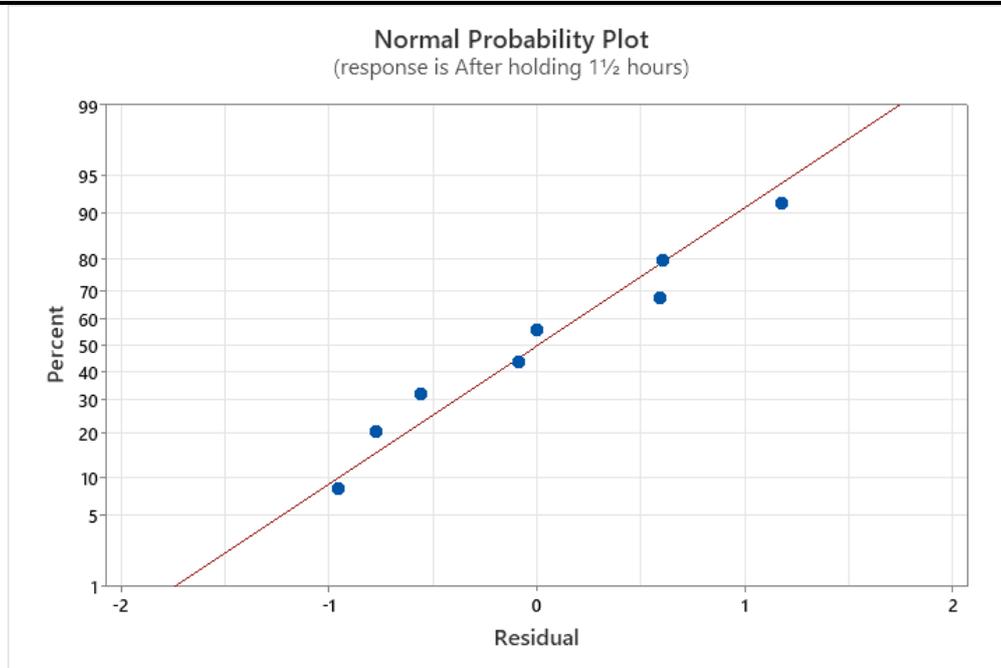
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	5.031	0.529	9.50	0.000	
GASSING TIME (min)	0.181	0.155	1.17	0.287	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.810325	18.55%	4.98%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	0.8973	0.8973	1.37	0.287
GASSING TIME (min)	1	0.8973	0.8973	1.37	0.287
Error	6	3.9398	0.6566		
Total	7	4.8371			



ANOVA ANALYSIS

Experimental data can also analyzed using Analysis of Variance (ANOVA) where the relative percentage contribution of all factors is determined by comparing with the relative variance. In ANOVA calculations, the degree of freedom for all factors is obtained first, the values of variance for all factors are then calculated and finally F-ratio and percentage contributions for the factors are calculated. The intention is to determine the significant control factors and their level of significance to optimize the process.

Standard deviation is the degree of dispersion or the scatter of the data points relative to its mean, in descriptive statistics. It tells how the values are spread across the data sample and it is the measure of the variation of the data points from the mean. The standard deviation of a data set, sample, statistical population, random variable, or probability distribution is the square root of its variance

Standard Deviation Formula

The spread of statistical data is measured by the standard deviation. The degree of dispersion is computed by the method of estimating the deviation of data points. You can read about dispersion in summary statistics. As discussed, the variance of the data set is the average square distance between the mean value and each data value. And standard deviation defines the spread of data values around the mean. Here are two standard deviation formulas that are used to find the standard deviation of sample data and the standard deviation of the given population.

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{n}}$$

Notations for Standard Deviation

- σ = Standard Deviation
- x_i = Terms Given in the Data
- \bar{x} = Mean
- n = Total number of Terms

Variance

Variance is the expected value of the squared variation of a random variable from its mean value, in probability and statistics. Informally, variance estimates how far a set of numbers (random) are spread out from their mean value.

The value of variance is equal to the square of standard deviation, which is another central tool.

Variance is represented by σ^2 , s^2 , or **Var(X)**

Degrees of freedom

In statistics, the number of degrees of freedom is the number of values in the final calculation of a statistic that are free to vary

The term is most often used in the context of linear models (linear regression, analysis of variance), where certain random vectors are constrained to lie in linear subspaces, and the number of degrees of freedom is the dimension of the subspace. The degrees of freedom are also commonly associated with the squared lengths (or "sum of squares" of the coordinates) of such vectors, and the parameters of chi-squared and other distributions that arise in associated statistical testing problems

Root mean square (RMS)

The **root mean square (RMS)** is the square root of the mean square, which is the arithmetic mean of the squares of a group of values. RMS is also called a quadratic mean and is a special case of the generalized mean whose exponent is 2. Root mean square is also defined as a varying function based on an integral of the squares of the values which are instantaneous in a cycle

P-Value

The p-value is the probability of obtaining results at least as extreme as the observed results of a statistical hypothesis test, assuming that the null hypothesis is correct. The p-value serves as an alternative to rejection points to provide the smallest level of significance at which the null hypothesis would be rejected. A smaller p-value means that there is stronger evidence in favor of the alternative hypothesis.

Assuming

Null Hypothesis

$$H_0 = \mu(\text{As gassed}) = \mu(\text{After holding } \frac{1}{2} \text{ hours}) = \mu(\text{After holding } 1 \text{ hours}) = \mu(\text{After holding } 1.5 \text{ hours})$$

Alternate hypothesis

$$H_a = \text{Not all } \mu \text{'s equal}$$

Analysis from the data given in (Table 14). Compressive strength obtained for 3.5% binder, 2.5 litre/min flow rate at different gassing and holding time.

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
As gassed	8	31.32	3.915	0.700086		
After holding ½ hours	8	32.2	4.025	0.462143		
After holding 1 hours	8	26.26	3.2825	0.126021		
After holding 1½ hours	8	34.25	4.28125	0.111384		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.32153	3	1.440511458	4.116823	0.015415	2.9467
Within Groups	9.79744	28	0.349908482			
Total	14.119	31				

Interpretation:

As the value of p- value of test statistics (0.015415) is less than the α (0.05), hence we can null hypothesis unacceptable but F test statistics of tested data is 4.1168, which is greater than F crit(2.9467). Hence our result lies in error free zone and null hypothesis is accepted.

Table 6: Analysis from the data given in (Table 16). Compressive strength obtained for 4.5% binder, 2.5 litre/min flow rate at different gassing and holding time.

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
As gassed	8	36.11	4.51375	1.764741		
After holding ½ hours	8	37.57	4.69625	0.316827		
After holding 1 hours	8	35.84	4.48	0.304914		
After holding 1½ hours	8	28.65	3.58125	0.301384		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6.003484375	3	2.001161	2.978067	0.048397	2.946685
Within Groups	18.8150625	28	0.671967			
Total	24.81854688	31				

Interpretation:

As the value of p- value of test statistics (0.0483) is less than the α (0.05), hence we can null hypothesis is acceptable also F test statistics of tested data is 2.978067, which is greater than F crit(2.94668527). Hence our null hypothesis is accepted. it means we can use 4.5% binder composition and 2.5 lit/min flow rate and successfully get the required compressive strength of the mould and we can use it for casting different material which in the given range compressive strength mentioned in the Table 7: Standard property range of sand casting of different alloy.(Dietert 1966) , depending upon the permeability range of mould of material.

Analysis from the data given in (Table 18). Compressive strength obtained for 5.5% binder, 2.5 litre/min flow rate at different gassing and holding time.

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
As gassed	8	44.7	5.5875	2.573393		
After holding ½ hours	8	45.95	5.74375	2.727455		
After holding 1 hours	8	47.95	5.99375	1.815313		
After holding 1½ hours	8	44.41	5.55125	0.691012		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.972259375	3	0.324086	3.260455	0.041836	2.9467
Within Groups	54.6502125	28	1.951793			
Total	55.62247188	31				

Interpretation:

As the value of *p*- value of test statistics (0.041836) is less than the α (0.05), hence we can null hypothesis is acceptable also *F* test statistics of tested data is 2.978067, which is greater than *F* crit(2.94668527). Hence our null hypothesis is accepted. it means we can use 5.5% binder composition and 2.5 lit/min flow rate and successfully get the required compressive strength of the mould and we can use it for casting different material which in the given range compressive strength mentioned in the Table 8: Standard property range of sand casting of different alloy.(Dietert 1966) , depending upon the permeability range of mould of material.

Permeability test: - An experiment was conducted to measure permeability of mould using different percentage of sodium silicate binder.

Sample preparation:

The measured amount of sand is filled in the specimen tube and a fixed weight of 6.35 to 7.25 kg is allowed to fall three times from a height of 50.8±0.125mm

Standard sample size: 50.8mm in diameter & 5.08cm in length

CALCULATION:

P (permeability No.)= Vh/PAT

Where,

V=volume of air=2000cm³

h=height of specimen= 5.08cm

p=Air pressure=10 gm/cm²

A= cross sectional area of the specimen=20.268cm²

Table 9: Result of permeability test of mould using different percentage of sodium silicate binder

SL.NO	Sodium Silicate	MOISTURE %	TIME (min)	PRESSURE (gm/cm2)	PERMEABILITY NO.	HARDNESS HB
1	3.5	6	0.50	10	100.26	45
2	4.5	6	1.00	10	50.13	52
3	5.5	6	1.50	10	33.42	58
4	6	6	2.00	10	25.06	63
5	6.5	6	3.00	10	16.71	71

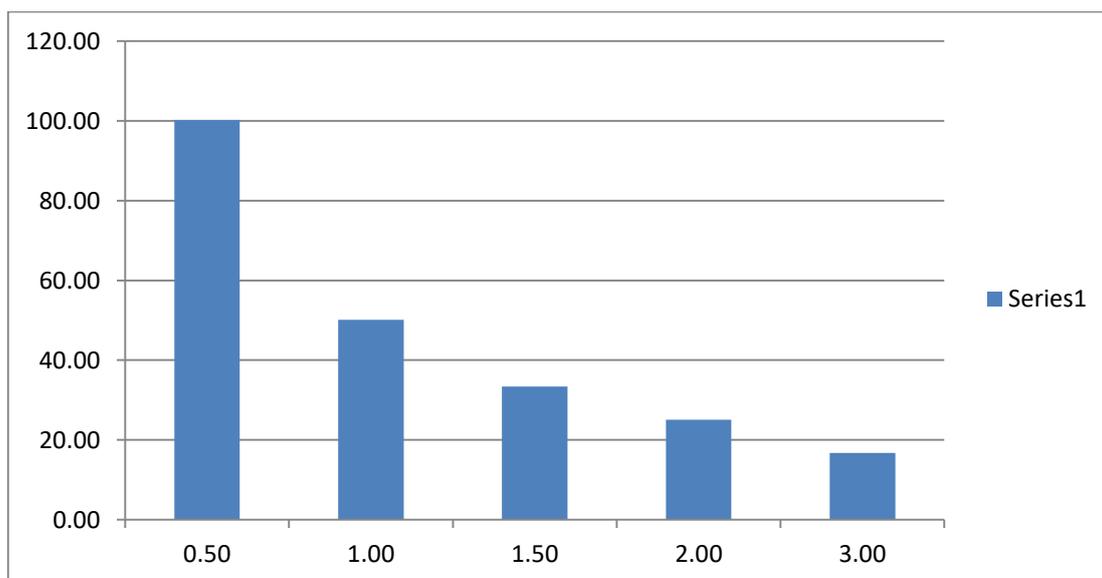


Figure 36: permeability vs. time of complete gassing of CO₂ through mould

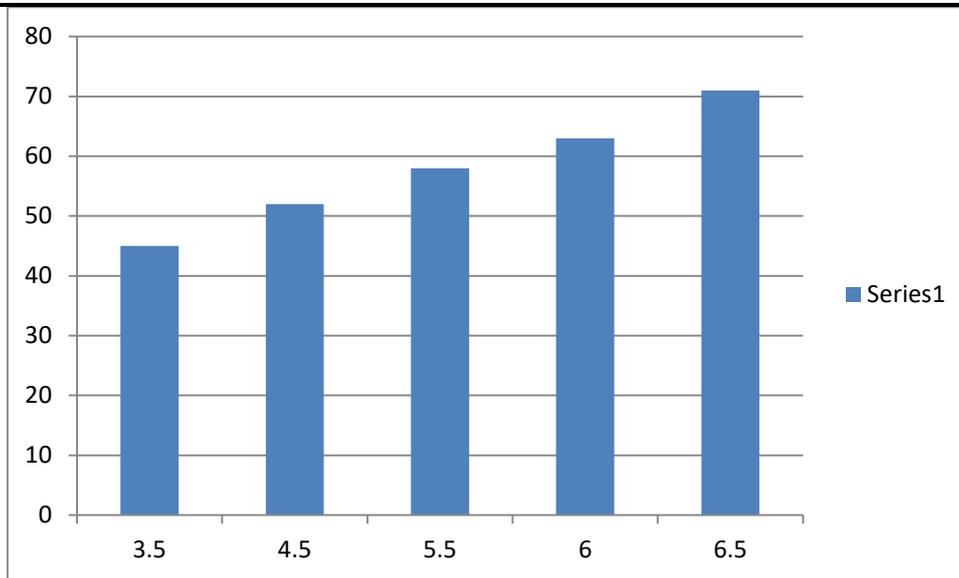


Figure 37: hardness of mould vs. % of sodium silicate binder used in mould

Metals	Green compression strength (kN/m ²)	Permeability (No.)	Dry compression strength(kN/m ²)	Dry compression strength (kg/cm ²)
Heavy steel	70-85	130-300	1000-2000	10.1-20.39
Light steel	70-85	125-200	4000-1000	40.77-10.19
Heavy grey iron	70-105	70-120	350-800	3.57-8.15
Aluminium	50-70	10--30	200-550	2.04-5.61
Brass and Bronze	55-85	15-40	200-880	2.04-8.97
Light grey iron	50-85	20-50	200-550	2.04-5.61
Malleable iron	45-55	20-60	210-550	2.14-5.61
Medium Grey Iron	70-105	40-80	350-800	3.57-8.15

Table 10: Standard property range of sand casting of different alloy.(Dietert 1966)

5.0 Conclusion

ON THE BASIS OF THE INVESTIGATION CARRIED OUT, THE FOLLOWING CONCLUSIONS HAVE BEEN MADE:-

1. IT IS OBSERVED THAT IN ALL THE THREE CASES THAT IS USING 3.5%,4.5% AND 5.5% OF SODIUM SILICATE COMPOSITION AND MAINTAINING THE FLOW RATE OF GAS AT 2.5LIT/MIN. HARDNESS OF MOULD INCREASES WITH INCREASE IN GASSING TIME BUT THE PERMEABILITY OF MOULD DECREASES.
2. GOES ON DECREASING ON THE HOLDING THE GASSED SPECIMEN AT HIGHER FLOW RATES.
3. IN DELAY IN MOULDING HAD ADVERSE EFFECT ON, TENSILE STRENGTH, BENDING STRENGTH AND SCRATCH DEPTH.
4. THE SPECIMEN PREPARED WITH OPTIMUM COMPOSITION SHOWED A TENSILE STRENGTH OF 22 N/CM², A BENDING STRENGTH OF 57 N/CM² AFTER 24 HOURS OF ROOM TEMPERATURE.
5. THE RETAINED STRENGTH DATA SHOWS ALKYD BONDED SAND SPECIMEN HAS VERY GOOD COLLAPSIBILITY.
6. THE CASTING IN THE MOULD HAVING OPTIMUM COMPOSITION SHOWED BETTER SURFACE FINISH THAN DRY SAND MOULD.
7. SAND MIX WITH 5.5% SODIUM SILICATE AT 3 MINUTES GASSING TIME AND 10 LITRE/MINUTE FLOW RATE IN AS GASSED CONDITION IS GIVING MAXIMUM COMPRESSIVE STRENGTH.
8. THE STRENGTH THE SAND MIX OF 4.5% BINDER, THERE IS NOT MUCH VARIATION IN THE COMPRESSIVE STRENGTH OF GASSING TIME UP TO 1 MINUTE.
9. COMPRESSIVE STRENGTH OF GASSED SPECIMEN INCREASES ON INCREASE OF BINDER PERCENT.

FUTURE SCOPE:

Using 3.5% sodium silicate composition, we got a permeability of 100.26. Hence comparing with the standard data (given in table 24) grey cast iron can be casted using (gassing timing >2 min, holding time 0.5 hr or 1.5 hr (preferred)).

Using 4.5% sodium silicate composition, we got a permeability of 50.3. Hence comparing with the standard data:

1) **Malleable cast iron** can be casted using (gassing time >1 min and holding time 0.5 hr or 1hr(preferred) or 1.5hr).

2) **Medium grey iron** can be casted using (gassing time >1 min and holding time 0.5hr or 1hr (preferred)).

Using 5.5% sodium silicate composition, we got a permeability of 33.5. Hence comparing with the standard data:

1)**Brass and bronze** can be casted using (any of the gassing time from 0.5min-6min and any of the holding time ranging from 0.5min-1.5min).

2) **Malleable iron** can be casted using (gassing time ranging from 0.5min- 1.5 min any of the holding time ranging from 0.5min- 6min)

3) **Light grey iron** can be casted using (0.5min of gassing time and any of the holding time from 0.5min-1.5min).

4) **MEDIUM GREY IRON** CAN BE CASTED USING (GASSING TIME > 1 MIN AND ANY OF THE HOLDING TIME RANGING FROM 0.5MIN- 1.5MIN).

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