FLUIDITY OF ALUMINUM IN GREEN SAND MOLDS

by

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CHAPTER I

THE PROBLEM AND ITS SIGNIFICANCE:

In progressive foundries it is recognized that the foundry sand deserves as much attention as the casting metal. Efficient sand control should cut the cost of the finished casting. First, by ensuring that the molds and cores are of uniform characteristics, thus minimizing the number of defective castings attributable to poor molding practice, and second, by avoiding the use of unnecessarily expensive molding sands.

Under uncontrolled conditions many foundries encounter a wide variation in casting properties within a few hours due to the change in the physical properties of the molding sand viz., green strength, permeability etc. These properties are further dependent on certain variables - moisture and clay - which bring about a radical change.

The change in the moisture content will effect the green compression strength, green tensile strength and permeability. The greater the green strength the less flowability of the sand. Greater green strength may be desirable in molding simple casting with flat surfaces. The change in clay content effects the permeability and green strengths. Low permeability may lead to "blows," "scabbing," and "misruns," particularly on thin walled casting.

Production of casting in sand molds is the basic and original method employed by the foundry industry. Other methods are the result of the technological advances, but none has resulted in the extreme flexibility of the sand casting process. Competitive markets make it necessary to reduce the cost of the sand casting parts. In the casting industry the cleaning, finishing and salvage costs contributes major portions to the unit cost. Also, in the foundry industry the ratio of defective product is higher than any other metal working field. Therefore, the knowledge of the castability of an alloy in green sand molds presents a problem of great economic importance.

The casting property of a metal or alloy may be affected by physical properties of the mold, which in turn are dependent on mold composition. The principal casting property affected is fluidity which is defined as "the property which allows metal to flow freely and evenly into a mold and fill it before such freezing occurs as would offer an obstruction to further flow."[1] The precise reasons for fluidity testing are: 1. The determination of fluidity testing of the unfamiliar alloys facilitates the selection of the best alloy for a specific application among several others which may be otherwise equally suitable. 2. The fluidity testing helps in maintaining the quality control; unfortunately, a factor to which some foundrymen have not given proper attention. In this investigation an attempt has been made to find the effect of the composition of the mold sand on the fluidity of the Aluminum Silicon alloy.

B. THESIS OBJECTIVE

The objective of this thesis is

1. To investigate the effect of some molding sand properties on the fluidity of some Aluminum-Silicon alloys in green sand molds.

Specifically to prepare green sand molds with varying water, clay and silica sand composition and perform a fluidity test with different melts of Aluminum.

2. To investigate, through standard foundry tests, the effect of variable percentages of water, clay, and silica sand on the permeability, green compressive strength, and green tensile strength of the standard sand samples.

C. SUMMARY OF FINDINGS.

An analysis of variance test of completely randomized molds (of different composition) indicated the difference in metal composition (Aluminum - 6% silicon and Aluminum - 12% silicon alloys) had no significant effect on fluidity.

However, a separate analysis of variance for each metal composition in different mold compositions indicated there was no significant effect of mold composition on fluidity results when pouring Aluminum - 6% silicon alloy. There was a significant effect of mold composition on fluidity results when pouring Aluminum - 12% silicon alloy. Duncan's test substantiated the results from analysis of variance and indicated the fluidity of Aluminum - 12% silicon alloy in the mold of composition 5% clay, 5% water and 90% silica sand was less than the fluidity in other molds of the different composition tested.

It has been found from this investigation on properties of green molding sand that the green compression strength increased from 2.133 lbs./sq. in. to 7.267 lbs./sq. in. and the green tensile strength increased from 6.1 oz./sq. in. to 16.233 oz./sq. in. as the clay content increased from 5 percent to 10 percent at 5 percent moisture level. The green compression strength increased from 1.8 lbs./sq. in. to 5.433 lbs./sq. in. as the clay content increased from 5 percent to 10 percent at 10 percent moisture level. There is a decrease in green strengths with an increase in moisture level from 5 percent to 10 percent. The permeability number decreases from 171.6 to 144.67 (at 5% moisture level) and from 156 to 111.67 (at 10% moisture level) as the clay content increased from 5 percent to 10 percent. The relationships between clay, water, green strengths and permeability over the range tested verify previous investigations.

CHAPTER II

REVIEW OF LITERATURE

The problem of fluidity of metals has long been considered important for the foundry. Due to the difficulties in finding an absolute definition of fluidity, various tests have been designed to provide information on a comparative basis. Much of the work done has been related to the metallurgical factors influencing fluidity such as metal composition, superheat above liquidus temperature and mode of solidification.

A review of the history of fluidity testing has been prepared by Clark,[2] Conard et al[3] and Krynitsky.[4] The investigations on the flow characteristics of molten metals cast into sand molds has been summarized. Many investigators have studied fluidity of metals and have prepared a great number of different tests. Fluidity values obtained from past investigators show a discouraging amount of scatter, and because of the different test designs correlation of data presented by different investigators is very difficult.

The spiral fluidity test by Saeger and Krynitsky[5] for cast iron and by Briggs, Taylor and Rominiski[6] for steel are generally accepted in America as a standard for fluidity test.

Adams et al[7] have prepared a new type fluidity test where the alloy being studied is drawn into a pyrex glass tube by means of vacuum. In this method test variables may be controlled closely and the fluidity values presented show excellent reproducibility. Fluidity results from the vacuum tube apparatus, however, may not be directly applicable to the problem of running thin section castings in sand molds. To perform fluidity test more closely resembling the conditions found in a sand mold should be of more direct value to the foundry.

Adams et al[8] have attempted to generalize fluidity variables by a mathematical interpretation based on physical properties which may not be of much practical importance in determining fluidity. Because it is too technical for an ordinary foundrymen to understand and work with so many variables and bring into consideration the physical properties.

Several researchers have studied the effect of chemistry on the fluidity of red brass employing the spiral test specimen.[9]

Flemings et al[10] employed a double spiral to study the effect of various mold coatings on the fluidity of Aluminum alloys. Two spirals were fed from a common gating system. Only one spiral was treated and the lengths to which each spiral filled was compared.

Latest work by Flemings et al[11] on the effect of surface tension on fluidity has shown that regardless of melt temperature a critical metal head is necessary to force Aluminum into small diameter channels. This critical metal head is that required to overcome surface tension.

CHAPTER III

DISCUSSION ON FLUIDITY VARIABLES

A. GLOSSARY OF CASTING DEFECTS CITED IN THIS THESIS

1. Blowhole: A hole produced in a casting when gas, entrapped while the mold is being filled or evolved during the solidification of metal, fails to escape and is held in pockets.

2. Scabbing: A blemish caused on a casting by eruption of gas from the mold face, or by uneven mold surfaces, or occuring where the skin from a blowhole has partly burned away and is not welded.

3. Misruns: Cast metal that was poured too cold so that it solidified before filling the mold completely.

4. Pulls: The cracks caused in a casting by thermal contraction when two portions become anchored as a result of an irregular shape.

5. Hot Tears: Cracks resulted from restrictions causing tensile stresses when the casting solidifies and contracts.

B. DISCUSSION ON FLUIDITY VARIABLES

The fluidity of metals depends upon three major variables, 1. metallurgical variables, 2. configuration of test pattern and variables of testing and 3. molding variables. Previous researchers listed the variables and the complexity of the fluidity investigation.[4] But, many investigators agree that the metallurgical factors, metal composition and degrees of superheat has the major effect on fluidity. To investigate these two factors effectively, it is necessary that the pattern variables should be kept stable and standardized molding techniques should be followed. Various additives such as sea coal, cereals, etc. may have an effect but these were not investigated.

METALLURGICAL VARIABLES

The following are the known metallurgical variables in a fluidity study:[12]

1. Metal composition (the mode of solidification and crystallization)
2. Degrees superheat
3. Metal viscosity
4. Surface oxide films
5. Absorbed gases and absorbed gas films preventing oxidation
6. Suspended inclusions
7. Inclusions precipitating during freezing

1. METAL COMPOSITION

The chemical composition effects the fluidity of the metal in two ways. The range of temperature for the solidification of a metal increases with the increase in impurities which in turn reduces the fluidity. This also results in an increase in the intervel of solidification.

The role of impurities in the solidification of a metal is of much importance in case of a pure metal entering a mold in the fluid state, the interface between the solid skin and the liquid metal is a smooth wall. The presence of the impurities even in small quantities results in a heterogenous composition of the solidified metal. It is indicated by the presence of the dendrites in the metal and the zone of dendrites is technically called the 'mushy' zone. The thickness of the mushy zone increases with the impurities, and also the chances for isothermal freezing becomes less.

The grain size of the components of the alloy is also an important factor. In case of the eutectic alloys, the grain size of the two precipitating phases is much finer than that of a pure metal and freezing starts at a lower temperature than that of either component in the alloy. "It has further been observed shell or skin formation does not occur as in pure metals. It has been postulated that the crystals which deposit on the mold wall are moved by convection and gravity toward the interior, fresh crystals being formed on the vaccated surface."[12]

Boyles[13] while working with gray cast iron observed that the eutectic developed in a cellular manner with growth occuring outward from each cell nucleous in a uniform manner. Near the surface of a casting more and finer cells are found than in the interior. This mechanism explains the fact that freezing does not occur along a sharp interface between solid and liquid and would also indicate the almost complete lack of temperature gradient during eutectic solidification that has been noted.

2. DEGREES SUPERHEAT

The liquidus temperature is defined as the temperature at which the metal or alloy remain always in liquid state. The degrees of superheat is defined as the temperature in number of degrees above the liquidus temperature.

The length of the casting flow channel in testing patterns is increased when the superheat of the molten metal is increased, all other things are being equivalent.

Since the temperature has the major effect on fluidity,[1] the control of this variable is important. The control of this variable is considered in Chapter IV.

3. METAL VISCOSITY

Viscosity is defined as the resistance offered to the flow of a liquid metal due to internal friction.

"There is a general belief that molten metals that flow poorly have high viscosity. In reality the viscosity of metals is very low, the kinematic viscosity is less than that of water in all metal investigated. Also, since viscosity changes only slightly with change of temperature, it is really a negligible factor in casting."[1]

To support it further Bastein et al have shown that "an apparent paradoxical result is that alloys or mixtures showing highest viscosity may have indeed the best flowability at constant superheat above liquidus."[14]

4. SURFACE OXIDE FILMS

The formation of oxide films is very important in the study of metal variables. High oxygen content at the time of pouring the liquid metal into the mold reduces the quality of the steel, because it makes the molding sand "wet," enhancing capillary action and increasing fluidity values.

Metals when heated in contact with air form oxides. In case of Aluminum silicon alloys the formation of oxide film is very rapid because of the high affinity of Aluminum for oxygen. Once the oxide film is formed it acts as a protective layer and does not increase in thickness with time of exposure to atmosphere. However, the thickness of the film will increase with increase in the impurities viz., inclusions and dissolved gases. The oxide on the melt surface contains a considerable amount of liquid metal causing the dross layer to be wet. The melting point of the oxide film is very high (about 4000°F) as compared to the alloy and thus the oxide does not dissolve in the molten stream.

From the foregoing account it is clear that the formation of the oxide film is unavoidable. The effect of this variable however, can be minimized by taking the following steps during the pouring. Skimming of the liquid alloy in the ladle and followed by fast pouring rate.

5. ABSORBED GASES AND ADSORBED GAS

The absorption of gases during melting and pouring of any metal should be reduced to a minimum. No degassing procedures may be required in subsequent operations if the absorption has already been minimized and if gas porosity is not a major factor in determining acceptable casting soundness and surface finish.

In the case of Aluminum alloys the absorption of hydrogen is extremely rapid when the oxide surface is broken, thus removing its protective action. The solubility of the gases varies as the square root of gas pressure above and around the metal. Oxygen is the only other important gas dissolved in effective quantities, but it reaches atmospheric hydrogen and the large amount of moisture that is present in the mold. Hence, poor gating practices which produce excessive turbulence in the gating system, and low sand permeability which causes the gas to penetrate the oxide surface and bubble into the melt greatly increase the source of this difficulty. Thus moisture control is one of the important factors. The gas absorption during and after the pour may be minimized by 1. reducing exposure of the metal to the atmosphere during the pouring operation, 2. reducing the height of the drop from the laddle lip to the mold cavity, and 3. using pouring and gating practices which minimize turbulence during the pouring operation. This is discussed at the end of the chapter.

6. SUSPENDED INCLUSIONS

The presence of suspended inclusions causes a rapid rise in the apparent viscosity of a liquid, since the included particles offer resistance to the flow of the fluid. They become an important factor when present in sufficient quantity being a qualitative variable. The rapid formation of oxide film in Aluminum alloys, the breaking of oxide films by the turbulent flow through the gating system serve as an obstruction in the flow channel and results in premature solidification.

The effect of the variable can be controlled indirectly by controlling the other factors viz., by minimizing the oxide film formation which has already been discussed.

7. INCLUSIONS PRECIPITATING DURING FREEZING

"This particular variable is not pertinent to the fluidity testing of the binary Aluminum-Silicon alloys because no similar inclusions (as in case of iron) precipitate during the freezing process."[15]

C. MOLD CHARACTERISTICS

1. The types of molding medium such as green sand, dry sand, metal and investment mold are discussed.

2. The properties of the green sand mold such as grain size and shape, clay, moisture, green strength and permeability are discussed.

GREEN SAND MOLDS

The essential components of a molding sand are the sand grains, the clay and the moisture. The sand is called 'green' because of the moisture present and is thus distinguished from dry sand. In green sand practice, the molds are cast with the molding sand nearly as moist as at the time when the pattern is withdrawn; loss of moisture by evaporation may occur if the mold cannot be closed and cast at once. The molding sands commonly used are prepared from naturally-bonded sands, high-silica sands, and bonding clays.

The size and section of castings which can be prepared by this method are limited by the strength of the green sand. Moreover, the surface of a green sand mold is susceptible to erosion by the flow of liquid metal during pouring, and the sand so removed produce defective castings such as misruns and scabs in the casting. The advantages of using the green sand are that it offers little resistance to the contraction of the mold during cooling, and thereby minimizes the risk of pulls and hot tears in the casting products.

DRY SAND MOLDS

In dry sand practice, after the pattern has been withdrawn from the moist sand, the surface of the mold is usually coated with a refractory material or an organic binder is mixed with the sand. Then the mold is placed in a drying furnace and baked hard at a temperature of 300-600°F. The molding sands used in dry sand work are similar to those employed in green sand work.

The strength of the dry sand mold is much higher than that of the green sand mold, and consequently resist the erosion by the molten metal much better than green sand surfaces. Dry sand molds can be used for larger castings than green sand molds. Furthermore, during casting the volume of gases evolved from dry sand mold is less than that of evolved from green sand mold, thereby reduce the risk of blow holes in the casting.

METAL MOLDS

Metal molds are usually made of good grade of dense cast iron, such as "meehanite" as are also most large cores. Small cores and many multiple cores are usually made from alloy steel to secure greater strength at the temperature of the cast metal and to prevent warping. Molds can also be built from Aluminum alloys. To get the better metal flow and for greater hardness the surface of the Aluminum mold is anodized. Metal molds are also made with special heat-resistant steels. The metal molds are made in two or more parts, which, when fitted will form the shape of the part to be cast as well as the gates and risers.

In general, mold thickness should be from 1 to 2 inches depending on the thickness of cast section, slightly greater for extremely heavy castings. Molds with thickness less than 1 inch are mechanically weak and suceptible to cracking and warping. The castings made out of metal molds will give good surface smoothness (500 micro inches r.m.s.), close dimensional tolerances (1/64 inch/inch), and good mechanical properties (23,000 psi tensile).[16]

The metal molds are generally limited to casting nonferrous metals. Iron and steel castings can be made when the molds are coated with refractory clay and a second layer of lamp black.

INVESTMENT MOLDS

Patterns for the investment casting process must be made of materials such as waxes and plastics that will melt, vaporize or burn completely leaving no residue. These patterns are made by the injection of the pattern material into metal dies. The wax patterns are assembled to a wax sprue and attached to a wax coated plate by a wax seal. A heat resisting metal flask is then placed around the pattern and sealed with wax. The assembly must be liquid tight. The flask surrounding the patterns is filled with a wet investment mixture made up of silica sand and crushed fire brick in a solution containing ethyl silicate, ethanol, and hydrochloric acid and also plaster of paris. Then this flask is placed on a vibrator to pack the investment mixture around the wax patterns and to ensure the removal of all air. This process is continued until hydrolysis takes place in a manner to set the investment mixture. Complete set up and curing time for the investment molds varies from 1/2 to 24 hours, according to whether plaster is used or a binder with a vehicle of alcohol or water. Then the molds are placed in a long continuous mold heating furnace upside down. In the preheating zone the wax is melted out and as the mold progresses in the furnace, it is heated to a temperature of 1400 to 2000°F. The total time required for the mold in the furnace is approximately 4 to 12 hours, depending on the type of investment and the character of both material and casting.

GRAIN SIZE AND SHAPE

Molding sands are classified according to silica grain size. The fineness of a sand refers to the size distribution of the grains. The average grain size is expressed as a fineness number for a sand. This number is approximately the number of meshes per inch of that sieve which would just pass the sample if its grains were of a uniform size of grains in the sample.

The strength of the molding sand is greatly dependent upon the surface area of the sand grains available for bonding. Fine sand presents more surface area and can develop high strength, but more clay is required. Size distribution of the molding sand (percentage on 3 adjacent screen) influences strength for the same reason. Wide sand grain size distribution favor strength, narrow sand grain distribution reduces strength. Angular sand grains promote greater strength than do rounded grains in molding sands because of keying.

Base permeability of a molding sand depends on the interrelation of grain sizes, grain shape and distribution. Coarser sands with greater void space have greater permeability than finer sands.

The sand grain shapes are classified into four shapes

1. Angular sand grains
2. Subangular sand grains
3. Rounded sand grains
4. Compound sand grains

Casting finish, mold permeability, sand strength, refractoriness and expansion characteristics are all influenced by the sand grain size, shape, distribution and purity.

CLAY

The clay content influences the green and dry strength. This property of sand is very important in imparting the required strength to the sand and also to counteract the thermal expansion of silica grains, by clays characteristic thermal contraction. The decrease in clay content will decrease the strength, increase the permeability and increase the flowability. An increase in clay content will increase mold hardness and green strength. Since strength is increased flowability is decreased.

Permeability is reduced by fine material in the sand. Increasing clay content therefore lowers permeability. Higher clay content requires more tempering water to dissolve clay and coat the sand grains. Hence, more steam is formed when the metal is poured.

MOSITURE

The determination and control of moisture is important because some of the major properties of the molding sand can vary with moisture content. The clay coating depends upon moisture content. The moisture content of a particular green sand mixture largely controls its green shear and tensile strengths and permeability. An increase in the percentage of water in the sand will decrease the green strengths, permeability hardness and bulk density.

GREEN STRENGTH

Green compressive strength of the molding sand is the maximum compressive stress which a mixture is capable of developing.

Green tensile strength of the molding sand is the maximum tensile stress which a mixture is capable of sustaining.

Green strength is important as a measure of the ability of a sand to withstand the stress that will be imparted to it. Sand that is too low in strength will not draw well from deep pockets and may drop from cope sections of the mold. On the other hand, sand that has higher green strength will ram hard and has poor flowability. Poor flowability, in turn, will result in a fluctuating mold surface hardness and poor pattern reproduction.

PERMEABILITY

Permeability is that physical property of the molded mass of a sand which allows gas to pass through it. Permeability is important as a measure of the ability of a sand to allow quick passage for gases created when molten metal is poured into the sand.

Permeability is affected by many factors including grain fineness, grain shape, grain distribution, clay, moisture and ramming coarser sands with greater void space have greater permeability than finer sands. Permeability is reduced by fine material. Therefore increasing clay content lowers permeability.

D. MOLD COATINGS

Castings with smooth surfaces are obtained by applying smooth and highly refractory surfaces on the molds. The refreactory coatings on the surfaces of sand mold cavities will prevent the fusing of the sand to the castings and resists the cutting action of the molten metal. The materials ordinarily used for this purpose are graphite, coke, charcoal, silica and mica. These materials are classified into two groups; the carbonaceous materials are known as blackings, and the other materials are designated as mineral coatings.

Refractory coatings are applied to mold surfaces in different ways. The finely ground material is often dusted on the mold surfaces from a cotton bag. Another procedure is to suspend the refractory materials in water to which some bonding material such as dextrin or bentonite is added.

The mold coatings have an effect on fluidity. Conard et al[3] have showed that a coating of finely powdered activated charcoal lowers fluidity when compared with torch blacking and a coating of crystalline graphite did not improve or deter fluidity. Further, they stated that the Hexachloroethane mold coatings increase the fluidity and the fluidity was increased with the increase in the thickness of the Hexachloroethane coating.

E. FLUIDITY TESTING PROCEDURE

1. THE PATTERN

Different types of patterns were used by various investigators for fluidity test. The simple spiral fluidity test used for this work is the result of modifications to obtain a test simple enough to foundry use and also accurate enough for more fundamental investigations dealing with small variations in fluidity, of little importance in foundry practice but very important in research.

The spiral fluidity test pattern used in this investigation was designed by Agee[15] in order to study the fluidity of Aluminum alloys in CO_2 cured molds. Figures 1A and 1B in Appendix A gives a schematic view of the pattern used.

The cope half of the pattern consists of Aluminum alloy pouring basin and down sprue. The drag half of the pattern consists of Aluminum alloy spiral pattern. If the test pattern is to develop good sensitivity, it must be designed to minimize the test pattern variables. Some of these variables can be controlled by following the proper pouring procedure for that particular design.

2. PRESSURE HEAD

"The pressure head is considered the effective height of liquid metal above the entrance to the flow channel acting to force the metal through the ingate."[15]

The pressure head and metal reservoir are the essential part of the mold. The height of the casting head and reservoir above the flow channel affects the length of the spiral run. The length of the spiral is directly proportional to the pressure head and increasing the pressure head results in an increase in the fluidity. The important feature is to maintain a constant pressure head above the flow channel, which is achieved by providing reservoir between the ladle and the down sprue of the mold. In the present investigation the same method[14] was used by adjusting the flow of metal at a faster rate into the reservoir than the flow from the reservoir to the mold cavity. The gating used in this system was so designed as to give a minimum turbulence.

3. GATING SYSTEM

The flow of the liquid metals can be classified into laminar and turbulent flow. In laminar flow, the particles follow well defined, non intersecting paths without turbulence. The turbulent flow, in which the paths of the liquid particles cross and recross one another in an intricate pattern of interlacing lines with eddies. The degree of turbulence vary widely depending on conditions of flow.[17]

Sharp changes in the cross-sectional area of the flow channel and the sudden changes in the direction of flow has greater effect on the degree of turbulence of a flowing stream. The turbulence can be reduced by providing a basin at the bottom of the down sprue.

The gating used in this investigation was designed after AGEE[15], in that the liquid metal enters the flow channel with a relatively low velocity and in a non-turbulent fashion. It is achieved by locating a well or base under the sprue. As the liquid metal fills this well or sprue base minimum turbulence is produced.

4. CROSS SECTIONAL AREA AND SHAPE OF FLOW CHANNEL

The cross sectional shape of the flow channel does not influence the practical values of the fluidity testing except for the ease with which the pattern is molded. Because the complete impression of the flow channel can be made in one half of the mold, and because of the ease with which the pattern may be drawn from the sand a trapezoidal is believed to be the most practicable.

Generally the horizontal flow channels leading from the sprue well are 4 to 6 times larger in cross sectional area than the bottom or choke in the sprue.[17] The increased sectional area results in decreasing the velocity of the molten metal in the flow channel thereby reducing turbulence and providing the oxide film an opportunity to rise or sink in the flow channel.

Clark[2] suggest that a half round or trapezoidal section having a cross sectional area between 1/12 and 1/7 square inch is believed to be the most practical.

5. MOLDING PROCEDURE

The ingredients silica sand, southern Bentonite clay, and moisture were weighed on a platform scale. Then the sand mixture was transferred to a muller and mulled for 15 minutes until the ingredients were thoroughly mixed. The muller used in this investigation is shown by photograph 1 in Appendix B, page 68. Molds should be poured within 4 hours after they were made in order to minimize any moisture loss due to evaporation.

The Aluminum alloy spiral pattern was mounted on the metal table of a jolt squeeze rollover pattern-draw molding machine by means of counter sunk screws. The molding machine with the fluidity pattern is shown by photograph 2, Appendix B, page 69. Pattern equipment was kept clean and dry. A small amount of parting powder was sprinkled on the pattern to facilitate easy parting of the mold and the pattern.

The sand mixture was then transferred into flask halves and around machine-mounted Aluminum alloy patterns and vent pin, from the muller. Then the molds were jolted 25 times mechanically and peen-rammed in flask corners. More sand was added and ramming was done with the rammer operated by air pressure. The hardness number being defined as resistance of penetration, indicated on dial in thousandth of an inch of penetration. The hardness number were within the narrow limits (within 68-78) in all molds prepared from different sand composition. A straight edge was used to scrape off the excess sand level and small amount of mix sprinkled on to bed the bottom board. The cope half of the pattern and the vent pin were unscrewed from jolt table, rapped, and drawn. The squeeze was placed in position and clamped, and the mold was rolled over and squeezed. The patterns were drawn and the mold halves were removed from the machine. The mold halves is shown by photograph 3, Appendix B, page 70.

6. <u>MELTING PROCEDURE</u>

An oil fired revecon reverberatory furnace, shown by photograph 4, Appendix B, page 71, was used to melt the Aluminum Silicon alloy. The furnace was preheated initially for 30 minutes. Then 50 pounds of new Aluminum silicon alloy was charged on the hearth through the stack opening and at the same time one pound of commercial Aluminum cover flux was charged into the furnace through the tapping spout. The tapping spout was closed. The heating was continued until the temperature of the melt reaches 450° 20°F above liquidus temperature. The temperature was determined in the ladle as soon as the liquid metal was tapped from the furnace by means of a chromel-alumel thermocouple.

Degassing was accomplished by introducing one commercial solid chloride base degassing tablet into the bottom of the melt. Since the gas or vapor bubble is not saturated in respect to hydrogen, some of the hydrogen in the melt diffuses into the bubble and is carried up to the surface and escapes with it. One advantage of using chlorine is that this will cause a separation of non-metallics suspended in the melt and produce a "dry dross" on the melt surface, the dry dross being one relatively free of liquid Aluminum.

After the degassing tablet was submerged, the melt was allowed to lay for 5 minutes. Then the melt was skimmed in the furnace and tapped into a small shank-type transfer ladle which was cleaned and preheated to above 212°F to remove absorbed moisture or moisture in the ladle coating if any. The same melting procedure was followed throughout the experiment. The new Aluminum silicon alloy ingots were used only in the first melt. Later on the same Aluminum silicon alloy was remelted and used. It is understood from the investigation of Agee[15] that the remelting of Aluminum silicon alloy has no significant effect on fluidity in CO_2 molds. Also it is learned from Shah[18] that the re-melting of Aluminum silicon alloy has no effect on the velocity of the flowing metal in CO_2 molds. Therefore, the author has assumed re-melting effects are insignificant and did not statistically test for these effects

7. <u>POURING PROCEDURE</u>

The manner in which the mold is poured has an important bearing on the length of the specimen. When the metal is poured from a considerable height, it is liable to enter the mold cavity in a violent and turbulent manner. This turbulent flow will lead to excessive cutting and arosion of the mold wall.

By providing a pouring basin, the danger of turbulence and vortexing with consequent air entrapment at the entrance is minimized. Pouring basin was designed in a such a manner so as to permit some floatation of dross and slag so that only clean metal enters the mold.

The length of the fluidity spiral depends upon the rate with which the metal is poured. Unless the pouring rate is governed by the gating design which was done in this case. A pressurized sprue was used. Pouring rate should be kept constant from one test to another because the length of fluidity varies when the pouring rate varies. The pouring rate should be initially slow as the basin fills up to the mouth of the down sprue and then very rapidly and continuously as the metal flows into the down sprue. The pouring lip should be held as low as possible so that free fall of metal from the pouring lip to the mold is a minimum distance. This will reduce the gas absorption and also reduce the cascade effect and entrainment of gas and dross in the metal flowing down the sprue due to the reduced height of the metal fall. This above pouring procedure was used in this investigation.

E. VARIABLES INVESTIGATED

1. 5% and 7% moisture (by weight)
2. 5%, 7½% and 10% clay (by weight)
3. Metal composition Al-12% Si and AL-6% Si

VARIABLES CONTROLLED AND/OR ELIMINATED

1. Degrees superheat
2. Metal viscosity
3. Surface oxide films
4. Absorbed gases and absorbed gas
5. Suspended inclusions
6. Inclusions precipitating during freezing
7. Pressure head
8. Pouring rate
9. Mold coatings
10. Sand additives

CHAPTER IV

THE INVESTIGATION

A. SAND ANALYSIS:

As mentioned in Chapter I, one of the objectives of this thesis investigation was to determine the effect of variable percentages of water, clay and silica sand on the permeability, green compressive strength and green tensile strength of standard sand samples. The sand analysis used throughout the investigation was synthetically prepared from Southern Bentonite clay, water and clean, dry, clay-free AFS 60 silica sand. Specifically the composition of the mixed molding sand by weight was

Clay	5%	5%	7 1/2%	7 1/2%	10%	10%
Water	5%	7%	5%	7%	5%	7%
Sand	90%	88%	87 1/2%	85 1/2%	85%	83%

Then, the individual mixes were prepared in a laboratory-sized muller and AFS standard specimens were prepared and test for permeability, green compressive strength, and green tensile strength with standard dietert testing equipment.

PERMEABILITY

Three AFS standard 2 inch x 2 inch specimens for each sand mixture were prepared using a Precision Scientific rammer. The weight to the nearest gram of sand required to produce these standard specimens was determined. An AFS standard permeability test was run on each of the three specimens using Precision Scientific permeter. In all cases 2000 cubic centimeters of air were used. The permeability number was noted from the dial gage. Any inaccuracy in dial gage reading was consistent for each specimen. The permeability testing apparatus is shown by photograph 5 in Appendix B, page 72.

Permeability number is the volume of air passed through a unit cube of the sand in one minute under unit pressure difference between the end faces of the cube.

GREEN COMPRESSIVE STRENGTH

Three AFS standard 2 inch x 2 inch specimens for each sand mixture were prepared using a Precision Scientific rammer. The specimen was carefully placed in the compression apparatus in such a manner that what was the top of the specimen, as rammed in the specimen container, rests against the upper head of the apparatus. A load against the plane surfaces was applied at a uniform rate until the specimen broke down. Load at rupture was recorded for each specimen. The green compression strength testing apparatus is shown by photograph 6, Appendix B, page 73.

GREEN TENSILE STRENGTH

A specimen container for green tensile test specimen is a two part container of such a design that the specimen may remain in the container during the testing and the two halves of the container will readily separate approximately at the middle of the specimen. The green tensile strength testing apparatus is shown by photograph 7, Appendix B, page 74.

Three AFS standard 2 inch x 2 inch specimens were prepared for each sand mixture using a Precision Scientific rammer. The specimen was carefully placed in the tensile testing apparatus and a tensile load was applied uniformly along the axis of the specimen. The result for green tensile strength were noted for each specimen.

FLUIDITY TEST

The simple spiral fluidity test pattern utilized for this work was intended to obtain a simple method for foundry use. The actual spiral has been designed by Agee[15] in order to study the fluidity of Aluminum alloys in CO_2 cured molds.

Using the spiral fluidity pattern, foundry size muller, and jolt-rollover pattern draw molding machine, six molds were prepared for each given sand sample. The composition of the sand samples has already been given in the preceeding section.

Each mold was prepared in the same manner and rammed to keep the hardness number within narrow limits (68-78). Then the molds were poured at random, first three molds with Aluminum-6% silicon alloy at a temperature of 200° superheat above the liquidus temperature of 1157°F and the second three molds with Aluminum-12% silicon alloy at a temperature of 200° superheat above the liquidus temperature of 1075°F.

A Revecon reverberatory furnace was used for melting. In measuring the inches of fluidity, it was observed that there was shrinkage at the extreme end of the spiral. The length of the spiral was measured only up to the point at which the shrinkage had not been observed.

TEMPERATURE CONTROL

The fluidity factor of degrees superheat has such a pronounced effect on inches of flow it was felt this factor merits special attention and a rigidly accurate control. The pouring temperature was taken with a chromel-alumel thermocouple connected to a calibrated Leeds and Northrup Millivolt potentiometer, immersed in the melt at the instant of pouring from ladle.

The thermocouple used to measure the temperature was made of new chromel-alumel, 22 gauge wire elements welded with a carbon arc to form the hot junction. The thermocouple elements were insulated with asbestos, ceramic, and rubber sleeves from cold junction to hot junction. The thermocouple was enclosed into a fused quartz tube which was sealed at one end. The two wires were prevented from shorting in the quartz tube by using a double hole ceramic insulator. The tube was enclosed in a steel tube with a graphite mix which was then baked.

The cold junction of the thermocouple was connected to a Leeds and Northrup potentiometer. The scales of the potentiometer were checked repeatedly and adjusted when necessary to compensate for room temperature fluctuations. The temperature of the molten metal was measured in the ladle and an allowance of 10°F drop in temperature for transfer of metal from the ladle to mold was allowed.

The temperature measurement apparatus is shown in photograph 8, Appendix B, page 75.

CHAPTER V

RESULTS

The results of this investigation can be classified under the following head lines:

A. Sand Analysis   B. Fluidity Test

A. SAND ANALYSIS

The average of the three readings of the sand analysis was used to plot the graph. The average was used because of the small variation in the readings.

1. GREEN COMPRESSION STRENGTH

The relationship between green compression strength and clay content in the molding sand at each moisture level was plotted. From the figure (1) it is seen that the maximum green compression strength was reached with higher clay content at 5 percent as well as 7 percent moisture levels, only three points were used to plot the curve. The general trend of each of the two curves reveal that green compressive strength increases with increasing clay content of the molding sand mix up to 10 percent, being the highest clay content in this investigation at which maximum green compressive strength was observed. As the moisture content increased from 5 percent to 7 percent, keeping the clay content constant, the green compressive strength decreased. The maximum moisture level was 7 percent in this investigation.

2. GREEN TENSILE STRENGTH

Figure (2) shows the relationship of green tensile strength and

Bentonite clay content in the molding sand at each of the two moisture levels. It is seen from the graph that the maximum green tensile strength was reached at higher clay content at 5 percent as well as 7 percent moisture levels, only three points were used to plot the curve. From the analysis it has been found that green tensile strength increases with the increasing clay content up to 10 percent. Maximum green tensile strength was attained at 10 percent with clay content. The investigation shows that an increase in the moisture content from 5 percent to 7 percent decreases the green tensile strength; percentage of clay content in the molding sand being constant. The divergence of the two line plots indicate an interaction between clay and water. The author did not use the statistical design to test this interaction.

PERMEABILITY

The permeability number is plotted (Fig.3) against varying clay content for each of the moisture levels. The general trend of each of the two curves reveals that increasing clay content reduces the permeability. Also from the investigation it has been found that when the moisture content changes from 5 percent to 7 percent there is a decrease in permeability, the clay content remaining constant.

A detailed account of the results has been given in Chapter VI.

FLUIDITY TEST

Fluidity test results of Aluminum - 6% silicon alloy and Aluminum - 12% silicon alloy in green sand molds made of different sand composition are given in Table No. II on page 40. Fluidity test results were analyzed statistically.

TABLE I

SAND ANALYSIS

SAND COMPOSITION	GREEN COMPRESSION STRENGTH LBS/SQ.IN.	GREEN TENSILE STRENGTH OZ/SQ.IN.	PERMEABILITY NUMBER
I 5% clay,	2.2	6.2	175
5% water,	2.0	6.1	165
90% silica sand	2.2	6.0	175
AVERAGE	2.133	6.1	171.6
II 7½% clay,	5.2	11.25	167
5% water,	5.1	11.20	165
87½% silica sand	5.0	11.00	170
AVERAGE	5.1	11.15	167
III 10% clay,	7.3	16.5	146
5% water,	7.3	16.7	140
85% silica sand	7.2	15.5	148
AVERAGE	7.267	16.233	144.67
IV 5% clay,	1.8	5.8	158
7% water,	1.8	5.7	155
88% silica sand	1.8	6.0	155
AVERAGE	1.8	5.833	156
V 7½% clay,	3.4	8.50	152
7% water,	3.5	8.45	153
85½% silica sand	3.3	8.70	151
AVERAGE	3.4	8.55	152
VI 10% clay,	5.5	11.0	115
7% water,	5.4	11.2	110
83% silica sand	5.4	11.5	110
AVERAGE	5.433	11.233	111.67

THE RELATIONSHIP BETWEEN GREEN COMPRESSIVE STRENGTH AND CLAY CONTENT

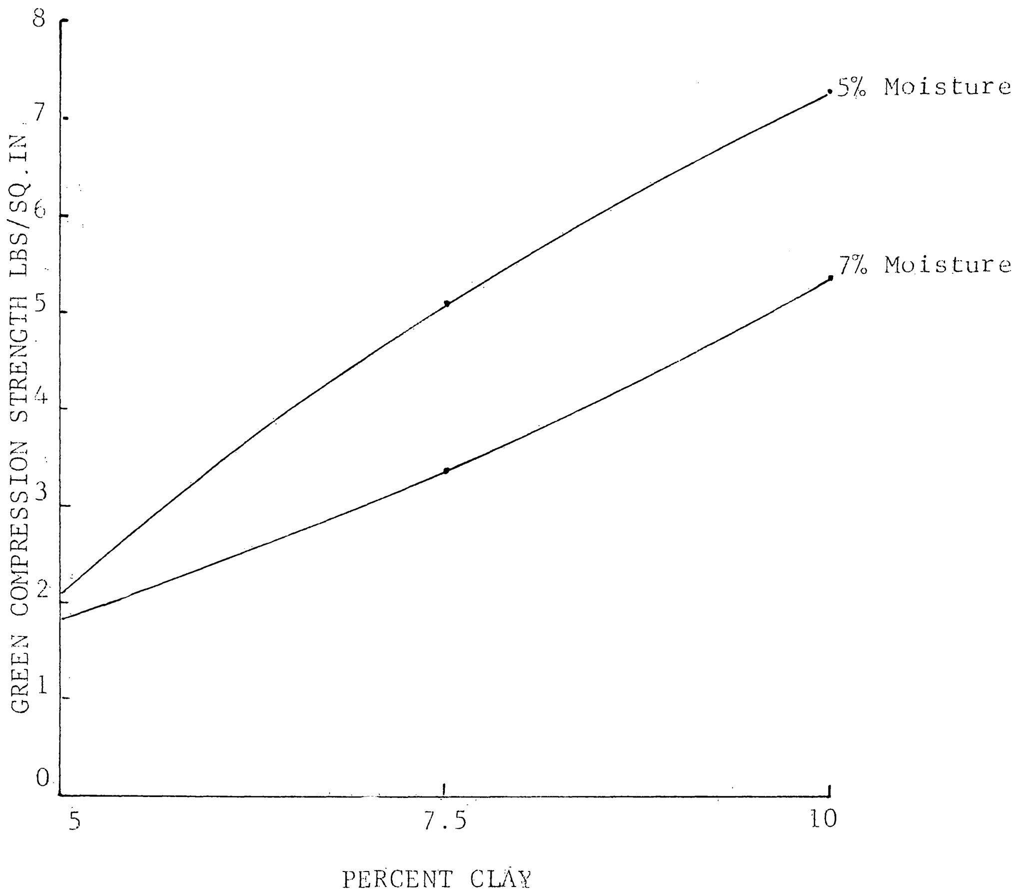


FIG. 1

THE RELATIONSHIP BETWEEN GREEN TENSILE STRENGTH AND CLAY CONTENT

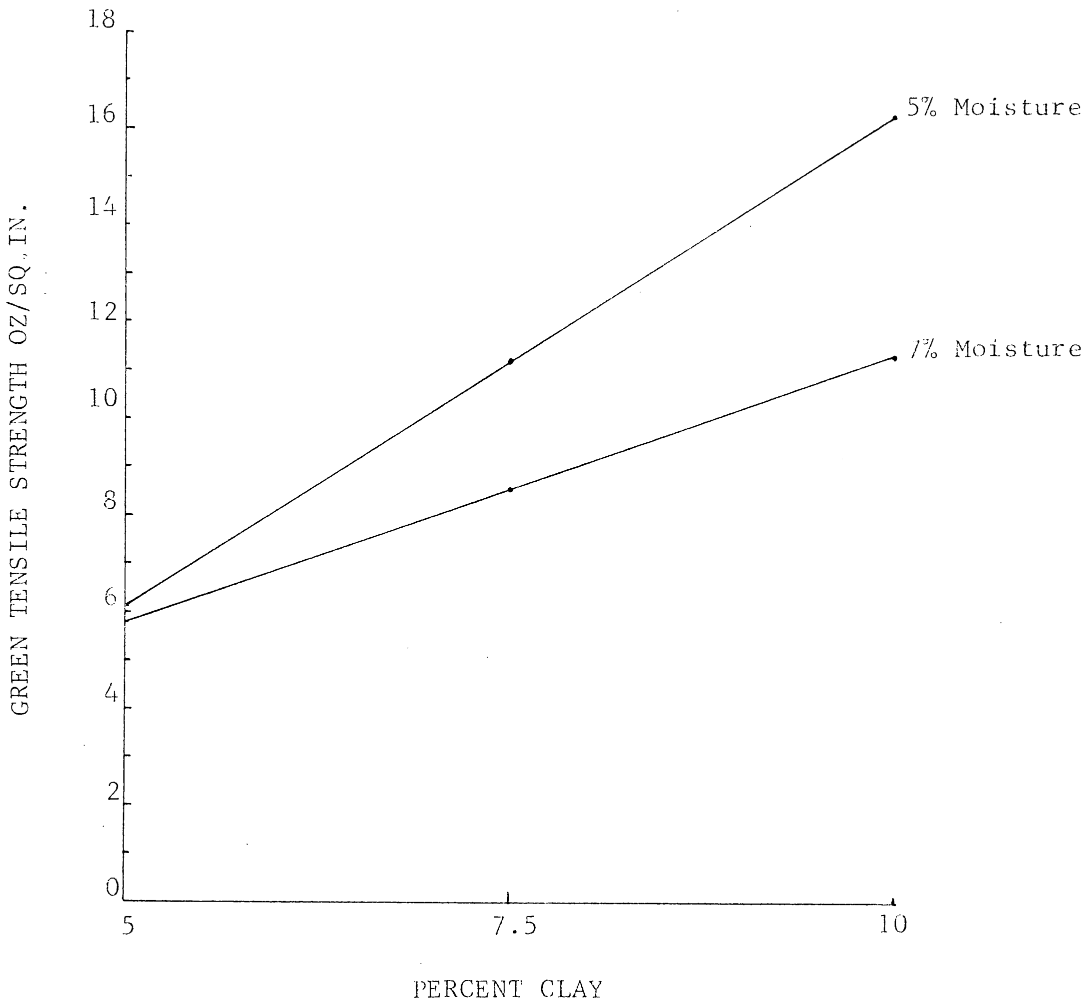


FIG. 2

THE RELATIONSHIP BETWEEN PERMEABILITY
AND CLAY CONTENT

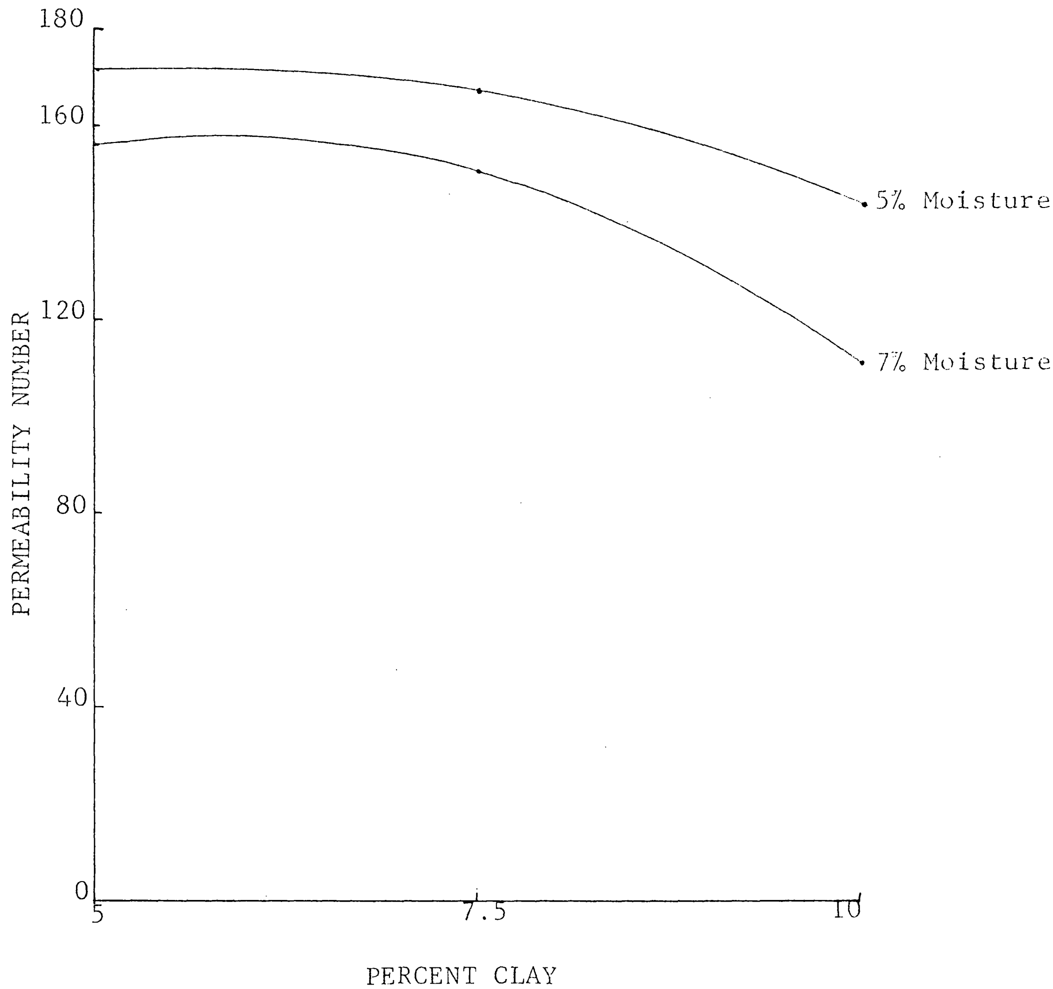


FIG. 3

TABLE II

FLUIDITY OF ALUMINUM SILICON ALLOYS

Fluidity in inches

Al-si Alloy	SAND SAMPLES 1	2	3	4	5	6
	5% water, 5% clay, 90% silica sand	7% water, 5% clay, 88% silica sand	5% water, 7½% clay, 87½% silica sand	7% water, 7½% clay, 85½% silica sand	5% water, 10% clay, 85% silica sand	7% water, 10% clay, 83% silica sand
	36.75	40.00	36.50	43.50	40.125	38.75
6%	34.125	35.25	35.125	43.25	40.50	46.50
	36.125	36.25	37.00	42.75	38.25	34.25
	34.75	41.00	44.00	40.00	46.00	47.00
12%	32.75	37.50	44.00	36.25	38.50	41.50
	35.50	38.25	42.25	41.25	43.25	43.125

Pouring temperatures: Aluminum 6% Silicon = 1357°F Level of Superheat = 200°F
Aluminum 12% Silicon = 1275°F Level of Superheat = 200°F

STATISTICAL ANALYSIS OF RESULTS

Situations often make it necessary to design an experiment in such a way that several variables or populations can be studied simultanously. The tests of this investigations were made in accordance with a statistical design and the results were analyzed with analysis of variance method.

The analysis of variance, as the name might indicate, consists of analyzing the variance of the sample into useful components. One of the most useful techniques for increasing the sensitivity of an experiment is the designing of the experiment in such a way that the total variation of the variable being studied can be separated into components that are of experimental interest. The remaining variation, is classed as the residual or error variation. This error variation would be the process variation, with which the other variances are compared. The error variation then, is the variation due to the method of experimentation. Strictly speaking all of these variances are estimates of the true value.

The analysis of variance provides for tests of significance (F-tests) by which it can be decided whether there is any significant difference in the real variation of results obtained from an applied treatment. (Variable being investigated).

The first step in the statistical analysis of results is to calculate the sum of squares for the observation, column treatments, row treatments and the interaction. The error sum of squares is then found by subtraction. The sum of squares are divided by their respective degrees of freedom to give the mean squares, which is an estimate of the standard deviation attributable to each source.

The physical meaning of degrees of freedom is explained by an example. If we have n-1 observations and are testing the hypothesis that the deviations from the mean of n observations are known, the other can be found by the identity $(x_1-\bar{x})-(x_2-\bar{x})---(x_n-\bar{x})-0$. Then n-1 degrees of freedom thus corresponds to the n-1 independent comparisons which can be made within the n observations.

Statistical Notations:

Y = an observation

G = grand total

N = total number of observations

R_i = row total

C_j = column total

r = number of rows (metal composition)

c = number of columns (treatments)

w = cell total

l = number of observations in each cell

Calculations are based on fluidity data in Table II, page 40.

Sum of Squares Total:

$$SS = \sum_i \sum_j \sum_k Y^2_{ijk} - \frac{(G)^2}{N}$$

$$= 56675.5156 - 55371.9722$$

$$= 1303.5434$$

Sum of Squares Rows (metal composition):

$$SS = \sum_i \frac{R_i^2}{cl} - \frac{(G)^2}{N}$$

$$= 55420.6814 - 55371.9722$$

$$= \underline{48.7192}$$

Sum of Squares Columns (sand samples):

$$SS = \sum_j \frac{C_j^2}{rl} - \frac{(G)^2}{N}$$

$$= 55538.9140 - 55371.9722$$

$$= \underline{166.9418}$$

Sum of Squares Interaction:

$$SS = \frac{W_{ij}^2}{l} + \frac{(G)^2}{N} - \left(\sum_i \frac{R_i^2}{cl} + \sum_j \frac{C_j^2}{rl}\right)$$

$$= 55742.8281 + 55371.9722 - 55420.6914 + 5538.9160$$

$$= 155.1989$$

Sum of Squares Error:

$$SS = \sum_i \sum_j \sum_k Y_{ijk}^2 - \sum_i \sum_j \frac{W_{ij}^2}{l}$$

$$= 56675.5156 - 55742.8281$$

$$= \underline{932.6875}$$

ANALYSIS OF VARIANCE TABLE

Source	SS	DF	MS	F
Rows (Metal Composition)	48.7192	1	48.7192	1.2034
Columns (Sand Composition)	166.9418	5	33.3883	0.8605
Interaction (Row x Column)	155.1989	5	31.0397	0.6525
Error	932.6835	24	38.8201	
Total	1303.5434	35		

The hypothesis under test are 1. The rows (metal composition) treatment effect on fluidity equals to zero. 2. The column treatments (sand composition) effect on fluidity equals to zero. 3. The interaction between columns and rows (sand composition and metal composition) effects are zero.

To test the hypothesis that the row treatment effects are equal, the statistic

$$F = \frac{\text{Row Treatment mean square}}{\text{Error mean square}}$$

With (r-1) and r.c(l-1) degrees of freedom is used.

To test the hypothesis that the column treatment effects are equal, the statistic

$$F = \frac{\text{Column Treatment mean square}}{\text{Error mean square}}$$

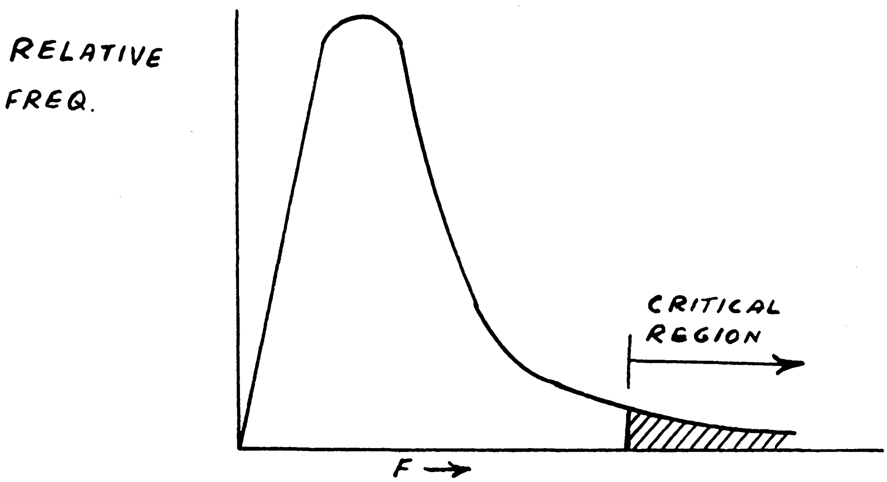
With (c-1) and r.c(l-1) degrees of freedom is used.

To test the hypothesis that the interaction effects are equal, the statistic

$$F = \frac{\text{Interaction mean square}}{\text{Error mean square}}$$

With (c-1)(r-1) and r.c(l-1) degrees of freedom is used.

These ratios follow a particular F -distribution which is defined by the number of degrees of freedom for that curve. The magnitude of the curve F - value enables the experimenter to decide whether an assignable cause exists. This is accomplished by defining a limit that the F-value can fall within and still be representative of the parent F-distribution. Outside of this limit the F-value belongs to some other distribution and hypothesis is rejected. One end of the curve is then marked off and classed the critical area. This is shown in figure below.



Thus if the F-value falls in the critical area then it is assumed it belongs to some other F-distribution.

Significance Level:

If we reject our hypothesis when it is actually true, we have committed an error called Type I Error. This percentage of all possible samples leading to the committing of a Type I Error is called the significance level. Consequently, the significance level is the probability of making Type I.Error.

1. Test of Hypothesis: Row Treatment (metal composition) effect.

Level of Significance = 10 percent

$$F = \frac{48.7192}{38.8201} = 1.2034$$

The calculated F-value of 1.2034 is less than the critical region F-value of 2.93 and therefore lies outside the critical region of the distribution. The hypothesis that the column treatment (metal composition) Aluminum silicon 6 percent and 12 percent) effects are equal to zero is accepted. <u>This test indicates the different Aluminum Silicon alloys (6% Si and 12% Si) have no significant effect on the fluidity.</u>

2. Test of Hypothesis - Column Treatment (sand composition) effect. Level of significance = 10 percent

$$F = \frac{33.3883}{38.8201} = 0.8605$$

The calculated F value of 0.8605 is less than the critical region F value of 2.10 and therefore lies outside the critical region of the distribution. The hypothesis that the column treatment (different sand mixture) effects are equal to zero is accepted. <u>This test indicates the molds of different sand mixture (as given in Chapter IV) have no significant effect on the fluidity.</u>

3. Test of Hypothesis - Interaction between metal composition and sand mixture effects.

Level of significance = 10 percent

$$F = \frac{33.0391}{38.8201} = 0.8525$$

The calculated F value 0.8525 is less than the critical region F value of 2.10 and therefore lies outside the critical region of the distribution. The hypothesis that the interaction (interaction between metal composition and sand mixture) effects are equal to zero is accepted. <u>This indicates that there is no interaction exists between metal composition and sand mixture.</u>

It now becomes necessary to examine individual treatments to know whether there is any difference between the treatments or not.

Duncan's New Multiple Range test was used to examine individual treatments to know whether there is any difference between the treatments or not. Duncan's New Multiple Range test is a method for comparing the individual treatments after an Analysis of Variance test has been done.

After having run an Analysis of Variance one has MSE (Mean Square Error)

TABLE I

a. Means Ranked in order

Column Treatments (Sand Mixture)	1	2	3	6	5	4
Fluidity	35.00	38.0416	39.8125	40.1876	41.1041	41.1666

b. Analysis of Variance

Item	D.F.	Variance	F. Ratio
Treatments	5	33.3883	0.8605
Error	24	38.8201	

c. Standard error of mean, $Sm = \sqrt{\frac{MSE}{n}} = \sqrt{\frac{38.8201}{6}} = 2.54$

Application Steps

We shall consider the application of a 5 percent level test to the fluidity means in Table I.

The data necessary to perform this test are: 1) the means, 2) the standard error, sm, 3) the degree of freedom on which this standard error is based, n = rl = 24.

First from the tables, significant ranges are extracted for samples of sizes p = 2, 3, 4, 5 and 6 at 5 percent significant level, and degrees of freedom = 24.

The significant ranges are then each multiplied by the standard error, Sm - 2.54 to form the least significant ranges. The least significant ranges are recorded below.

a. Least Significant Ranges:

(2)	(3)	(4)	(5)	(6)
7.42	7.80	8.00	8.18	8.33

b. Results

1	2	3	6	5	4
35.00	38.0416	39.8125	40.1876	41.1041	41.1666

Note: Any two means not underscored by the same line are significantly different. Any two or more means underscored by the same line are not significantly different.

From this test it has been found that there is no significant difference in fluidity due to the column treatments. (Different sand mixtures). Molds of different sand mixtures have no significant effect on the fluidity.

It now becomes the task of finding out whether there is any difference in fluidity of particular Aluminum-Silicon Alloy in different molds. This is accomplished by testing Aluminum - 6% Silicon and Aluminum - 12% Silicon Alloys separately.

Analysis of Variance for Al - 6% Si

Sand Mixture	Al-6% Si Fluidity in inches		
	MOLD 1	MOLD 2	MOLD 3
1	36.75	34.125	36.125
2	40.00	35.25	36.25
3	36.50	35.125	37.00
4	43.50	43.25	42.75
5	40.125	40.50	38.25
6	38.75	46.50	34.25

Sum of Squares Total:

$$SS = \sum_i \sum_j Y_{ij}^2 - \frac{(G)^2}{N}$$

$$= 27{,}052.3125 - 26068.0555$$

$$= \underline{984.257}$$

Sum of Squares Row Treatments (sand mixture):

$$SS = \frac{\sum R_i^2}{c} - \frac{(G)^2}{N}$$

$$= 26{,}190.8020 - 26068.0555$$

$$= \underline{122.7465}$$

Sum of Squares Error:

$$SS = \sum_i \sum_j Y_{ij}^2 - \frac{\sum R_i^2}{c}$$

$$= 984.2570 - 122.7465$$

$$= \underline{861.5105}$$

Analysis of Variance Table

Source	SS	DF	MS	F
Row Treatments (Sand Moisture)	122.7465	5	24.5493	0.3419
Error	861.5105	12	71.7925	
Total	984.2570	17		

Hypothesis under test: Row Treatment effects are equal to zero.

Level of significance = 10 percent

$$F = \frac{\text{Row Treatment Mean Square}}{\text{Error Mean Square}}$$

$$F = \frac{24.5493 \text{ w/5 degrees of freedom}}{71.7925 \text{ w/12 degrees of freedom}}$$

$$F = \underline{0.3419}$$

The F-value of 0.3419 is less than the critical region F-value of 2.39 and therefore lies outside the critical region of the distribution. The hypothesis that the row treatment effects are equal to zero is accepted. <u>This indicates the different sand composition of the molding sand have no significant effect on the fluidity of Aluminum-6% silicon alloy</u>.

Duncan's New Multiple Range Test:

Test on Rows:

Means ranked in order

1	3	6	2	5	4
35.667	36.208	36.500	37.166	39.625	43.166

Standard Error of a mean = $Sm = \sqrt{\frac{MSE}{n}}$

$$Sm = \sqrt{\frac{71.7925}{3}} = \underline{4.88}$$

d.f. = 12 Significant level = 0.05 (5 percent)

Least significant ranges

(2)	(3)	(4)	(5)	(6)
15.04	15.77	16.25	16.39	16.59

Results

1	3	6	2	5	4
35.667	36.208	36.500	37.166	39.625	43.166

The above test shows there is no significant differences between row treatments on the fluidity.

That there is no significant difference between molds made of different sand composition, on the fluidity.

Analysis of Variance Test Al-12% Si.

Sand Mixture	Al-12% Si. Fluidity in inches		
	Mold 1	Mold 2	Mold 3
1	34.75	32.75	35.50
2	41.00	37.50	38.25
3	44.00	44.00	42.25
4	40.00	36.25	41.25
5	46.00	38.50	43.25
6	47.00	41.50	43.125

Sum of Squares Total:

$$SS = \sum_{i}\sum_{j} Y_{ij}^{2} - \frac{(G)^2}{N}$$

$$= 29{,}623.2031 - 29{,}352.5147$$

$$= \underline{270.6884}$$

Sum of Squares Row Treatment: (sand mixture)

$$SS = \frac{\sum R_i^2}{c} - \frac{(G)^2}{N}$$

$$= 29552.0260 - 29352.5147$$

$$= \underline{199.5113}$$

Sum of Squares Error:

$$SS = \sum_i \sum_j Y_{ij}^2 - \frac{\sum R^2_i}{C}$$

$$= 29{,}623.2031 - 29{,}552.0260$$

$$= \underline{71.1771}$$

Analysis of Variance Table

Source	SS	D.F.		F
Treatments	199.5113	5	39.9022	6.73
Error	71.1771	12	5.9314	
Total	270.6884			

Hypothesis under test: Row Treatment effects are equal to zero.

Level of significance = 10 percent

$$F = \frac{\text{Row Treatment Mean Square}}{\text{Error Mean Square}}$$

$$F = \frac{39.9022 \text{ w/5 degrees of freedom}}{5.9314 \text{ w/12 degrees of freedom}}$$

$$F = 6.73$$

The F-value of 6.73 is greater than the critical region F-value of 2.39 and lies within the critical region of the distribution. The hypothesis that the row treatment effects are equal to zero is rejected.

This indicates the different sand composition in the molds have significantly different effects on the fluidity of Aluminum-12% Silicon alloy.

Duncan's New Multiple Range Test.

Test on Rows:

Means Ranked in order

1	2	4	5	3	6
34.33	38.91	39.17	42.58	43.41	43.87

Standard error of a mean $= Sm = \sqrt{\frac{MSE}{n}}$

$$Sm = \sqrt{\frac{5.9314}{3}} = 1.4$$

d.f. = 12 Significant level = 5 percent

Least significant ranges:

(2)	(3)	(4)	(5)	(6)
4.312	4.522	4.662	4.704	4.760

Results:

1	2	4	5	3	6
34.33	38.91	39.17	42.58	43.41	43.87

The test indicates that the fluidity in the mold of sand composition 5% clay, 5% water and 90% silica aand differs from the other molds of different sand composition. Also the fluidity in the mold of sand composition 5% clay, 7% water and 82% silica sand differs from the mold of sand composition 10% clay, 7% water and 83% silica sand.

CHAPTER VI

DISCUSSION OF RESULTS

Results of the sand testing data in Table I show that the clay and moisture plays an important part on the strength and permeability of the green sand mold. The results show that increasing the clay content in the sand mixture from 5 percent to 10 percent for the given percentage of moisture levels of 5 percent increases the green compressive strength from 2.133 pounds per square inch to 7.267 pounds per square inch. As also in the case of 7 percent moisture level the green compressive strength increase from 1.8 pounds per square inch with to 5.433 pounds per square inch. The green tensile strength also increase from 6.1 oz./sq.in. to 16.233 oz./sq.in. with the increase in clay content from 5 percent to 10 percent, at the moisture level of 5 percent.

The permeability number of the sand mixture decreases from 171.6 to 144.67 with the increase in clay from 5 percent to 10 percent, moisture level being constant at 5 percent. The permeability increase may be due to the presence of the more fine material in the sand. Green compression and tensile strengths are reduced with an increase in the moisture content. For example, when the moisture content is increased from 5 percent to 7 percent the green compression strength is reduced from 7.267 pounds/sq.inch to 5.433 pounds/sq.inch, the percent of clay being constant at 10 percent. From this results it has been noticed that the change of percentage of the ingredients clay, moisture, and silica sand in the molding sand affects the physical properties of the mold.

Statistically in the overall analysis there was no significant difference in fluidity with the Aluminum-silicon (6 percent) alloy and

Aluminum-silicon (12 percent) alloy in the varying composition of the green mold sand. Apparently none of these variables seem to affect the fluidity to a considerable extent. Curry[20] (1927) working with cast iron found that variation of three to seven percent moisture content of the molding sand appeared to make little difference in the measured fluidity.

The individual fluidity analysis of Aluminum - 6% silicon alloy in molds of varying composition did not indicate any significant difference. In other words the varying moisture and clay content of the molding sand does not effect the fluidity of Aluminum-silicon (6 percent) alloy.

On the other hand, the fluidity of Aluminum - 12% silicon alloy was effected by variations in the composition of the molding sand.

Duncan's test was used to compare the fluidity in a given mold with the fluidity in other molds. That is the difference in individual mold effects on fluidity was evaluated. Sand composition of 5 percent clay and 5 percent moisture apparently reduced the fluidity as compared to all other molds of different composition of sand. The fluidity in the mold of sand with the composition 5 percent clay and 7 percent moisture differs as compared to the mold of sand composition 10 percent clay and 7 percent moisture.

CHAPTER VII

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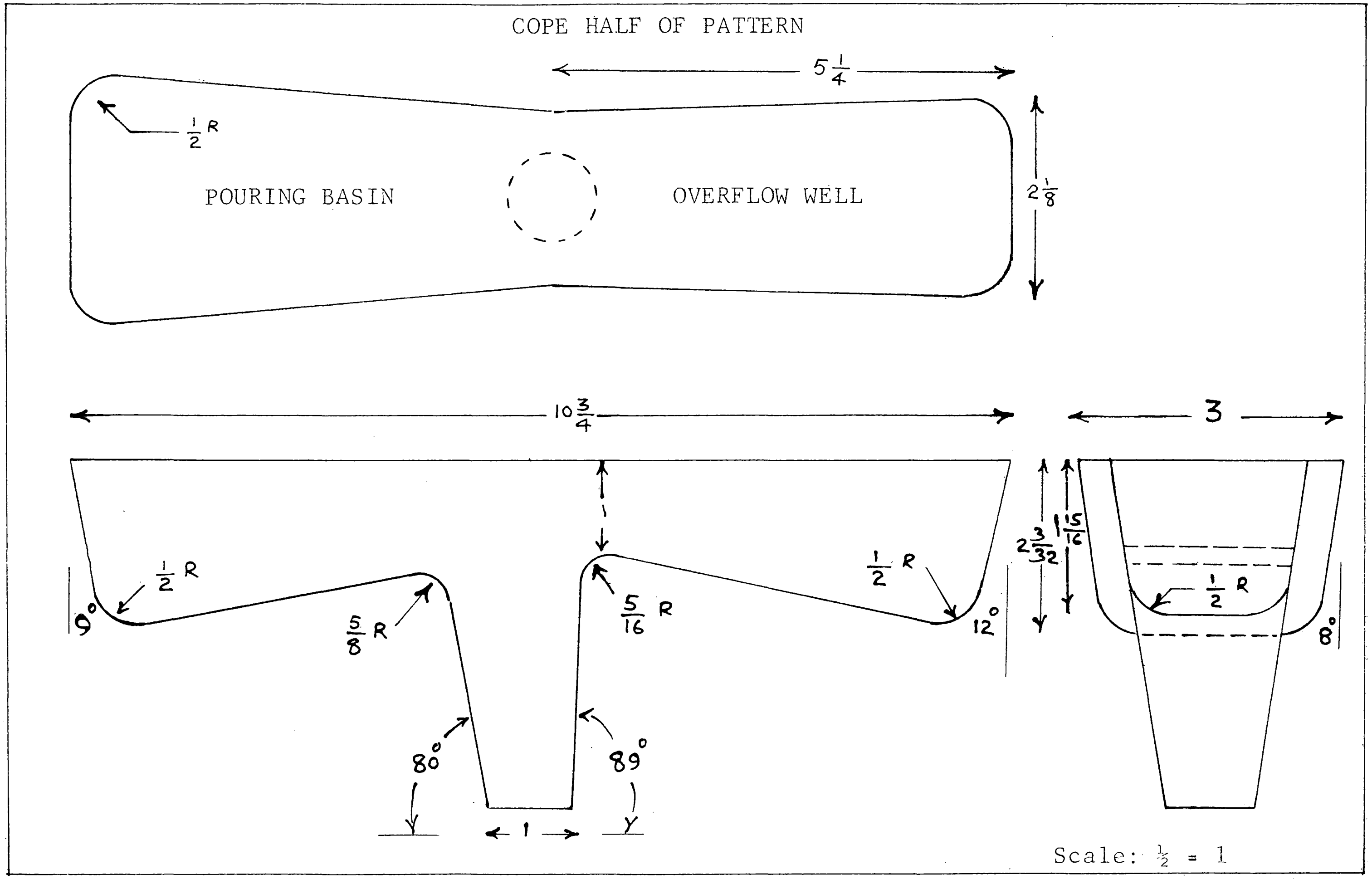
CHAPTER VIII

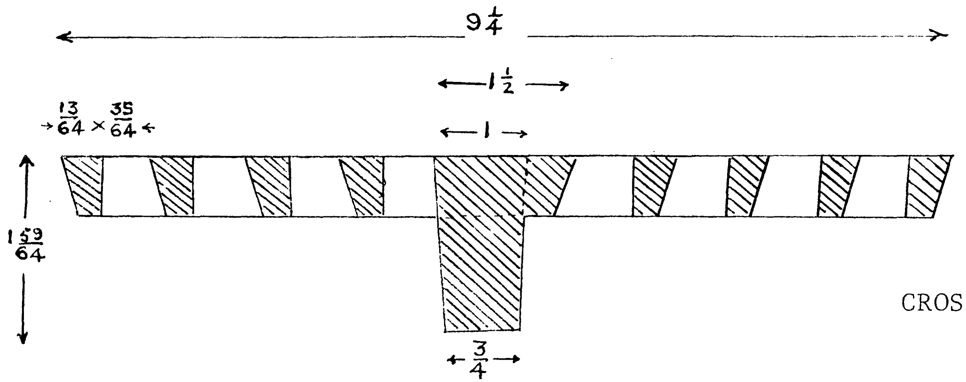
APPENDICES

APPENDIX A

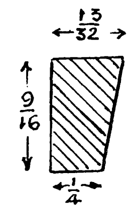


Sketch 1A - Cope Half of Fluidity Pattern

DRAG HALF OF PATTERN



SCALE: ½" = 1"



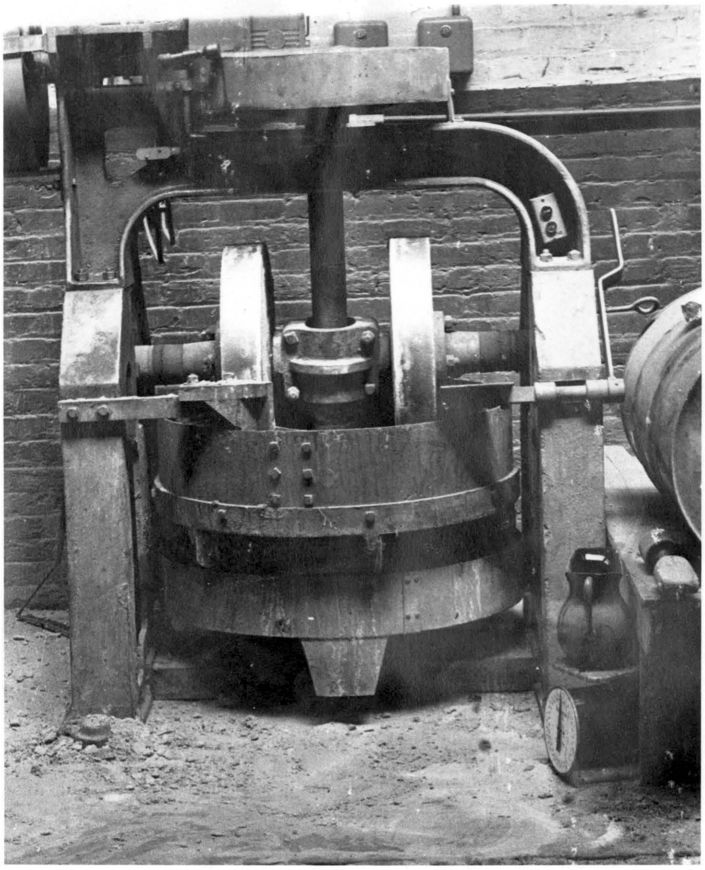
CROSS-SECTION OF SPIRAL CHANNEL
SCALE: 1" = 1"

LEGEND

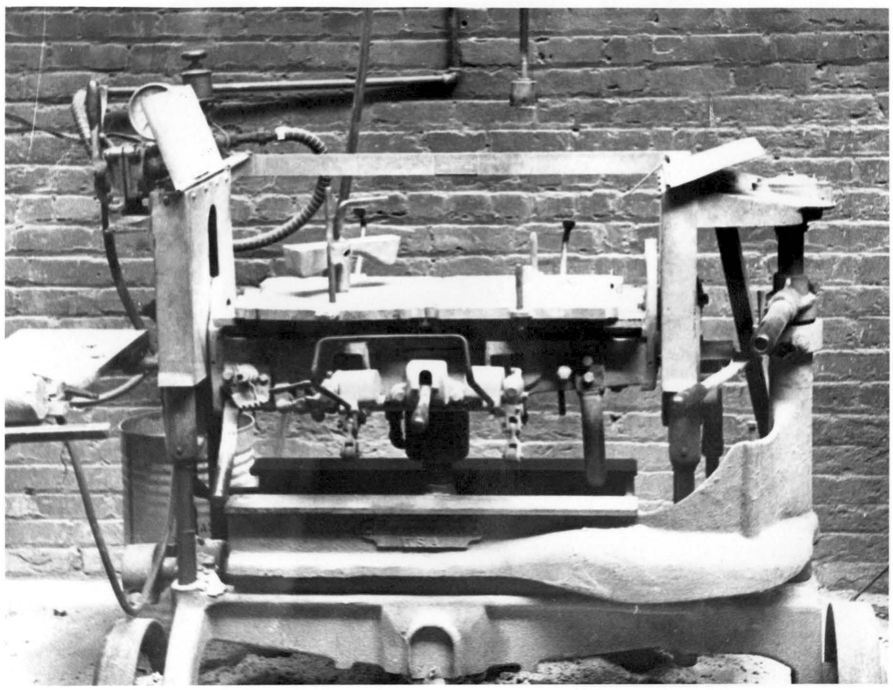
1.	Length of spiral flow channel	=	66 in.
2.	Cross-sectional area of flow channel	=	0.185 in.^{2}
3.	Ratio of sprue base cross-sectional area to flow channel cross-sectional area	=	4 1/4 to 1
4.	Static Pressure Head	=	3 35/64 in.

Sketch 1B - Drag Half of Pattern

APPENDIX B

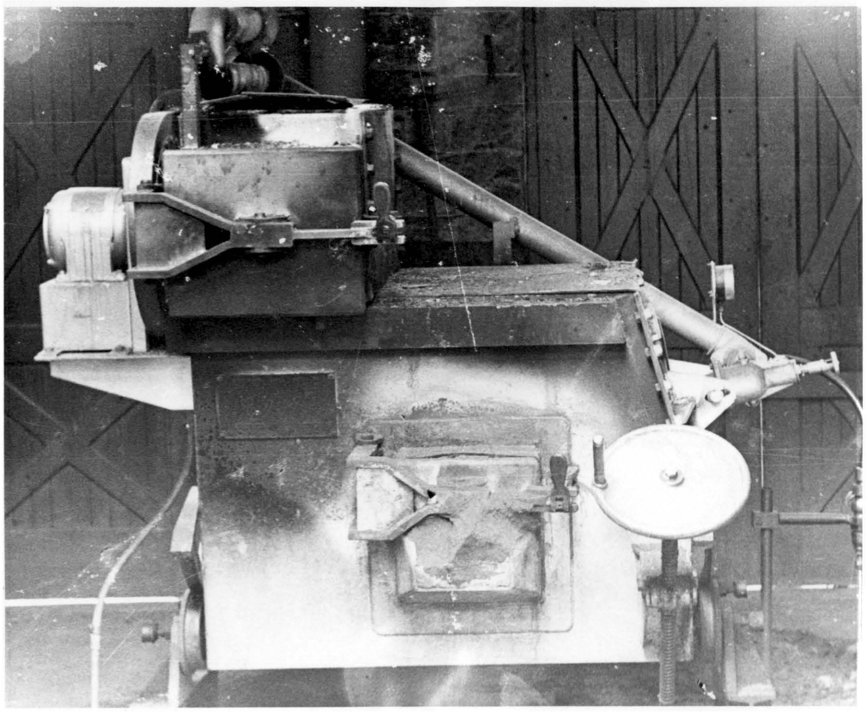


Photograph 1 - FOUNDRY SAND MULLER



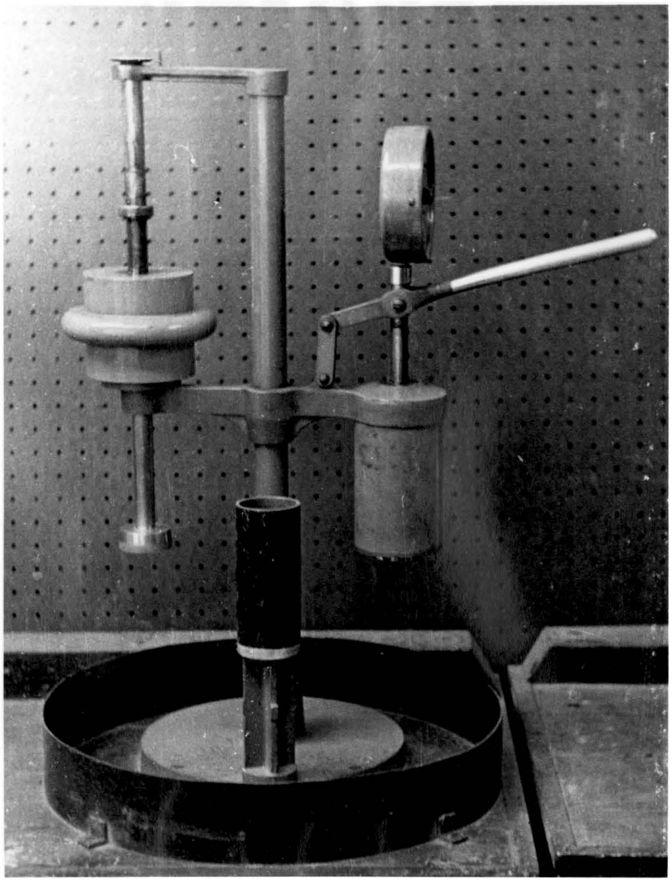
Photograph 2 - MOLDING MACHINE WITH PATTERN
MOUNTED ON THE JOLT TABLE

Photograph 3 - SAND MOLDS

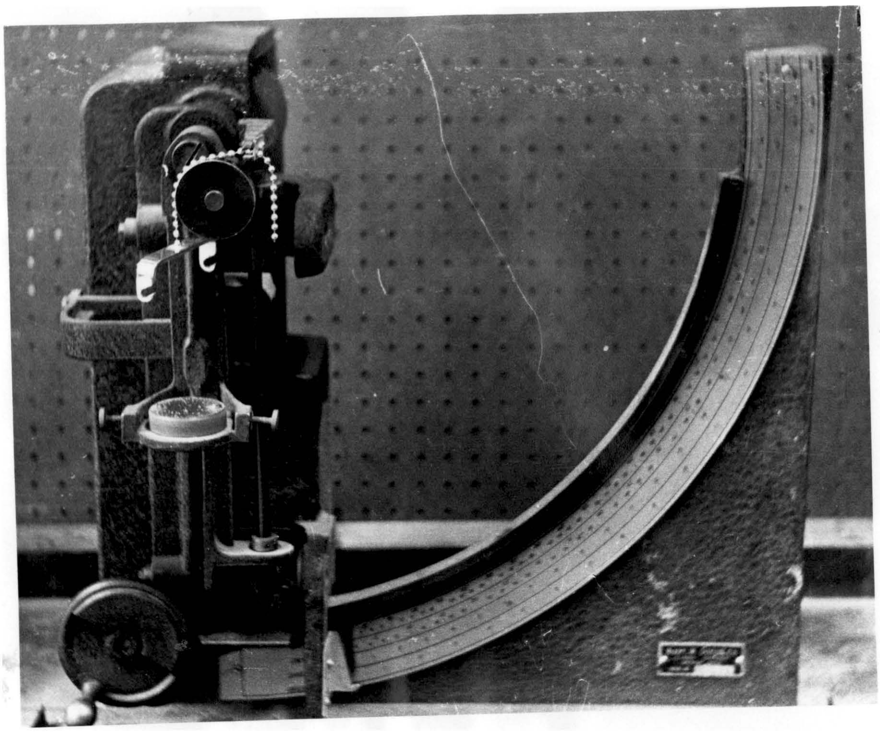


Photograph 4 - REVECON REVERBERATORY FURNACE

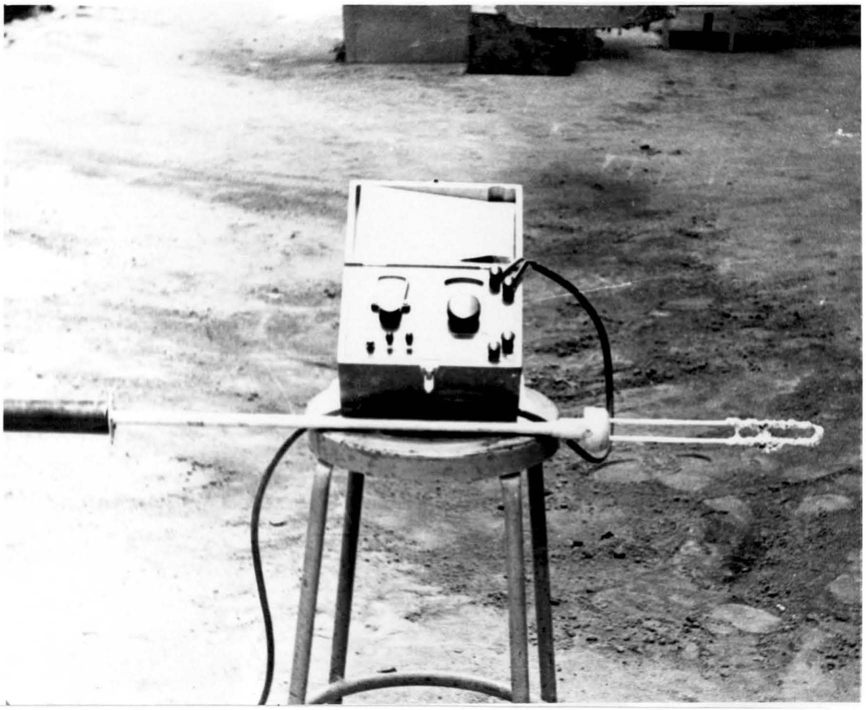
Photograph 5 - PERMEABILITY METER



Photograph 6 - GREEN COMPRESSION STRENGTH TESTING APPARATUS



Photograph 7 - GREEN TENSILE STRENGTH TESTING APPARATUS



Photograph 8 - TEMPERATURE DETERMINATION APPARATUS

ABSTRACT

Production of casting in sand molds is the basic original method employed by the foundry industry. Other methods are the results of the technological advances, but none has resulted in the extreme flexibility of the sand casting process. The control of the sand properties is important in order to produce casting of good quality.

This paper presents a limited analysis of the properties of the green molding sand and the fluidity of Aluminum-Silicon alloys in the green sand molds. The fluidity is the casting property of an alloy or metal, in a qualitative measure to completely fill the mold before it solidifies and is normally expressed as inches of flow in a small channel.

The properties of the green molding sand with change in the composition of sand viz., clay and moisture contents. The standard AFS procedure is suggested in testing the physical properties of the green molding sand. In fluidity test a standard method of molding, melting and pouring is suggested to control certain variables.

The statistical analysis of results indicates that there is no appreciable difference in the fluidity values

1. For different metal composition (Aluminum 12% silicon and Aluminum 6% silicon)
2. In green sand molds of vary composition of clay and moisture (clay 5%, 7% and 10%, moisture 5% and 7%)