THE DESIGN OF AN EXPERIMENT TO INVESTIGATE THE FLUIDITY OF ALUMINUM SILICON ALLOYS IN CARBON DIOXIDE CURED MOLDS

by

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ABSTRACT OF THESIS ON
THE DESIGN OF AN EXPERIMENT TO INVESTIGATE THE FLUIDITY OF ALUMINUM SILICON ALLOYS IN CARBON DIOXIDE CURED MOLDS

The last decade has seen many new developments in the foundry industry, among them the CO_2 process for curing molds and cores. The CO_2 process consists essentially of mixing dry, clay-free, silica sand with an organic liquid sodium silicate binder, then ramming this mix into molds or core boxes and injecting CO_2 gas. The CO_2 gas reacts with the sodium silicate binder forming a silica gel which hardens rapidly in atmospheric conditions. The CO_2 molds are more resistant to metallostatic pressure and erosion than either green or dry sand molds but more expensive also. The CO_2 cores are hardened rapidly without the benefit of a baking cycle characteristic of the production of conventional organically-bonded cores. The CO_2 cores are more economically compared with other core-making processes than the CO_2 molds are compared with other sand-molding processes.

The casting property, fluidity, is a qualitative measure of the ability of a metal to completely fill a mold cavity and is normally expressed as inches of flow in a small channel. Mold material

variables, gating and flow-channel variables, and metallurgical variables, such as metal composition and the number of degrees superheat, all effect the fluidity values.

This paper presents a spiral fluidity pattern for determining the fluidity of aluminum-silicon alloys in CO_2 molds made by a standard procedure. A standardized molding, melting, and pouring procedure is suggested to control certain fluidity variables while investigating the influence of other fluidity variables. Finally, a statistical method is presented to ascertain the significance of the effect certain variables may have on fluidity. Preliminary investigations pertinent to the major objective of this paper indicate aluminum-silicon alloys are less fluid in CO_2 molds than in green sand. Investigations also indicate that certain variabilities in testing procedure which an operating foundry might encounter have no statistically significant effect on fluidity.

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II
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III
INTRODUCTION

Although the metal casting industry is one of the basic metal-working industries and originated around 4000 B.C., it has long been dependent upon craftsmen's skill, and only in relatively recent history has scientific and engineering techniques been applied to the solution of foundry problems. Among the more recent developments in the United States foundry industry has been the carbon dioxide process for rapidly and economically hardening cores.

The carbon dioxide process consists essentially of mechanically mixing clean, dry, clay-free, silica sand grains with a liquid sodium silicate binder and then purging this mixture with CO_2 gas. The chemistry involved is complex and not definitely agreed upon, but essentially an aqueous silica gel is formed which rapidly hardens in atmospheric conditions.[1-2]

As in many new developments in the manufacturing processes field, information remains to be learned about the general adaptability of the carbon dioxide process as a production tool. Advantages and disadvantages have been reported.[2-3] However, the major attributes of this process are evident when compared with the more conventional method of hardening sand cores by baking.

Many foundrymen believe the CO_2 process will supersede the older method of curing cores which involves a lengthy cycle of mixing silica sand with an organic binder, such as linseed oil, then ramming this mixture into a core box. The green core is then drawn onto a core plate or core drier and inserted into some type of oven. The organic binder polymerizes with heat and sets, developing sufficient strength to be handled and resist the liquid metallostatic pressure when the casting is poured. The carbon dioxide process offers a method of expeditiously hardening cores without expensive baking and the danger of overbaking or underbaking cores having varying sizes and shapes. The simplicity of the process may foreseeably provide the basis for developing it as a mold material for special applications and/or a replacement for more expensive techniques.

The present rocket age has stimulated the development of many new alloys and manufacturing processes to work these alloys most beneficially. Competitive enterprise has necessarily sought better economic procedures for the processing of individual designs. In the metal casting industry particularly, these economic gains are most often realized through better production methods rather than by direct material changes since the metal

cost itself is usually a very minor element in the total cost. Cleaning, finishing, and salvage costs are frequently a major portion of the unit cost. Such costs increase as the complexity of the design increases. Further, the ratio of defective product to total product is probably higher in the foundry industry than any other metal-working field. Castability is therefore pertinent and centers about a knowledge of so-called casting properties of any given alloy. Liquid steel, for example, is more dense than a liquid aluminum alloy and thus requires more precautionary molding techniques to prevent erosion in a green sand mold.

Such a casting property is fluidity which is formally 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."[4] A mold cavity of intricate design and very thin sections requires a liquid metal of high fluidity to fill the cavity before solidification occurs. Thus, when the person responsible for casting operations has the choice of two or more alloys having equivalent mechanical properties, he may make a decision between them on the basis of castability and hence fluidity.

The idea of fluidity testing is not new. Many investigations have been made over the years using varied and numerous test

patterns, mold materials, types of metals, and testing procedure as outlined in the Review of Literature. However, all investigations have one basic idea in common in that molten metal is caused to flow in some small cross-sectional flow channel. The distance metal flows before it solidifies and stops is a measure of its fluidity.

The lack of any available published information (1959) on fluidity of metals in CO_2 cured molds has motivated this author to design the testing procedure herein described. The investigation is carried out with an aluminum-silicon alloy poured into CO_2 molds made from a commercial recipe.

The aim has been toward establishing a practical fluidity testing procedure that can serve as a means of quality control for an operating foundry. It is felt that a mathematical interpretation[5] and purely experimental control of atmospheric conditions[6] is of less consequence to the operating foundryman than a simple test made on the foundry floor which has reproducibility within statistical limitations.

Investigations of fluidity in the past have generally proven that degrees superheat of the metal and method of solidification are the two metallurgical variables having the greatest influence

on metal fluidity. This fluidity investigation is therefore mainly concerned with (1) the development of usable shop control techniques on these and other influential variables and (2) the design of a simplified fluidity test pattern to ascertain the effect of the above-mentioned metallurgical variables.

The investigation is presented generally in the following manner:

A. Opening discussion on influencing variables

B. The procedure followed in carrying out the investigation

C. Analysis of results

D. Recommendations for further testing

IV
REVIEW OF LITERATURE

Excellent bibliographies on the history of fluidity testing have been prepared.[7-8-9] The period covering the earliest investigation on the flow characteristics of molten metals cast into sand molds (1902)[8] until the present time (1959)[7-8-9] has been comprehensively summarized.

Correlation between the earliest experiments carried on by different investigators was poor owing to the many different pattern designs employed, mold materials used, types of metals poured, and control techniques devised. The spiral fluidity test by Saeger and Krynitsky[10] for cast iron and by Briggs, Taylor, and Rominski[11] for steel are now accepted in America as standards for determining fluidity of ferrous metals.[8]

Fewer investigations were made on non-ferrous alloys prior to 1957 than on ferrous alloys.[8] Those reported[12-13] were either very complex and inconvenient or lacked reproducibility from test to test.[7]

A new approach in fluidity testing was developed by Adams, Ragone, and Taylor[6] whereby the liquid metal was drawn into a pyrex glass tube by means of a vacuum. Variables of this test

were determined experimentally and analytically using low-melting point alloys. Later, investigations have employed this method in precise determination of the fluidity of aluminum alloys.[14]

Recent work by Adams, Ragone, and Taylor[5] seeks to generalize fluidity variables by a mathematical interpretation based on physical properties. Such an analysis would seem to equate experimental differences in results but may be of little practical value to the operating foundryman in determining fluidity.

One of the latest investigations of fluidity by Conrad, Flemings, and Taylor[8] introduces a new, simplified pattern to test the fluidity of aluminum alloys and evaluate the effects of mold treatments. They found fluidity can be considerably improved by the proper choice of mold coatings.

A general treatment of the CO_2 process essentials has been given by Atterton.[1] Some advantages and disadvantages of the CO_2 application are enumerated by Huss.[2] Various properties of the organic sodium silicate binder have been evaluated;[15] the effect of numerous additives on CO_2 mold properties have been investigated;[16-17] and the influence that variations in curing techniques have on mold strength has been studied by Wulff.[18]

The literature available, particularly that published since

1946, offers excellent material on the history of fluidity testing and the CO_2 process in general. At the time this thesis work was started (1959), there were no reported investigations on fluidity of aluminum alloys in CO_2 cured molds. To the author's knowledge, there has been nothing published yet (1960). Further, fluidity test patterns for non-ferrous alloys have not been standardized and none are available commercially.

V
DISCUSSION ON FLUIDITY VARIABLES

The pertinent variables in a fluidity investigation may be grouped into three arbitrary classifications: Metallurgical Variables, Test Pattern Variables, and Molding Variables. The following detailed listing and discussion of these variables will indicate the complexity of the fluidity investigation. However, the most convenient interpretation of fluidity for the operating foundryman is an empirical one and the fluidity value is an integration of several variables. Fortunately, theory has been advocated and generally proven[9] that, of the metallurgical factors, metal composition and degrees superheat are the two most prominent factors affecting fluidity. To investigate these two factors effectively, one must standardize molding techniques and stabilize the test pattern variables with proper pattern design.

A. Metallurgical Variables

The known metallurgical variables in a fluidity study are as follows:

Metal Composition (The mode of solidification and crystallization)

Degrees Superheat

Surface Films

Suspended Inclusions

Gas Content

Viscosity

Surface Tension

Inclusions Precipitating during Freezing

1. Metal Composition

In order of decreasing fluidity, one may list pure metals, eutectic compositions of alloys, alloys having narrow solidification ranges, and alloys having wider solidification ranges. Verification of this may be reasoned as follows: Pure metals freeze at constant temperature and therefore have a solidification interval of extremely short time duration dependent upon the latent heat of fusion for the particular type metal. Practically, the total time for liquid to solid transformation involves the volume of metal and heat transfer rate. However, the mechanism of freezing is the important consideration here. The so-called mushy stage of solidification whereby projecting grains of solid metal are surrounded by still-liquid metal does not exist for pure metals. The freezing of a stream of pure metal within a flow channel is initiated at the outside surface of the stream contacting the mold wall. Freezing of this

pure metal is a gradual inward growth of a relatively smooth solid-liquid metal interface which offers little impedance to flow of the still-liquid interior.

Eutectic compositions of alloys exhibit a similar freezing mechanism as the pure metals in that the liquid alloy freezes isothermally, or synonymously, at a constant temperature. There is no surface of demarcation between liquid and solid as clearly evident as when pure metals freeze. The solid progresses toward the higher energy order liquid in a wavelike manner thus offering more frictional resistance to fluid flow than the characteristically smooth solid-liquid interface of the pure metal.[19]

An alloy having a solidification range is characterized by the first solid nuclei forming at some temperature and complete solidification being consummated at some lower temperature. The freezing of a stream of such an alloy within a flow channel again originates at the contact surface between metal stream and mold wall. A thin layer of fine-grained metal is first formed. Grain growth is inhibited due to the initial rapid heat transfer from metal to mold material. The thermal gradient soon diminishes and solidification progresses inwardly by solid metal fingers called columnar dendrites, preferentially oriented perpendicular to the

mold wall. This step in the freezing process has been termed the mushy stage and identifies a network of solid dendrites surrounded by liquid metal near its freezing point. Thus, the irregularities of the solidifying network offer physical and frictional obstacles to fluid flow of the still-liquid interior. With alloys having wider solidification ranges, the physical and frictional obstacles have a more pronounced deleterious effect on fluid flow.

2. Degrees Superheat

The liquidus temperature of a particular metal or alloy means the temperature above which the alloy is always in the liquid state. The degrees of superheat means the number of degrees temperature above the liquidus temperature.

Disregarding the effect variable temperatures may have on other factors, such as gas absorption by the liquid metal and surface tension, it is reasonable to expect that metal which is heated to a higher temperature above liquidus will have a longer period in the mold as a liquid, hence it will flow farther than metal not so highly heated.

Fluidity is extremely sensitive to temperature changes, and the accurate determination of the temperature of the liquid metal as it enters the pouring basin is critical. The control

of temperature is treated more fully in Section VI. D. of this thesis.

3. Surface Films

Some oxide films, such as iron oxide on molten steel will "wet" molding sand, enhancing capillary action and increasing fluidity values. On the other hand, the tough aluminum oxide Al_2O_3, is very rapidly formed by contact of the liquid aluminum melt with the foundry atmosphere. This oxide possesses a surface tension value greater than the pure aluminum or aluminum alloy. This high surface tension opposes capillary action and retards flow in a small channel. The melting point of the oxide is near 4000°F which is considerably higher than that of the parent aluminum alloy, and the oxide will therefore not dissolve in the molten stream.

Since the thickness of the oxide coating is a function of exposure to the atmosphere, the foundryman may control this variable by skimming the liquid alloy in the ladle just prior to actual pouring and then proceeding with a fast pouring rate. A bottom pour ladle may also be used but was not used for this investigation.

4. Suspended Inclusions

"Suspended inclusions are known to increase the resistance to flow of a fluid when these inclusions are present in sufficient quantity."[20]

The aluminum oxide film may become broken by turbulent flow through the gating system, become entrapped, serve as an obstruction in the flow channel and result in premature solidification.

The effect of this variable is qualitative, and the foundryman should strive toward eliminating its influence. Using a clean ladle, skimming the liquid alloy in the ladle just prior to pouring, a fast pouring rate, and proper fluidity pattern design are means used to counter this variable and attain reproducibility of fluidity values from test to test.

5. Viscosity

"Viscosity, the internal friction of a flowing metal, has long been suspected as a factor influencing fluidity. More viscous metallic alloys should flow more slowly (and be less fluid) than alloys of lower viscosity. In reality, the viscosity of metals is very low and differences in viscosity with changes in temperature and composition are not great. It is generally agreed today that variations in viscosity have a negligible effect on fluidity." [20]

6. Surface Tension

The cohesive forces of a liquid metal, surface tension, trys to confine the surface into the smallest volume to

surface area relationship. These forces tend toward restricting the flow of a metal stream into a small channel.

True surface tension is not an important factor in determining metal fluidity since the magnitude of its potential effect can be calculated to be quite small in ordinary size flow channels.[20]

The presence of some aluminum oxide film formed on the leading tip of an aluminum-silicon alloy flowing into a fluidity spiral will overshadow any effect surface tension may have on fluidity. Again from the foundryman's standpoint, this variable will have a qualitative effect and is of little consequence.

7. Inclusions Precipitating during Freezing

An example of alloys which precipitate a solid inclusion during the freezing process are the hypereutectic iron-carbon alloys. These alloys, on cooling through the solidification range down to about 2100°F, will precipitate exceedingly coarse graphite flakes. These flakes are called "kish" and float to the top of the liquid melt.[21] The "kish" particles thus serve as nuclei for solid metal grains and also as a physical obstruction to fluid flow through a small channel.

This particular variable is not pertinent to the

fluidity testing of the binary aluminum-silicon alloys because no similar inclusions precipitate during the freezing process.

8. Gas Content

Most commercial metals will dissolve gases from the atmosphere if time permits. The solubility of the gas varies as the square root of gas pressure above and around the metal.[22] The solubility of the gas in solid metal is considerably less than the solubility of the gas in liquid metal.[22-23] Therefore, the atomically dissolved gas tends to evolve molecularly leaving behind gas holes, the number varying with freezing time.[22]

Hydrogen, oxygen, and water vapor which dissociates forming hydrogen and hydroxyl ions are the main considerations when pouring aluminum alloys. The oxygen reacts rapidly with the liquid aluminum alloy surface forming the tough refractory oxide, Al_2O_3, and little or no oxygen gas is absorbed into the metal underneath. Hydrogen is absorbed readily into the liquid melt and is therefore the gas of major importance when pouring aluminum alloys.[22]

The correlation between gas content and fluidity is nebulous and any reasoning is done on a qualitative basis. One can infer that metal flowing in a channel may be separated from the channel wall by a thin layer of gas thus slowing down the heat transfer rate, prolonging solidification, and increasing fluidity.

The evolution of the hydrogen gas from a moving stream may also break up oxide films or prevent the formation of them thus improving fluidity. This is doubtful, however, in the case of the tough aluminum oxide. At any rate, for fluidity testing, an effort can be made by the foundryman to control this variable, and a suggested method is outlined in Section VI. D. of this thesis.

A somewhat different viewpoint is that gas may prevent metal from flowing into a channel unless the mold material has sufficient permeability to allow the escape of the gas. Proper molding techniques and/or pattern design will eliminate the possibility of this back pressure.

B. Test Pattern Variables

During the past, correlation between fluidity tests carried out by different investigators has been poor because of the variations in test pattern design and the variations in testing procedure. For investigating the fluidity of aluminum-silicon alloys in CO_2 molds, it is felt a spiral design patterned after that used by Briggs, Rominski, and Taylor[11] will most closely approximate actual foundry conditions. The pattern used by this author follows these general design features and dimensions fall within those suggested by Clark[7] and hereinafter discussed.

Once the pattern is made within the specified limits,[11-7] all of the following variables, with the exceptions of pouring rate and pouring height, are fixed:

Pressure Head

Energy Losses due to Turbulence in Flow

Cross-sectional Area of the Flow Channel

Cross-sectional Shape of the Flow Channel

Pouring Basin Design

Pouring Rate

Pouring Height

1. 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.

A constant pressure head is maintained on the metal in the gating system by incorporating an overflow well of sufficient size into the gating design as depicted in Sketch 1 of Appendix A. The pressure head is concurrently standardized by a pressurized gating system design. That is, the sprue is filled with metal much more rapidly than it can run out into the flow channel.

Although increasing pressure heads increase fluidity,[20]

a short tapered sprue giving a low pressure head from one to two and one-half inches minimizes sand erosion at the bottom of the sprue and reduces turbulence of flow. A fast pouring rate in a pressurized system eliminates any vortex effect at the sprue mouth and consequent air aspiration into the mold cavity.

2. Energy Losses Due to Turbulence in Flow

The recommended ratio of cross-sectional areas of downsprue base to flow channel ingate should be approximately six to one.[7] The sprue is quickly filled; the velocity of metal just before it enters the channel is low; and turbulence is reduced. Turbulence also can be reduced by providing a basin at the bottom of the downsprue. In general, streamlining of the gating system will reduce energy losses and result in more consistently predictable results.[24]

3. Cross-sectional Area and Shape of the Flow Channel

"The effect of channel size on length of flow of a molten metal is readily apparent; small cross sections result in shorter flow. This is so because solidification is more rapid in smaller cross sections and probably also because the effect of certain resistance to flow (such as surface tension, surface films, and others) become of more relative importance in smaller channels."[20]

"Since the practical value of a fluidity test is mainly relative, it appears that the cross-sectional shape makes little

difference except for the ease with which the pattern is molded. A half-round or trapezoidal section having a cross-sectional area between 1/12 and 1/7 inch^2 is believed to be the most practical." [7]

4. Pouring Basin Design, Pouring Rate, and Pouring Height

The kinetic energy of the liquid metal going into the gating system can be increased by increasing the pouring height and turbulence of flow will be enhanced. Splattering of the metal may result in cold shots and oxide inclusions. Erosion of the mold may cause sand inclusions. All of which will cause erratic fluidity results. The distance from pouring lip to pouring basin should be short and consistent from test to test. Discrepancies in pouring height from test to test are compensated for by providing a pouring basin sufficiently large and streamlined to dissipate some of the kinetic energy of the liquid metal before it enters the downsprue. The pressurized gating system design will further control this variable. In addition, the use of an overflow well to insure a constant pressure head on the liquid metal going into the flow channel practically eliminates this factor as a variable in fluidity testing.

More consistent results in fluidity testing are obtainable if the pouring rate from ladle to mold cavity is controlled

by a stop watch. The pouring rate should be initially slow as the pouring basin fills up to the mouth of the downsprue and then very rapid and continuous as the metal flows into the downsprue. Again, the pouring rate may be controlled by using a pressurized gating system.

To compensate for these variables, elaborate systems have been devised such as the use of a fusible plug at the top of the downsprue which burns out after the pouring basin has been completely filled.[9] Difficulties with other variables arise, however. This author feels the operating foundryman can obtain worthwhile and satisfactory results using the precautions discussed above and in general following the testing procedure outlined in this thesis.

C. Mold Material Variables

There are many possible groups of molding materials that can be used, such as green molding sands, dry molding sands, metals, graphite, investments, and others. The variations one can make within each group are also numerous. For example, in the metal classification, one could have plain low carbon steel, high alloy steel, aluminum alloys, etc. For green molding sands, one can vary the moisture content, binder content, and amount of additives.

The possible combinations of variables are practically infinite and considerably beyond the scope of this thesis.

It is quite evident, however, that the type of molding material will have a definite influence on fluidity. Assuming other fluidity variables equivalent, a metal mold material has a higher thermal conductivity than a green sand mold material, solidification thus occurs more rapidly, and fluidity values will be comparatively lower in metal molds than in green sand molds.

To compensate for mold material variables in the investigation of metallurgical variables, it is only necessary to establish a standard combination of ingredients and method of molding, then control these from test to test. If the effect of one mold material factor is to be investigated, it can be varied and the others controlled.

Some work on fluidity in green sand molds has been done[11] and it is reported[20] that variations in grain size, moisture content, and permeability are of no significance in determining fluidity.

The molding material and method of molding parameters peculiar to the CO_2 process which may be varied are:

Amount and Type of Binder (usually organic liquid sodium silicate)

Amount and Type of Additives

Mulling Cycle Time and Method

CO_2 Gassing Time and Method of Application

CO_2 Gas Pressure

Temperature of CO_2 Gas

Mold Curing Time

VI
THE INVESTIGATION

The plan was to first make a suitable fluidity spiral pattern, then justify the need for designing the fluidity experiment by comparing the fluidity of aluminum alloys in green sand molds with the fluidity of the same alloys in CO_2 molds. The next portion of the investigation was devoted to experimentation with the fluidity testing procedure in an effort to isolate minor foundry testing variabilities so that an effective method of procedure could be set up. The suggested procedure and pertinent comments follow in the Final Investigation section.

A. Production of the First Test Pattern

1. The Drag Half

The spiral fluidity pattern was designed after that used by Briggs, Rominski, and Taylor[11] with dimensions within the limitations suggested by Clark.[7]

Two straight three and one-third foot sections of white pine lumber were prepared with a trapezoidal cross-section. The wooden patterns, incorporating a double solid shrinkage allowance for a lead alloy and an aluminum alloy and a machining allowance, are the first step in making the spiral portion of the total pattern.

The wooden patterns were used to prepare a green sand mold that was poured with a lead alloy. The two lead alloy strips were then soldered together and cut to a 66-inch length. The lead alloy strip was placed on a wooden pattern mount with the base of the trapezoid down. One end of the strip was centered on the pattern mount and anchored in place.

The ductile and malleable lead alloy strip was then bent against one-half inch wooden spacers to progressively form the spiral. The spiral was then "caged" with small nails to prevent slippage on the wooden pattern mount and the assemblage transferred to a drill press. Small holes were drilled intermittently through the lead alloy strip and small nails (without heads) were used to anchor the spiral to the mount. Beeswax was used to fill any cavities and the nail "cage" removed.

A slightly tapered wooden dowel pin was glued to the pattern mount near the ingate of the spiral. This dowel pin provided for the basin at the bottom of the downsprue which reduced the kinetic energy and turbulence of the liquid stream. The ingate of the flow channel was streamlined to the downsprue basin by using beeswax. A small circular piece of wood was glued to the mount at the end of the spiral to provide for the

later location of a vent pin. The vent at the end of the spiral prevents any chance for mold gases to exert any back pressure on the flowing stream. The final step in this stage of pattern development was to lay off two-inch increments around the pattern and indent the spiral at these points with a punch.

The mounted drag half of the pattern was used to prepare a second green sand mold spiral cavity into which an aluminum - 12 percent silicon alloy was poured. After shake-out, this spiral was machined to final size and smooth surface finish.

This aluminum alloy spiral pattern was mounted on the metal jolt table of a jolt squeeze rollover pattern-draw machine by means of countersunk screws. Depressions were filled in with beeswax thus completing the patternmaking and mounting for the drag half of the pattern.

2. The Cope Half

The cope half of the pattern consisting of the pouring basin and downsprue was first made of wood with dimensions similar to that of the aluminum alloy pattern depicted in Sketch 1 of Appendix A. (The overflow well was added to the pattern after the second preliminary investigation.) The pattern allowances were for the solid shrinkage of the aluminum alloy, draft allowance on

the pouring basin and a finishing allowance.

The wooden pattern was used to prepare a green sand mold cavity into which an aluminum - 12 percent silicon alloy was poured for the final pattern.

The aluminum alloy pattern was surface finished, and a hole was drilled through the center of the downsprue. A shaft, with handgrip, was turned to fit the pattern hole and threaded on one end. A corresponding hole with internal threads was machined at the proper location (to align the downsprue with the downsprue basin and flow channel ingate) on the metal jolt table of the jolt squeeze rollover pattern-draw machine. This feature enabled the cope half of the pattern to be drawn by hand each time a mold cope half was made. The final step in mounting the cope half of the pattern was to prepare a metal vent pin threaded at one end and to machine a corresponding internally threaded hole on the machine jolt table. This location aligned the vent with the end of the spiral flow channel in the drag. The vent pin could also be drawn after each cope half was molded. Photographs 1 and 2 of Appendix C illustrate the patterns used in this investigation of fluidity.

B. First Preliminary Investigation

1. Fluidity in green sand molds versus fluidity in CO_2 cured molds.

A brief preliminary investigation was made comparing fluidity values (measured in inches of flow) of aluminum and aluminum alloys poured into green sand molds with those of the same metals poured into CO_2 molds to establish that the differences in molding materials would affect fluidity. Alcoa aluminum pig of 99.85 percent purity and an aluminum alloy of approximately 50 percent silicon analysis were used for these initial tests. As in all of the liquid metal investigations of this thesis, melting was done in an oil-fired Revecon reverberatory furnace using a direct neutral flame. Molding was accomplished on a jolt squeeze rollover pattern-draw machine. The data and results of this investigation are recorded and discussed in subsequent sections of this thesis.

The green molding sand ingredients were AFS 103 silica sand, 18 percent clay binder, and 7.4 percent moisture. A basic CO_2 mix of 4 percent (by weight) liquid organic sodium silicate binder and AFS 60 clean, dry, clay-free, silica sand was used.

The results of this investigation were not conclusive owing to poor control of variables. The pouring rate varied considerably. Temperature control with a lance-type

pyrometer was poor. The pouring basin had no overflow well thus allowing a fluctuating pressure head. The tests were generally indicative; however, that fluidity was considerably less in the CO_2 molds.

The results of this first preliminary investigation are shown in Table I and Table II of Appendix B.

C. Second Preliminary Investigation

The first preliminary investigation justifiably showed that fluidity values in CO_2 molds were less than the fluidity values obtained in green sand molds under equivalently controlled testing procedures.

The second preliminary investigation was the pouring of an aluminum - 12 percent silicon alloy into CO_2 molds to gain general background information about the fluidity in CO_2 molds to effectively standardize the overall procedure.

Foundry floor testing variabilities were simulated in an effort to isolate minor fluidity factors from the major ones. The anticipated foundry floor variables being (1) small differences in pouring rates, (2) small differences in mold curing time, and (3) remelting of alloy. The major fluidity factors being (1) degrees superheat, and (2) mode of solidification.

The eutectic alloy of aluminum - 12 percent silicon was poured into six different groups of CO_2 molds prepared under the same standard conditions from a basic mix of 4 percent liquid organic sodium silicate binder and AFS 60 dry, clay-free, silica sand.

Each group of test molds consisted of five molds poured at temperatures of 1450°F, 1375°F, 1300°F, 1225°F, and 1150°F. The degrees superheat being 360°F, 285°F, 210°F, 135°F, and 60°F respectively. The temperatures were determined by a chromel-alumel thermocouple in a lance-type pyrometer. The same test pattern was used as in the first preliminary investigation. The aluminum alloy was melted in a Revecon reverberatory furnace using a direct neutral flame, and the same degassing cycle repeated from batch to batch.

Five groups of CO_2 molds were poured approximately two hours after CO_2 injection, whereas one group of molds was poured twenty-four hours after gassing. Fluidity was not noticeably affected by the difference in these short cycle curing times.

Four groups of molds were poured with new Alcoa aluminum - 12 percent silicon pig, and two groups were poured with the remelt of these fluidity spirals. Fluidity was not noticeably

affected by the remelting of the new alloy pigs, i.e. any compositional change due to remelting was negligible in effect on fluidity.

The pouring of the test molds was done randomly by different operators, and the times were recorded. The fluctuations in pouring times were within .03 minutes and .09 minutes. Small differences in times of .01 and .02 minutes had little effect on fluidity, but larger differences in pouring times did have. The faster the pouring rate, the greater the fluidity.

The results of these pours are recorded in Table III-A of Appendix B and general remarks in Table III-B of Appendix B. As mentioned previously, actual foundry floor testing conditions were simulated, and some interaction between minor variables occurred due to nonrigid control of all variables except the one being investigated. It was learned that small changes in these minor variables had little effect on fluidity even though not rigidly controlled.

After this second preliminary investigation was made, the experimental design was altered by the following:

1. Overflow well was added to the pouring basin.
2. New mold ingredients were selected.
3. A different method of determining pouring temperatures was used.

4. Pouring rates were controlled more effectively.

The final investigation, incorporating the above listed changes, and suggested method of procedure follows as outlined:

1. Addition of Overflow Well to Pattern
2. Ingredients and Preparation of Ingredients
3. Comments on Molding Procedure
4. Preparation of Molten Metal and Pouring
5. Temperature Control

D. Final Investigation

1. Addition of Overflow Well

In the preliminary investigations, it was believed that some of the variance in fluidity was attributable to varying pressure heads on the metal going into the flow channel. An overflow well was therefore added to the pouring basin. A wooden pattern of the overflow well was made and glued to the original wooden pattern of the gating system. Then an aluminum - 12 percent silicon alloy composite pattern was made. The completed pattern is shown in Sketch 1 of Appendix A.

2. Ingredients and Preparation of Ingredients

a. Ingredients

(1) Liquid organic sodium silicate (4.0 percent) was the binder.

(2) Molasses (1.0 percent) was added to promote collapsibility.

(3) Pitch (1.0 percent) was added to prevent metal penetration and improve surface finish.

(4) Corn flour cereal (0.5 percent) was added to improve green strength and cushion sand expansion.

(5) Calcined clay (Satintone) (1.5 percent) was added to promote dry strength.

(6) AFS 60 dry, clay-free, silica sand was used.

b. Preparation of Ingredients

All ingredients were weighed individually on a portable Fairbanks scale. The dry ingredients (silica sand, pitch, corn flour, "Satintone") were charged into a muller and mixed for one minute. The wet ingredients (sodium silicate and molasses) were then added, and the composite was mulled for an additional five minutes. The batch should not remain exposed to the atmosphere long for it will very quickly begin to harden unless covered with a moist cloth.

3. Comments on Molding Procedure

a. Machine Cycle

The mix from the muller was then loaded into flask halves and around machine-mounted aluminum alloy patterns

and vent pin, all previously lightly lubricated with kerosene to facilitate parting. The mold halves were then mechanically jolted 30 times and peen-rammed in flask corners. The average permeability determined by standard AFS test was approximately 150. After jolting, additional molding sand was heaped in the flask halves, struck off, and a small amount of mix sprinkled on top of each half to prevent sag of mold during pattern-draw cycle. The cope half of the pattern and the vent pin were unscrewed from jolt table, rapped, and drawn. The squeeze board was positioned and clamped, and the mold was rolled over and squeezed. The patterns were drawn, and the mold halves were removed from the machine.

b. CO_2 Injection and Mold Storage

(1) CO_2 Injection

The mold halves were separately cured with a CO_2 kit shown in photograph 4 of Appendix C. The commercial carbonic gas was injected into each mold half with a line pressure of 40 psi, through a rubber cup, at five locations (four corners and center) for .05 minutes at each location.

(2) Mold Storage

After the CO_2 gassing cycle, the mold halves were aligned, clamped, and a cover board was placed over

the pouring basin. The completed molds were stored until poured on a flat concrete floor to minimize leveling discrepancies. The molds were stored approximately two hours before pouring was done. They were continuing to cure at the time of pouring according to Lange and Morey.[15] Lange and Morey also report that the CO_2 molds will develop a peak strength over some period of time and then undergo deterioration due to the absorption of moisture from the atmosphere by the hygroscopic mold material. This complete time cycle is very lengthy and not applicable to this investigation of fluidity.

4. Preparation of Molten Metal and Pouring

a. Charging of Furnace

The Revecon oil-fired reverberatory furnace was preheated for a period of thirty minutes to a temperature of approximately 1800°F. About ten pounds of new Alcoa 99.85 percent pure aluminum was charged onto the hearth through the tapping spout and approximately fifty pounds of the same kind of pig was charged through the stack opening. One-half pound of commercial aluminum cover flux was charged into the furnace at the same time. The direct flame was adjusted to a neutral one. The tapping spout was closed.

b. Degassing of Melt

The metal was melted and superheated to 1850°F in approximately thirty minutes. The furnace was shut off.

The tapping spout was opened, and one commercial solid chloride-base degassing tablet was submerged in the melt. The submerged tablet was moved slowly around in the melt by a perforated gray iron container with shank handle. The decomposition of the solid tablet liberated chlorine gas which reacted with and served to remove hydrogen from the melt. The melt then was allowed to lay for three minutes.

After the three-minute cycle, one-half pound of aluminum cover flux was thrown onto the surface of the melt and slowly "chopped" into the melt. A second degassing tablet was added to the melt in the same manner as in the first step. After decomposition of this second tablet, the melt was again allowed to lay for three minutes. The melt was then skimmed in the furnace and poured into a small shank-type transfer ladle which had been previously cleaned and preheated. This procedure was rigidly followed from batch to batch to foundry-control the variable of entrapped hydrogen gas and its effect on fluidity.

Approximately 200°F was lost in the degassing cycle. The furnace was cleaned with flux after each melting cycle.

c. Pouring of Molds

One heat of new pig and three heats of "remelts" were melted and poured into four groups of three molds each. The three molds of each group were poured at 1545°F, 1445°F, and 1345°F which was 300°F, 200°F, and 100°F superheat respectively. The ladle was positioned near the mold to be poured. When the temperature had dropped to the correct degrees superheat, the surface of the melt was carefully and quickly skimmed, then poured into the mold basin. The pouring was manually done from a controlled height and stop-watch controlled to .05 and .06 minute cycles.

After solidification, the spirals were broken out, and fluidity was measured in inches of flow.

5. Temperature Control

Since the degrees superheat and chemical composition has the greatest influence of all the metallurgical variables on the fluidity of aluminum-silicon binary alloys, the correct determination of temperature is essential. The instrument used should, of course, be accurate but also provide a quick response to temperature changes. The temperature was determined by using a

chromel-alumel thermocouple connected to a Leeds and Northrup potentiometer in this experiment.

The new chromel-alumel 22-gauge wire elements were butt-welded with a carbon arc to form the hot junction. The thermocouple elements were insulated with asbestos, ceramic, and rubber sleeves from hot junction to cold junction. The hot junction was inserted into a clean, dry, thin quartz protection tube four inches long. The protection tube assembly was then inserted through an 18-inch long steel handling tube. The protection tube was sealed into one end of the steel tube with a graphite mix which was then baked. The graphite seal excluded the atmosphere from the inside of the quartz tubing and hence eliminated oxidation of the carbon-arc-welded thermocouple joint.

The cold junction of the thermocouple was at the terminals of the indicating potentiometer, the scales of which were repeatedly checked and adjusted when necessary to compensate for room temperature fluctuations. The temperature control setup is shown by Photograph 5 in Appendix C. Initially the temperature determination was attempted by placing the quartz-protected hot junction of the thermocouple into the pouring basin but response was not rapid enough for the short pouring cycles.

The final method was to determine the temperature of the melt in the ladle and allow $10^{o}F$ for transfer of liquid metal from the ladle to the pouring basin.

VII
RESULTS

A. First Preliminary Investigation

The results from pouring both pure aluminum and foundry grade aluminum - 50 percent silicon alloy into green sand and CO_2 molds were somewhat inconsistent because of inadequate control of variables. The temperature determination was inaccurate, the static pressure head fluctuated because of no overflow well on the pouring basin, the molds were not clamped nor leveled, and the pouring rate varied.

The results, as tabulated in Tables I and II of Appendix B, did generally show that the pure aluminum was more fluid for a given degrees superheat than the aluminum - 50 percent silicon alloy, which has a wide solidification range. Secondly, increasing the degrees superheat for a given metal or alloy increases fluidity. The results also indicated that the aluminum and aluminum - 50 percent silicon alloy were more fluid in the green sand molds than in the CO_2 molds.

B. Second Preliminary Investigation

The second stage of the overall investigation was the pouring of the eutectic aluminum - 12 percent silicon alloy into

CO_2 molds made with standard basic ingredients. The results are tabulated in Table III - A and Table III - B of Appendix B. The main purpose here was to collect fluidity data from molds poured by different operators at different pouring rates, from molds that had different curing cycles, and from molds that were poured with different furnace heats of the aluminum - 12 percent silicon alloy; the first heat being new pig, the second heat being the first remelt, etc. These variations supposedly simulated some of the normal variabilities that an operating foundry might have in fluidity testing.

Since this second preliminary investigation served as a pilot run to familiarize the author with the general process of fluidity testing in CO_2 molds, control of the variables was not stringent, and comparisons of fluidity factors were random. The information gained was not conclusive but enabled a more effective testing procedure to be designed and executed in the final stage of the investigation.

C. Statistical Interpretation of Final Investigation Data Handling[25]

1. Preface

The changes in the experimental design specified

in subparagraph D of the Investigation section of this thesis were made prior to the execution of the final tests.

The final tests were made in accordance with a randomized block statistical design hereinafter described. Four Revecon reverberatory furnace heats of 99.85 percent pure aluminum were poured into four groups of three molds each. Each group of three molds was poured at 300°F, 200°F, and 100°F superheat respectively. The results are tabulated as follows:

Pouring Temp. °F	°F Super-heat	Heat No. 1 Fluidity (in)	Heat No. 2 Fluidity (in)	Heat No. 3 Fluidity (in)	Heat No. 4 Fluidity (in)
1545	300	53.00	57.50	56.50	61.00
1445	200	42.00	48.50	47.75	55.25
1345	100	36.50	35.25	39.00	38.50

2. Explanation of Randomized Block Design

a. General

"Randomized blocks" designate the particular statistical design for this experiment and is the design preferred when the specimen under investigation is subjected to two or more

treatments. The term "treatment" then refers to some action on some article. In this case, a treatment means a particular degrees superheat for the 99.85 percent pure aluminum such as 300°F. In this randomized block experiment, the three molds were randomly selected within the group to be poured at either 300°F, 200°F, or 100°F superheat. Each block of the design represents a complete experiment by itself. The number of complete blocks is called the number of "replications" of an experiment. In this analysis, the replications are the different furnace heats.

Treatment 1 = 300°F superheat

Treatment 2 = 200°F superheat

Treatment 3 = 100°F superheat

Replication 1 = First melt of new 99.85 percent aluminum pig

Replication 2 = First remelt

Replication 3 = Second remelt

Replication 4 = Third remelt

b. Statistical Notations

The statistical notations and their descriptions as used in the "randomized blocks" experimental design are as follows:

k = number of treatments

n = number of replications

y = an observation

T_t = treatment total

$\bar{y}_t$ = treatment mean

T_r = replication total

$\bar{y}_r$ = replication mean

G = grand mean

$\bar{\bar{y}}$ = general mean

c. Short-cut Method of Computing the Treatment Effect and the Replication Effect on the Article, Fluidity

Step 1: Arrangement of Data

	Treatment 1	2	3	Repl. Total T_r	Repl. Means $\bar{y}_r$	Repl. Effects $\bar{y}_r - \bar{\bar{y}}$
Repl. 1						
Repl. 2						
Repl. 3						
Repl. 4						
T_t						
$\bar{y}_t$						
$\bar{y}_t - \bar{\bar{y}}$						

Step 2: Preliminary Calculations

PRELIMINARY CALCULATIONS					
(1)	(2)	(3)	(4)	(5)	
Type of Total	Total of Squares	No. of Items Squared	No. of Observations per Squared Item	Total of Squares per Observation (2) ÷ (4)	
Grand	G^2	1	kn	G^2/kn	(I)
Replication	ΣT_r^2	n	k	$\Sigma T_r^2/k$	(II)
Treatment	ΣT_t^2	k	n	$\Sigma T_t^2/n$	(III)
Observation	Σy^2	kn	1	Σy^2	(IV)

Step 3: Analysis of Variance

Source of Variance	Sum of Squares SS	Degrees of Freedom DF	Mean Square MS	F
Replication	(II) - (I)	n - 1	$\frac{SS}{DF}$	$\frac{MS_r}{MS_e}$
Treatment	(III) - (I)	k - 1	$\frac{SS}{DF}$	$\frac{MS_t}{MS_e}$
Error	(IV)-(III)-(II)+(I)	(k-1)(n-1)	$\frac{SS}{DF}$	
Total	(IV) - (I)	kn - 1	$\frac{SS}{DF}$	

Step 4: Test of hypothesis that the treatment effects on fluidity are equal. Test of hypothesis that the replication effects on fluidity are equal.

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

$$F = \frac{\text{treatment mean square}}{\text{error mean square}}$$

with (k - 1) and (k - 1)(n - 1) degrees of freedom is used.

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

$$F = \frac{\text{replication mean square}}{\text{error mean square}}$$

with (n - 1) and (k - 1)(n - 1) degrees of freedom is used.

These ratios follow a particular F-distribution curve defined by the number of degrees of freedom that curve has. The F-distribution is a family of curves varying with number of degrees of freedom.

For the "randomized block" design, any observation can be expressed as the sum of the (1) general mean, (2) replication effect, (3) treatment effect, and (4) error. Each partition of an observation has certain degrees of freedom. The physical meaning of degrees of freedom can best be illustrated by

an example. Assume k treatment effects. Since the sum of the k treatment effects is equal to zero, if (k - 1) treatment effects are known, the remaining one is automatically determined. There are then (k - 1) degrees of freedom for the treatment effect distribution.

Assume some F-distribution curve exists representing either the statistic

$$F = \frac{\text{treatment mean square}}{\text{error mean square}}$$

or

$$F = \frac{\text{replication mean square}}{\text{error mean square}}$$

The questions arise: Is the sample F-ratio indicative of the parent F-distribution curve? Within what limits can the sample F-value fall and be representative of the parent F-distribution curve? One tail-end of the total F-distribution curve is marked off for this purpose. This marked-off portion is called the critical region. When the statistic

$$F = \frac{\text{treatment mean square}}{\text{error mean square}}$$

falls within this critical region (ratio greater than 4.0 in Figure 1 below) of the F-distribution curve defined by certain degrees of freedom, the hypothesis that the treatment effects are equal to zero

is rejected. If the F-statistic fell outside the critical region (ratio less than 4.0 in Figure 1 below), then the hypothesis that the treatment effects are equal would be accepted.

By the same token, when the statistic

$$F = \frac{\text{replication mean square}}{\text{error mean square}}$$

falls within the critical region of some other F-distribution curve, the hypothesis that the replication effects are equal to zero is rejected. If the F-statistic fell outside the critical region, then the hypothesis that the replication effects are equal would be accepted.

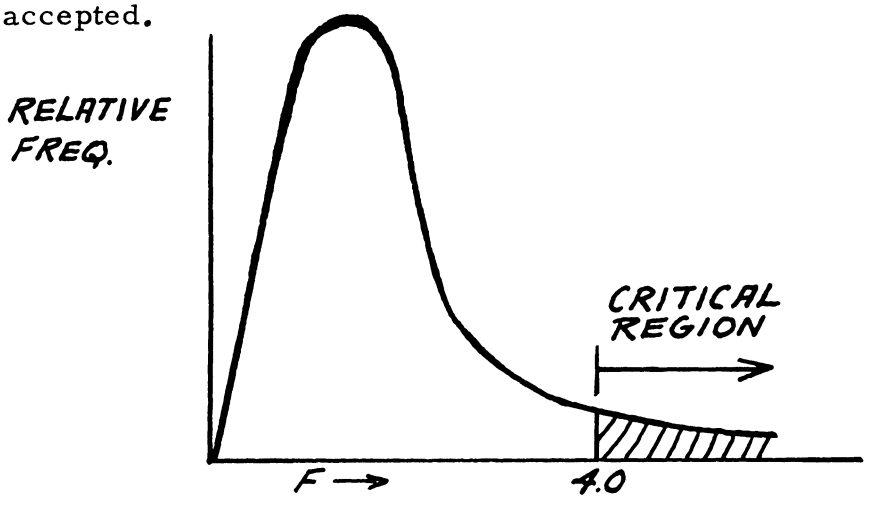

Figure 1: F-Distribution

When making an inference about a particular F-distribution curve from a given sample value, one may make an erroneous rejection of a true hypothesis. This is called a 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 that a Type I error may be made on the basis of a single sample.

Theoretically, the significance level is arbitrarily chosen, but in practice 5 percent and 1 percent significance levels are usually used and once selected determine the critical region for a particular F-distribution curve.

No attempt is made in this thesis to give the mathematical and statistical proof of the "randomized block" design and of inferences made from the calculated results. It is felt that the brief introduction here will suffice, and the reader can consult reference 25 in Literature Cited for the details.

D. Final Investigation

Step 1: Arrangement of Data

y = an observation (fluidity in inches of flow)

The treatments 1, 2, and 3 are $300^{\circ}F$, $200^{\circ}F$, and $100^{\circ}F$ superheat respectively.

The replications 1, 2, 3, and 4 are the first furnace melt, first remelt, second remelt, and third remelt respectively.

	Treatment			Repl. Total	Repl. Means	Repl. Effects
	1	2	3	T_r	$\bar{y}_r$	$\bar{y}_r - \bar{\bar{y}}$
Repl. 1	53.00	42.00	36.50	131.50	43.83	-3.73
Repl. 2	57.50	48.50	35.25	141.25	47.08	- .48
Repl. 3	56.50	47.75	39.00	143.25	47.75	.19
Repl. 4	61.00	55.25	38.50	154.75	51.58	4.02
T_t	228.00	193.50	149.25	570.75	190.24	0
$\bar{y}_t$	57.00	48.38	37.31	142.69	$\bar{\bar{y}} = 47.56$	
$\bar{y}_t - \bar{\bar{y}}$	9.44	.82	-10.25	0		

Step 2: Preliminary Calculations

(1)	(2)	(3)	(4)	(5)
Type of Total	Total of Squares	No. of Items Squared	No. of Observations per Squared Item	Total of Squares per Observation
Grand	325,755.56	1	12	27,146.30
Replication	81,711.94	4	3	27,237.31
Treatment	111,701.81	3	4	27,925.45
Observation	28,055.44	12	1	28,055.44

Step 3: Analysis of Variance

Source of Variance	Sum of Squares SS	Degrees of Freedom DF	Mean Square MS	F
Replication	91.01	3	30.34	4.67
Treatment	779.15	2	389.58	59.94
Error	38.98	6	6.50	
Total	909.14	11		

Step 4: Test of Hypothesis

Hypothesis No. 1: The treatment effects are equal to zero.

Level of Significance: The 5 percent significance level is used.

Critical Region: The critical region is that $F > 5.1433$. The number of degrees of freedom of F are 2 and 6 from the statistic

$$F = \frac{\text{treatment mean square}}{\text{error mean square}}$$

$$F = \frac{389.58 \text{ w/2 degrees of freedom}}{6.50 \text{ w/6 degrees of freedom}}$$

$$F = 59.94 \text{ w/2 and 6 degrees of freedom}$$

The calculated F value of 59.94 is greater than the critical region F value of 5.1433 and therefore lies within the critical

region of the distribution. The hypothesis that the treatment effects are equal to zero is rejected. This test indicates the different degrees of superheat ($300^{o}F$, $200^{o}F$, $100^{o}F$) have significantly different effects on the fluidity of 99.85 percent pure aluminum in CO_2 molds.

Hypothesis No. 2: The replication effects are equal to zero.

Level of Significance: The 5 percent significance level is used.

Critical Region: The critical region is that $F > 4.7571$. The number of degrees of freedom of F are 3 and 6 from the statistic

$$F = \frac{\text{replication mean square}}{\text{error mean square}}$$

$$F = \frac{30.34 \text{ w/3 degrees of freedom}}{6.50 \text{ w/6 degrees of freedom}}$$

$$F = 4.67 \text{ w/3 and 6 degrees of freedom}$$

The sample F value of 4.67 is less than the critical region F value of 4.7571 and therefore lies outside the critical region of the distribution. The hypothesis that the replication effects are equal to zero is accepted. This indicates the different furnace heats (new, first, second, third remelts) have no significant effect on the fluidity of 99.85 percent pure aluminum in CO_2 molds.

VIII
DISCUSSION OF RESULTS

The test pattern and testing procedure presented in this thesis seem adequate for the investigation of the fluidity of aluminum alloys in CO_2 molds. This conclusion is based on the statistical interpretation in the preceding Results section, wherein it was determined that the number of degrees superheat has a significant effect on fluidity, and that the number of furnace remelts has no significant effect on fluidity. The results show that increasing the number of degrees superheat for a given metal or alloy increases the fluidity. The conclusion substantiates those made by past investigations of fluidity. The results also show that the 99.85 percent pure aluminum pigs do not undergo compositional changes (due to contamination) sufficient to significantly effect the fluidity when they are melted in the Revecon reverberatory furnace. Remelting effects may therefore be disregarded as a factor influencing fluidity in this study.

Since the only fluidity factors investigated were degrees superheat and furnace melting effects, it cannot be concluded that this fluidity testing procedure is valid in investigating all fluidity factors.

The "randomized blocks" statistical design may be similarly used to investigate other treatment and replication effects on fluidity. For example, the treatments could be alloy compositions, such as aluminum - 3 percent silicon, aluminum - 6 percent silicon, and aluminum - 9 percent silicon (all molds poured at a constant degrees superheat). The replications could be the same as before or molds having different curing times. The treatments could be different sodium silicate mold binder contents (all molds poured at a constant degrees superheat), and the replications could be molds having different permeabilities.

However, when the variables under investigation have interaction or are suspected of having interaction, a factorial experimental design and analysis would be preferred.[25] Such a situation occurs when increasing the degrees of superheat of a given metal increases the solubility of gases in the liquid metal. Several treatments, replications, and interactions may be investigated together by this factorial method.

More consistent results from test to test may have resulted if a fibrous strainer core had been used at the base of the downsprue to filter out undesirable oxides and other foreign materials. Turbulence would also have been reduced.

Investigations of additional fluidity factors should be made before this method of procedure proves satisfactory for fluidity testing on the foundry floor. The results from this investigation indicate that the effect on fluidity of minor foundry variabilities, such as small differences in pouring rates, different furnace heats of a given metal, different mold curing times, etc. can be evaluated by statistical means and probably proven to be insignificant.

IX
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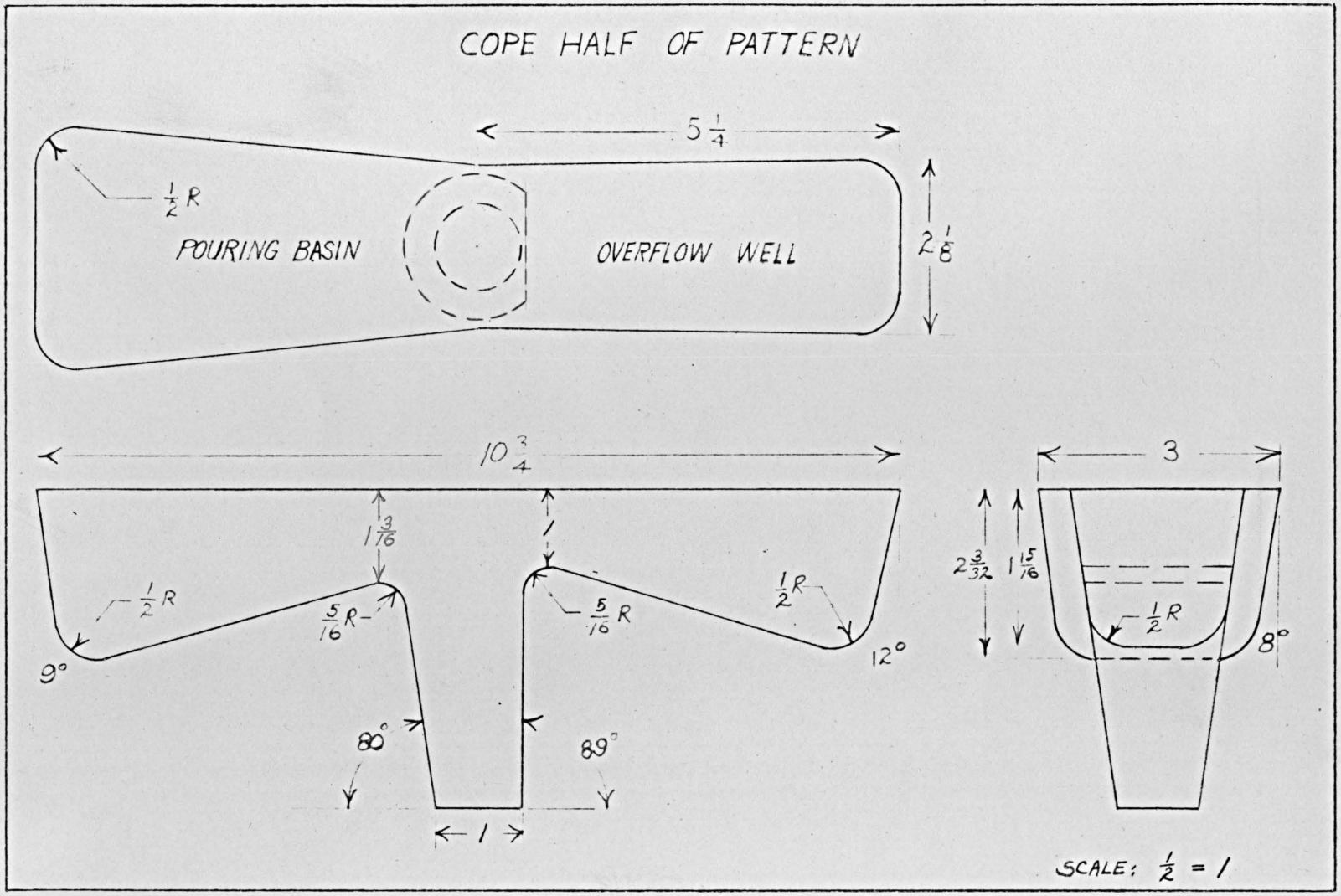
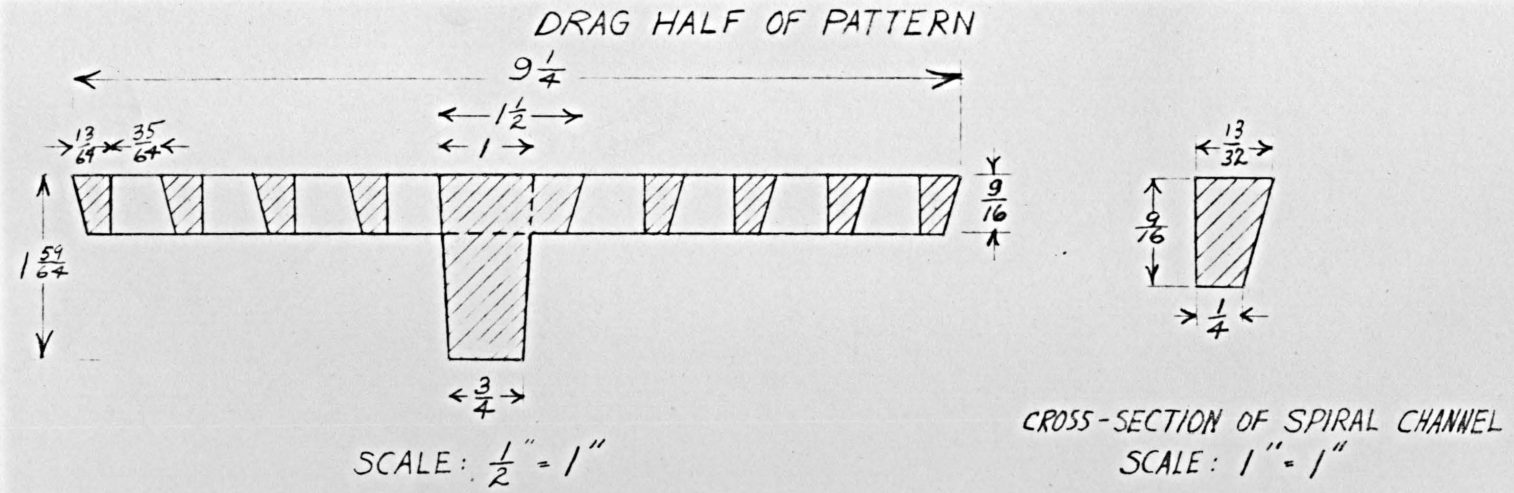
XII
APPENDICES

APPENDIX A



Sketch 1A - Cope Half of Fluidity Pattern



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

TABLE I
FIRST PRELIMINARY INVESTIGATION
Fluidity of 99.85 Percent Pure Aluminum
*Melting Point 1245°F

GREEN SAND MOLDS					CO_2 MOLDS				
Pouring Temp.(F)	Super-Heat (F)	Fluidity (inches) 1	2	3	Pouring Temp.(F)	Super-Heat (F)	Fluidity (inches) 1	2	3
1450	205	54	56	52	1440	195	35	32	32
1400	155	50	51	52					
1350	105	48	46	41(1)	1350	105	24	23	22
1300	55	32	33	36(2)	1275	35	12	8	9

(1)Slow pouring rate.

(2)Runout at parting surface.

GENERAL REMARKS: (a) The pouring rate from mold to mold was not stop-watch controlled; (b) Lance-type pyrometer for temperature determination was not correctly calibrated; (c) Molds were not clamped or properly leveled; (d) Increasing degrees superheat increases fluidity; (e) Results indicate the aluminum alloy is less fluid in CO_2 molds than in green sand molds; (f) Overflow well was not used on the cope half of this pattern and pressure head varied.

*Aluminum-Silicon Binary Diagram, Metals Handbook, 1948, p. 1166.

TABLE II
FIRST PRELIMINARY INVESTIGATION
Fluidity of Aluminum - 50 Percent Silicon Foundry Grade Alloy
*Melting Point 1915°F

GREEN SAND MOLDS					CO_2 MOLDS				
Pouring Temp.(F)	Super-Heat (F)	Fluidity (inches) 1	2	3	Pouring Temp. (F)	Super-Heat (F)	Fluidity (inches) 1	2	3
2135	220	28	28	28	2150	235	22	22	66(1)
2060	145	26	24	24	2050	135	12	14	12
1960	45	16	17	18	1950	35	12	10	18(2)
1910	-5	16	17	19	1925	10	10(2)	16(2)	8

(1)Very bad runout at parting surface.

(2)Slight runout at parting surface.

GENERAL REMARKS: (a) The pouring rate from mold to mold was not stop-watch controlled; (b) Lance-type pyrometer for temperature determination was not correctly calibrated; (c) Molds were not clamped or properly leveled; (d) Increasing degrees superheat increases fluidity; (e) Results indicate the aluminum alloy is less fluid in CO_2 molds than in green sand molds; (f) Overflow well was not used on the cope half of this pattern and pressure head varied.

*Aluminum-Silicon Binary Diagram, Metals Handbook, 1948, p. 1166.

TABLE III - A
SECOND PRELIMINARY INVESTIGATION
Fluidity of Aluminum - 12 Percent Silicon Alloy in CO_2 Molds
*Melting Point 1090°F

Pouring Temp. °F	Mold Number	VARIABLES				
		Pouring Time	New Melt (Pig)		Remelt	
			24 hr cure	2 hr cure	24 hr cure	2 hr cure
1450	1	.04	52			
	2	.04		55		
	3	.03			59	
	4	.05				59
	5	.03		61		
	6	.04		56		
1375	1	.06	49			
	2	.09		48		
	3	.04				50
	4	.06				50
	5	.03		50		
	6	.04		45		
1300	1	.04			33	
	2					
	3	(1) .04	40			
	4	.05		36		
	5	.03		44		
	6	.04		44		
1225	1	.04		27		
	2	.04		25		
	3	.04	31			
	4	(1) .05		31		
	5	.04			26	
	6	.04				27
1150	1	.04			14	
	2	.04				13.5
	3	.06	13			
	4	.06		15		
	5	.04		17		
	6	.03		18		

(1) Runout at parting line

*Aluminum-Silicon Binary Diagram, Metals Handbook, 1948, p. 1166.

TABLE III - B
SECOND PRELIMINARY INVESTIGATION

GENERAL REMARKS

(a) Variance in pouring rates seem to have little effect on fluidity when the difference in time is of such small magnitude (one-hundreths minute). However, a fast pouring rate tends toward increasing fluidity very slightly.

(b) Mold curing time within 2 - 24 hours has negligible effect on fluidity.

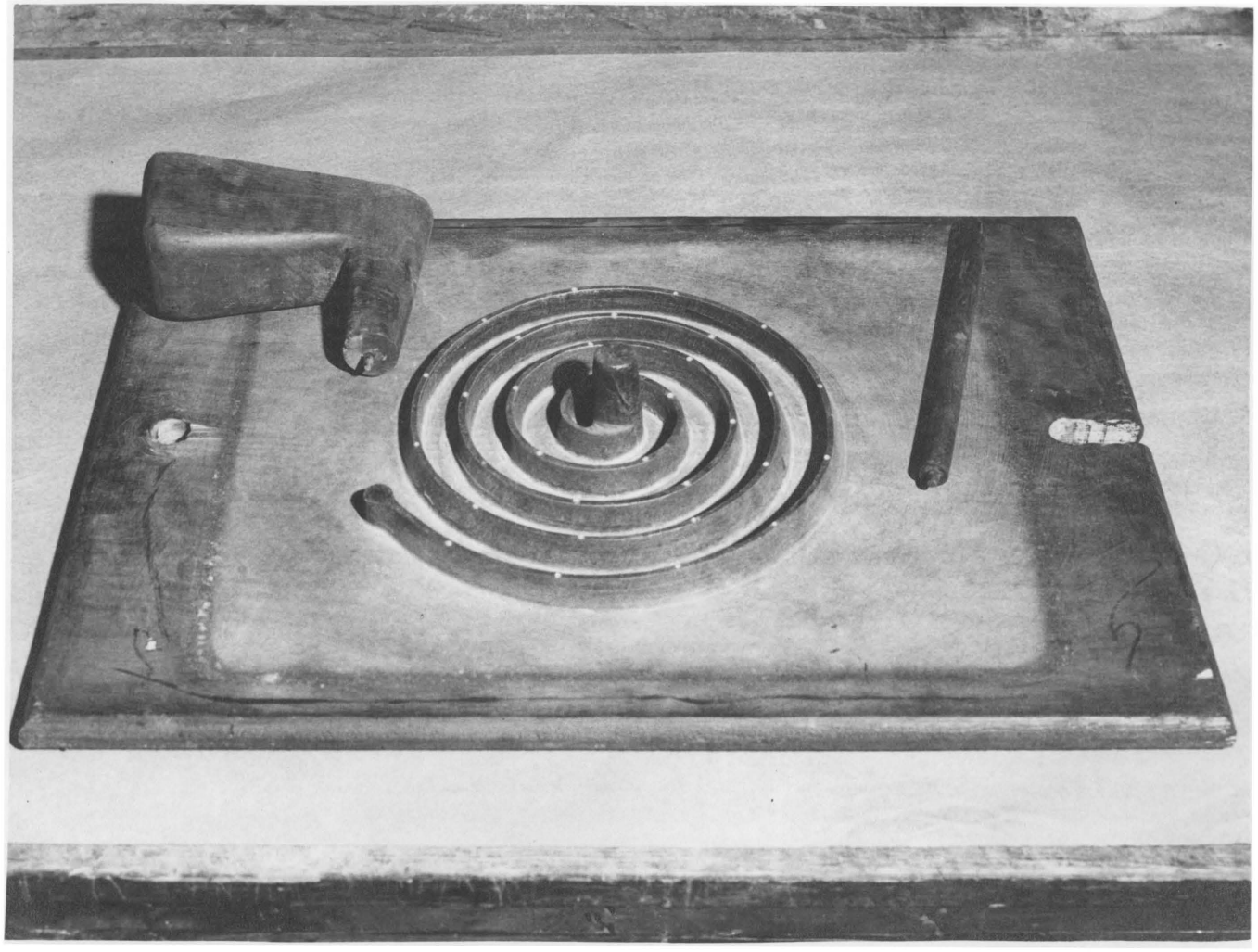
(c) The metal composition change from one heat to another is negligible.

(d) Molds were clamped, but two runouts were experienced due to mold sag at the parting surface. It is thought insufficient sand was used to back up in molding procedure allowing sag after rollover.

(e) Overflow well was not used on the cope half of this pattern, and pressure head varied.

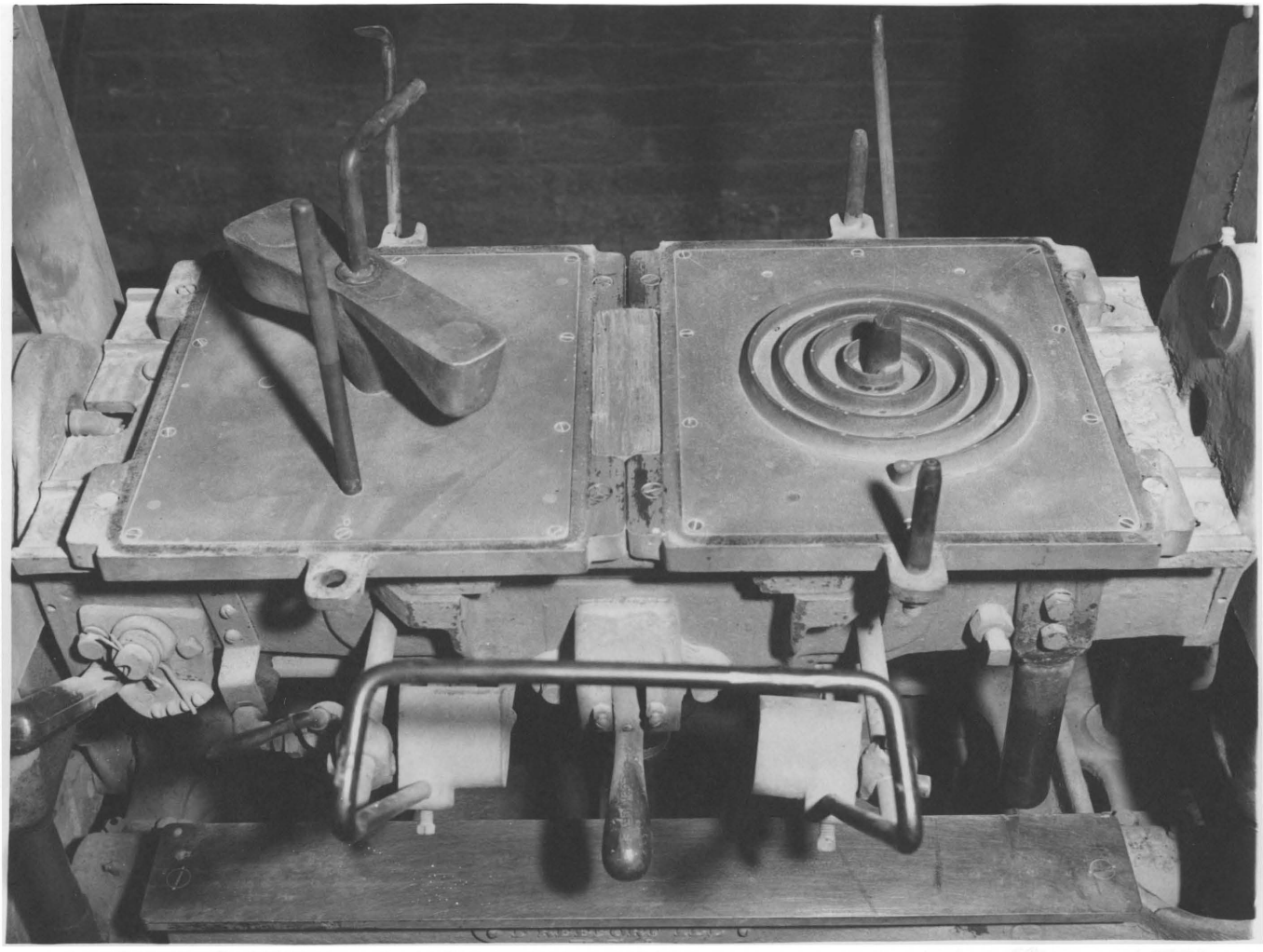
(f) Lance-type pyrometer may have been incorrectly calibrated over full temperature scale.

APPENDIX C



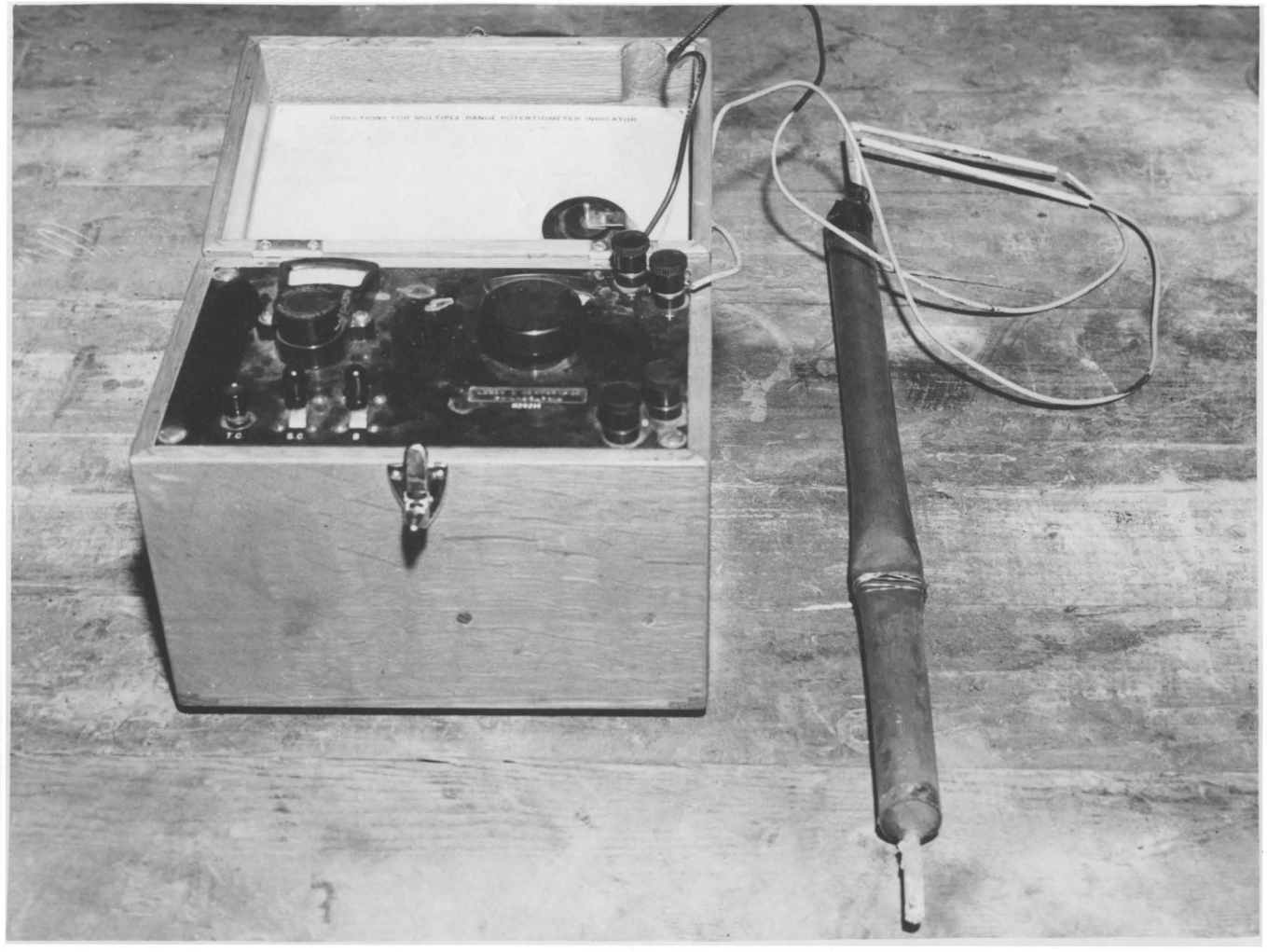
Photograph 1 - Spiral Pattern Mount

Photograph 2 - Aluminum Alloy Fluidity Pattern Halves



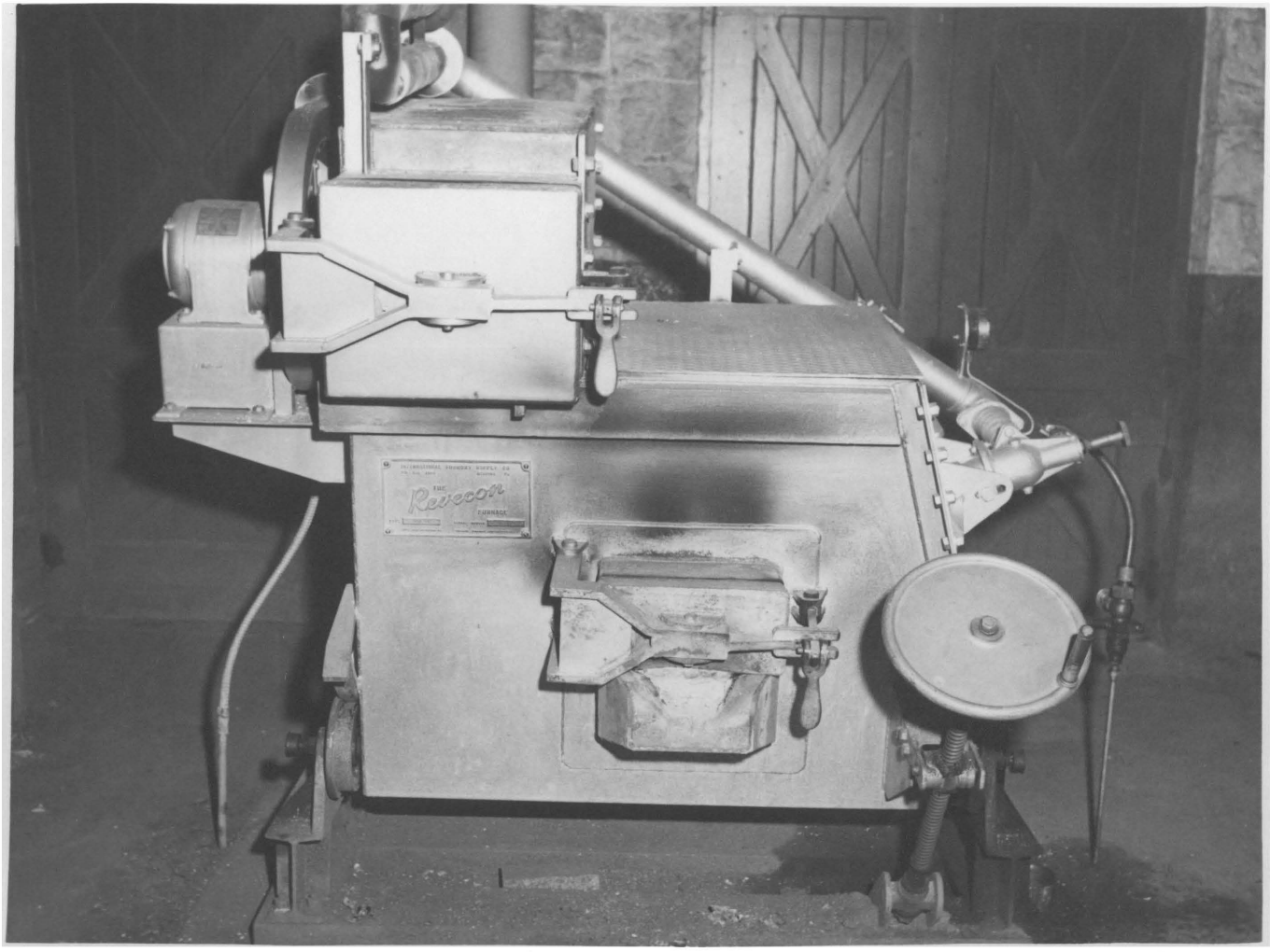
Photograph 3 - Machine-Mounted Fluidity Pattern

Photograph 4 - CO_2 Gassing Unit

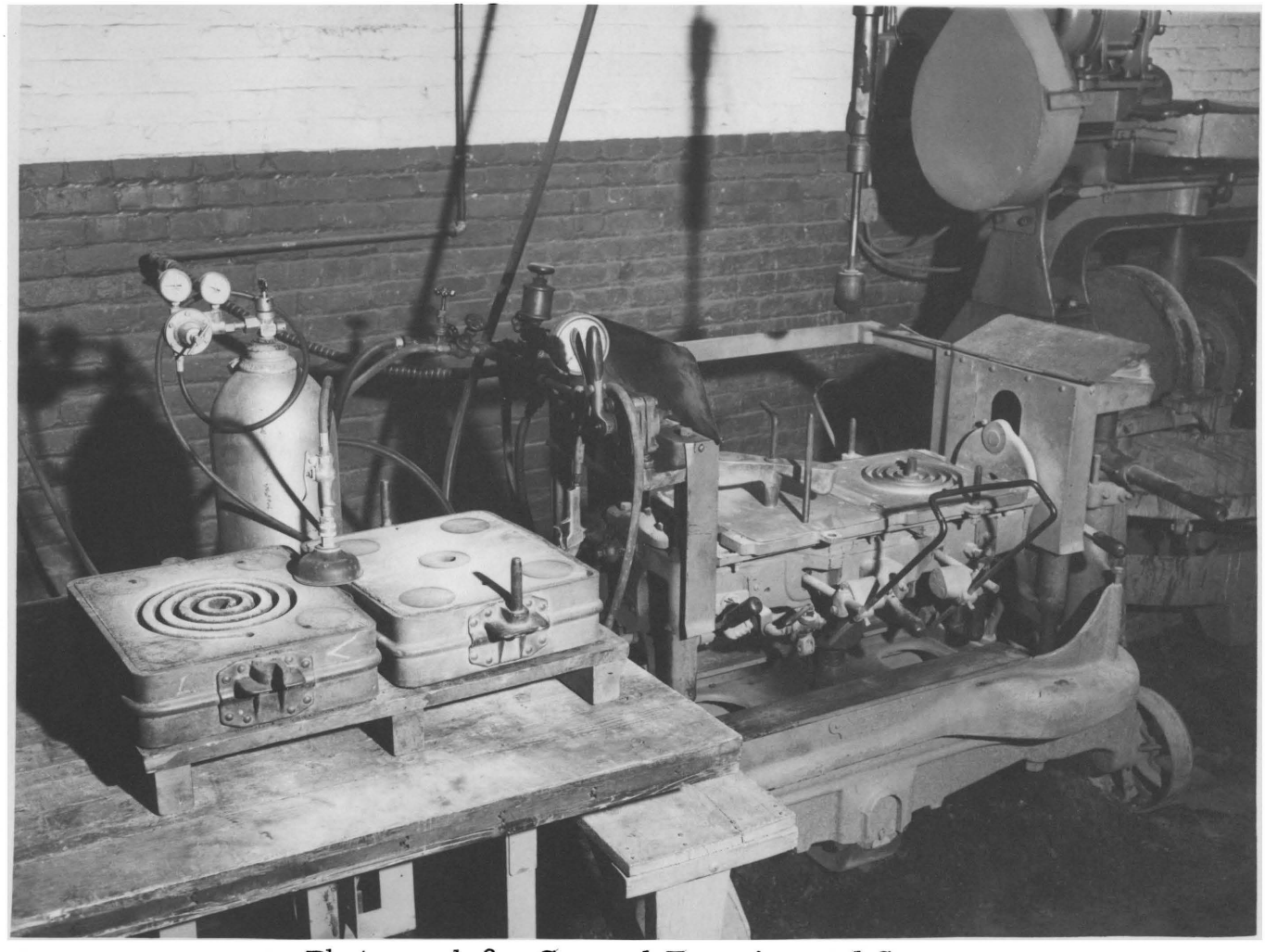


Photograph 5 - Temperature Determination Apparatus

Photograph 6 - Test Molds Poured at 300°F, 200°F, and 100°F Superheat



Photograph 7 - Revecon Reverberatory Furnace



Photograph 8 - General Experimental Setup