2 May 1941

NRL Report No. H-1731

NAVY DEPARTMENT

Report
on the
Development, Operation and Foundry Application
of the
Spiral Fluidity Mold
for
Measuring the Fluidity of Cast Steel

FR-1731

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WASHINGTON, D. C.

Number of Pages: Text - 8 Plates - 9

Authorization: BuEng. let. QP/Castings (6-19-Ds) of 13 July 1928.

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Distribution: BuShips (30)

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ABSTRACT

A test mold employing a spiral flow channel is described which can be used satisfactorily for measuring the fluidity (castability) of steel in the furnace prior to tapping or in the ladle on the pouring floor.

Advantages resulting from the use of this test for measuring the fluidity of the steel made in the three-phase electric arc furnace at the Naval Research Laboratory are described. The results of experimental tests made at the Washington and Norfolk Navy Yards are included.

It is possible to follow changes in the castability of steel brought about by deoxidizers and alloying elements or by variations in temperature or in furnace practice. The technique for obtaining such information is described.

AUTHORIZATION

1. The studies of steel castings were originally authorized by the Bureau of Engineering letter QP/Castings (6-19-Ds) of 13 July 1928.

INTRODUCTION

2. In order to obtain the best possible steel casting, the quality of the molten metal must be considered. Not only must composition be held to rigid specifications but fluidity (variously termed "castability," "life," "fluid life," "runnability" or "shankability") must be such that the molds will be readily and satisfactorily filled. Porous and incompletely run castings, lapped surfaces and unfaithful mold reproduction can often be laid directly to the sluggishness of the steel used for pouring. Badly skulled ladles with their corresponding inconveniences are not an uncommon problem. It has been suggested from time to time that the efficiency of risers, center line weakness, resistance to hot tearing and the like may be influenced by the fluidity of the casting metal.

STATEMENT OF THE PROBLEM

3. The problem undertaken at the Naval Research Laboratory consisted of:

(a) Development of a mold and technique of testing suitable for measuring the flowing quality of steel in the furnace in order to determine the proper tapping time; and

(b) A modification of this test to enable the foundryman to determine the fluidity of the steel in the ladle at any particular time.

4. The experimental test piece developed at the Naval Research Laboratory proved so satisfactory that it was modified to fulfill both requirements.

KNOWN FACTS BEARING ON THE PROBLEM

5. The final choice of test piece for fluidity measurements was influenced by the following requirements:

(a) The test piece should be capable of measuring accurately small variations in fluidity and yet faithfully evaluate maximum and minimum values which result from extreme conditions of temperature and composition.

(b) The mold must be simple, inexpensive and convenient to prepare, easy to manipulate and direct reading. Accurate leveling should not be necessary and provision should be made for maintenance of a constant flow head or at least one which varies within narrow limits.

(c) Results from the test piece should be reproducible.

KNOWN FACTS AND THEORETICAL CONSIDERATIONS

6. The spiral type of test piece for measuring the fluidity of cast metals was proposed as early as 1919 but it remained for Saeger and Krynitsky, working at the National Bureau of Standards, to adapt it for use with cast iron and non-ferrous metals. The work was published in 1936 and later this test became an A.S.T.M. standard for measuring the fluidity of these metals.

7. Several attempts have been recorded where a spiral flow channel has been tried with cast steel but little success reported. Some time prior to 1936 Ruff found the spiral not fully satisfactory and concluded that dynamic laws applied more directly when straight flow channels were employed. Accordingly, he developed a test for use in measuring the fluidity of cast steel which involved a straight cylindrical flow channel 3/16-inch diameter fed through a simple conical runner. Plate 1 shows the mold recommended by him for experimental and shop use. In all tests discussed the flow channel was made in sand molds of either the green or air dried type. The straight flow channel has been used extensively in England for both research and plant testing and to some extent in America. Opinion varies widely on the effectiveness of this method of testing for routine foundry practice.

8. Kron and Lorig, working at Battelle Memorial Institute, published the results of work on the subject in 1940. They used straight flow channels, 7/32-inch diameter, and their mold was an improvement over that of Ruff because of the inclusion in the design of a carefully controlled ferrostatic head which governed the entry of metal into the flow channel.

9. From a careful study of the results obtained by the various investigators using the straight flow channel it was apparent that this type offered little promise as a foundry tool. Test values were not dependable and lengths of flow were very short. However, several tests were made at the Naval Research Laboratory before this type was discarded in favor of the spiral type.

10. The results of preliminary tests indicated the following:

(a) The Ruff mold, unless provided with means for controlling ferrostatic head and regulating the flow of metal, did not give consistently reproducible results and experimental points were badly scattered.

(b) The 3/16-inch diameter flow channel failed to give significant lengths of flow in steels which were still fluid enough to fill a mold. The maximum lengths of flow for steel of average analysis at normal pouring temperature were never greater than 12 inches. It was impossible, in this size channel, to accurately measure small variations in fluidity.

(c) The mold employing a straight flow channel required careful leveling before pouring.

11. Because of the success reported when Saeger and Krynitsky used the spiral mold for measuring the fluidity of cast iron, this type offered more promise as a test for cast steel. Accordingly this type was next tried, and after the modifications necessary to adapt it to steel, a satisfactory test was developed. The details of the final design are given in Plates 2, 3, and 4, and photographs of actual molds are given in Plate 5.

12. In order to standardize the method, however, it was necessary to determine the influence of variables, in particular to determine the effect of sand grain size, of green, dry, and cement sand, pouring height, and in the case of tests at the arc furnace, to determine the effect of time of holding the sample in the spoon before pouring and to determine the amount of aluminum to be added to the spoon sample. The results of such tests as were found necessary to evaluate these variables are summarized below. A more detailed treatment is given in Naval Research Laboratory Report No. M-1657 where results of individual experiments are given in detail.

13. Nearly all of the development work was done using a 300-pound induction furnace, as melting and sampling were greatly simplified and results were fully as applicable as though all tests had been made on spoon samples taken from the arc furnace. From the results of this work the following conclusions may be drawn:

(a) The spiral test piece, as finally adopted, is satisfactory for evaluating the fluidity of cast steel. Results are reproducible, and the mold is simple and convenient to prepare. Reference marks on the cope surface of the casting make it direct reading.

(b) Variations in sand grain size from AFA fineness number 53 to 123 showed no selective influence on casting length. Molds made from bentonite bonded green and dried sand, and cement sand, when poured under identical conditions, gave equal spiral lengths. Thus the test is not sensitive to any normal differences in the various molding practices and results from all foundries would be comparable.

(c) Within reasonable limits (variations from 2 to 10 inches above the pouring basin) pouring height did not affect the reproducibility of the test.

(d) Varying the amount of aluminum added to 10-pound spoon samples taken from the arc furnace indicated that 0.4 ounce (strip 3/16" x 1/16" x 12" long) was the proper amount for average heats of plain carbon (0.15 to 0.30% C.) steel in the unkilled condition.

(e) In testing at the arc furnace the time normally required to pour the fluidity test casting from the instant of dipping is about 4 seconds. To determine what variation might exist as the speed of the operator varied from plant to plant, tests were made which proved that it was possible to hold the metal in a well slagged spoon as long as

15 seconds (ample time for the very slowest operator) without invalidating the results of the test.

(f) Composition has a marked influence on fluidity, the magnitude varying with the nature and amount of the alloying element. The state of oxidation of the bath is a major factor governing fluidity. Results indicated that a critical amount of deoxidation was essential to maximum flow. Variations above or below this value resulted in shorter spiral lengths for any given temperature.

(g) The temperature of the steel was found to have a predominant influence on casting length. The relationship for ordinary analyses is not a linear function as the temperature increases from 1500°C (2732°F) to 1700°C (3092°F). The increase in test casting lengths resulting from an increment of temperature change decreases at the higher temperatures.

DESCRIPTION OF THE SPIRAL FLUIDITY TEST AND ITS APPLICATION TO ROUTINE FOUNDRY PRACTICE

14. Plates 2, 3, and 4 show the detailed dimensions of the spiral fluidity test piece finally adopted and Plate 5 is a photograph of the steps in preparing the mold. Ordinary molding technique is used and molds may be either green or dried sand. If dry or cement sand is employed, it is necessary to dry the molds assembled to prevent fins which would otherwise lead to poor results. Figure 4 of Plate 5 shows a mold clamped and ready for use except for the addition of the runner guide. In making tests with this mold (Plate 4), the steel is poured into the runner guide (c), builds up to the lower overflow level, runs into a pouring button (d) and hence into the spiral. (F) is a second overflow trough, 1/4 inch higher than the first, which empties into a catch basin (a). This arrangement prevents the ferrostatic head from changing more than about 1/4 inch and provides a smooth flow of metal into the spiral. A completely filled casting weighs 12 pounds when the overflow basin is filled. The usual test weight, however, is 8 pounds as it is not desirable to completely fill the overflow.

15. The testing technique finally adopted as standard practice for use with the laboratory 1/2 ton, 3-phase arc furnace has proved very satisfactory and is shown by action photographs in Plate 6. The mold described above is placed in position near the furnace door as shown in Figure 1. The sampling spoon shown holds about 10 pounds of steel and is welded to a 3/4 inch diameter rod 8 feet long. A coil of aluminum (3/16" x 1/16" x 12" long wound on the end of a small rod) can just barely be seen lying on the front of the mold. These are all the essential requirements for the test. Whenever a test is desired the operator warms the spoon and slags it carefully. The sample is taken at a point as near the center of the bath as possible and quickly drawn from the furnace. As the spoon crosses the door sill a second operator vigorously stirs in the small spiral of aluminum for deoxidization. He does this while the man handling the spoon is moving it

into pouring position and does not interfere with the test. The spoon is then dumped without loss of time (but only conveniently fast) into the runner guide. It has not been found necessary to slag the sample in the spoon but this may be done if desired. The spiral immediately solidifies and can be shaken out of the mold and its length observed. Figures 2, 3 and 4 of Plate 6 show the above operations clearly. The reference marks on the cope surface of the spiral are 2 inches apart and facilitate reading the length of flow which is taken as the index of fluidity. The aluminum only needs to be used for tests prior to final addition or when necessary to insure a killed sample, but as long as a standard practice is observed it will be satisfactory to use it at all times.

OPERATING TESTS AT THE ARC FURNACE

16. From routine use of this test on all heats made in the Laboratory arc furnace definite advantages in better steel and cleaner ladles have resulted. Not only has it been possible to follow the progress of the heat to determine the proper tapping time, but it has been possible to determine the effects of changes in slag or charging practice, alloying elements, and type, amount, time, and order of adding deoxidizers. Rapid changes in fluidity as a result of suddenly increased or decreased power input can be readily detected.

17. For example, one test was made on relatively cold steel giving a spiral length of 10 inches. A subsequent test taken 10 minutes later while the power had been raised sharply gave 17 inches. Tests taken before and after final manganese additions gave 18 inches and 18-1/4 inches respectively, whereas tests 3 minutes later, before and after final silicon additions, gave 18-1/2 and 26 inches respectively. Fluidity was greatly improved by the addition of silicon but was not changed by the manganese. One series of tests involved measurements at the furnace as well as on the pouring floor. Just before adding the final additions of manganese and silicon the length of spiral was 17 and 16-1/2 inches on two tests. Following the addition the flow increased to 20 and 20-1/4 inches. At this point the bath was rabbled and tapped and optical pyrometer readings indicated the temperature as 2925°F. Using a 1/2-ton capacity teapot ladle a mold was poured taking about 300 pounds of metal. Next two fluidity test pieces were poured and flow had fallen to 16-1/4 and 16-1/2 inches as a result of heat loss to the ladle and atmosphere, the temperature indicated as 2730°F. Two more large castings were poured and then three spirals were poured in order at 1 minute intervals. Only a small amount of metal was left in the ladle and temperature was falling rapidly. The casting lengths were 15-1/4, 14, and 12 inches in the respective pouring order. The temperature was estimated by quick pyrometer readings to be about 2680°F for the last mold. It was found possible, by associating the length of spiral obtained at the furnace before tapping with the manner in which the steel handled on the pouring floor and with the quality of castings obtained, to predict the casting behavior of any heat of steel. Spiral lengths of at least 20 inches are required before the addition of final deoxidizers in the practice at the Naval Research Laboratory. This usually results in a spiral length of 25 to 28 inches just prior to tapping. 32 to 36 inches final fluidity is recommended for larger heats where more molds must be poured.

RESULTS OF TESTS AT THE WASHINGTON NAVY YARD

18. Following the satisfactory application of the spiral mold for fluidity measurements at the half ton furnace at the Naval Research Laboratory, tests were made using the 3-ton furnace at the Washington Navy Yard. In this case removal of the sample was thought to be complicated by the more intense heat from the larger door opening and the greater distance to the center of the bath. Planning for this, a larger and heavier spoon was welded to a 1-1/2 inch diameter iron bar about 4-1/2 feet long. A pipe section 4 feet long was then welded on the bar to give an overall length slightly greater than 9 feet without unnecessary weight. The heavy iron bar was necessary to prevent bending from the weight of sample when the rod heated up near the spoon. The technique for handling this sampling spoon is the same as for the smaller one used at the half-ton furnace except that as it is drawn from the furnace two extra men are needed to support the sample and move it into position for pouring. This is done by means of a cross bar slipped under the rod at any convenient point between the sample and the operator.

19. Several satisfactory tests were made in this way, but it was later found that sampling could be done with the smaller spoon which requires only a single operator. In larger furnaces, however, this might be impossible and the use of the larger spoon would be necessary. The total time for making the complete test is well under 2 minutes so the use of four men (three to handle the spoon and one to stir in the aluminum) is not a disturbing factor.

20. Results obtained from this work at the Washington Navy Yard are few because the method has only been tried for a short time. Tests taken before and after final deoxidizing additions to the furnace gave 26 and 36 inches of flow respectively on a plain carbon heat of approximately 0.20 per cent carbon. A nickel steel heat from which a spiral was poured just before tapping gave 49 inches flow. This steel was known to be more fluid than plain carbon steels because of the presence of 3-1/2 per cent nickel.

LARGE FLUIDITY TEST PIECE FOR USE ON THE POURING FLOOR

21. The small mold previously described is satisfactory for 1/2-ton or smaller ladles but is unsatisfactory for larger bottom pouring ladles because of the rapid rate of flow of steel from the nozzle. At the request of the Norfolk Navy Yard for a method of measuring fluidity of cast steel under these conditions, the test piece shown in Plates 7, 8 and 9 was designed. This is merely a large scale modification of the smaller fluidity test mold. Principles of flow are identical and measurements made by the appropriate use of either test are comparable.

22. The molds can be made of green sand if desired, but dry sand is preferable when they are allowed to stand unused for more than a few hours. Ordinary molding methods are used and the effects of variables are the same as discussed for the small mold. The Norfolk Navy Yard made the mold of cores, thus obviating the necessity for a flask, and molds were made up and stored for use as needed.

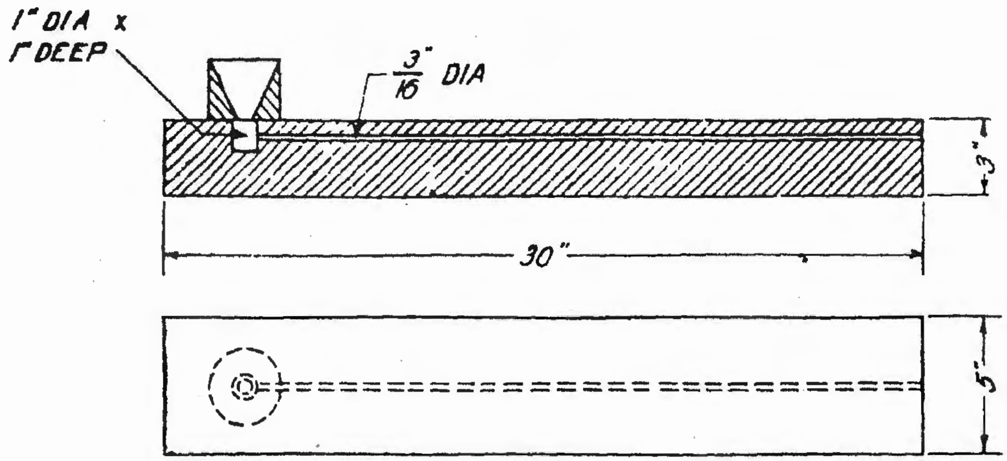
23. When making a test the ladle nozzle is centered above the pouring reservoir (B, Plate 7) and the mold filled at an ordinary rate. The metal builds up to the level of the overflow into the pouring button and fills the spiral under conditions as free from turbulence as possible. The overflow trough (F) is 1/4 inch higher than the first and limits the variation in ferrostatic head to about this amount. As soon as the metal starts to flow into the overflow reservoir (A), an observer calls "full" and pouring is stopped as quickly as possible. If metal should build up above the level of the overflow, the value of the controlled head would be lessened and it would be harder to shake the test casting from the mold than would be the case if pouring were stopped rapidly enough to prevent any metal being left on the slanting overflow.

24. Tests were made at the Washington Navy Yard and it was found necessary to place a sand baffle plate (shown as E in Plate 7) in front of the overflow into the spiral to prevent metal splashing or spurting prematurely into the flow channel and interfering with normal flow. This baffle also serves as a skim gate to keep slag or dross from getting into the test channel. A runner guide, shown in Plate 9, is always used.

25. After providing the baffle core a series of tests were made at the Washington Navy Yard which proved the test piece to be satisfactory. Six dry sand molds were prepared and placed in position on the foundry floor. Small castings were being poured and several openings were necessary so that there was a large drop in the temperature of the steel between the beginning and end of pouring. A 10-ton ladle was used and after first pouring a large mold to heat up the nozzle, two test castings were poured. These measured 26 and 25-1/2 inches. After approximately half the metal in the ladle had been poured into nine molds, the second pair of tests was taken. Only one spiral filled in this test as sand had clogged the flow channel but the good spiral measured 19 inches. After pouring nearly all the remaining metal into sixteen molds, the final pair of tests measured 8 and 7 inches in the order poured. These tests as well as one more series which gave equally good results established the spiral mold as satisfactory for measuring the fluidity of cast steel on the foundry floor.

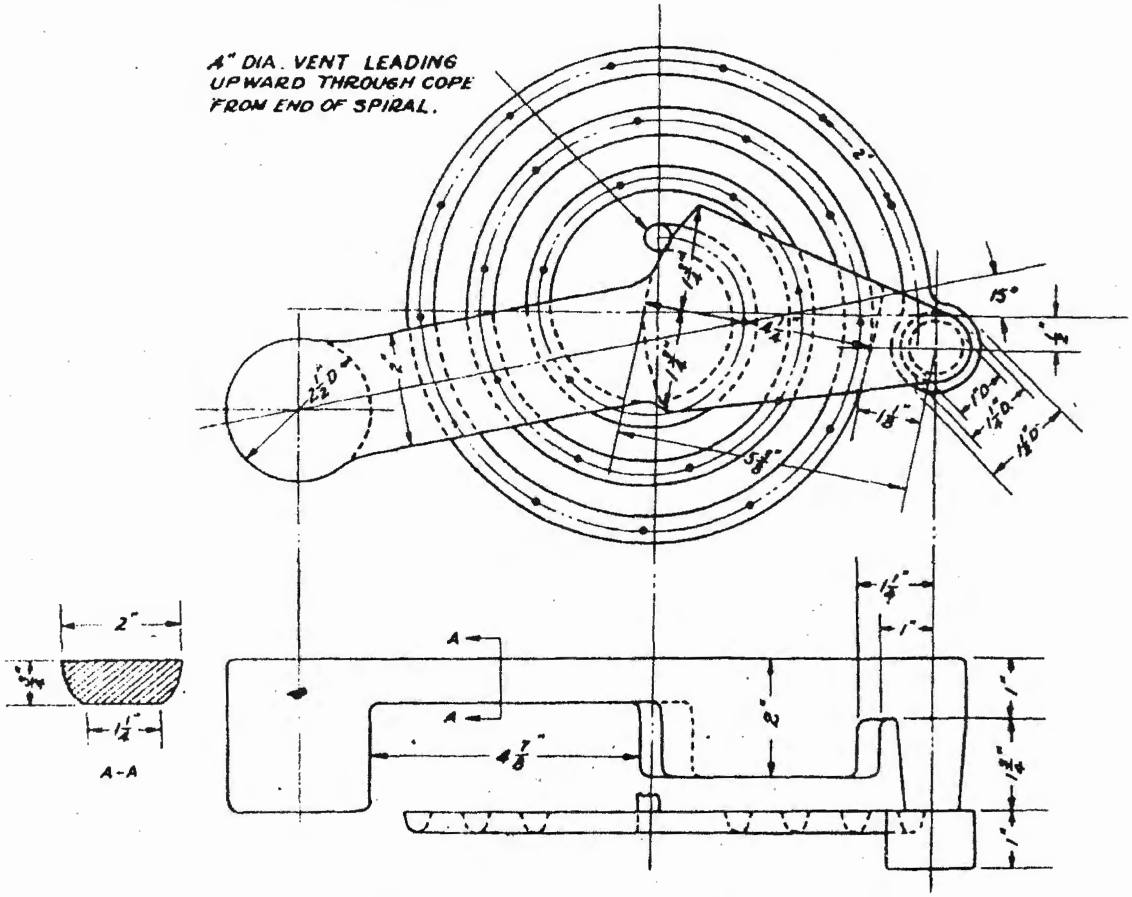
26. It is impossible to list all applications for this type of testing as they depend largely upon the individual foundry. For example, a small casting producer would only be concerned with the fluidity test at the furnace while the heavy casting manufacturer would also be interested in the condition of the metal at the time of pouring. By taking tests before and/or after pouring a large casting, it would be possible to tell the effect of fluidity on such factors as hot-tear, center-line weakness, etc. If aggravated conditions in the cooled casting could be associated with the fluidity of the steel used, many current founding problems would be explained and the foundryman possibly provided with a means for their solution. It might prove practical to mark clearly on the pattern the spiral lengths of the metal to be used for pouring a particular casting. This would facilitate the manufacture of castings ordered from this pattern at some later date when the foundry details had been forgotten.

27. From the large number of tests conducted with the smaller fluidity mold and from the comparatively few trials made with the large type, several advantages can be claimed for the spiral as an effective medium for measuring the fluidity of cast steel. The mold is simple, convenient to prepare, economical, direct reading, and compact and results obtained from its use are highly reproducible. No careful leveling is necessary and the design of the flow channel is such that differences in flow lengths satisfactorily indicate small variations in the fluidity of the steel. Provision is made for 55 inches of flow, and while this length is seldom reached (never for plain carbon steels at temperatures below 1700°C (3092°F)) the difference in flow between extremely low temperatures and high temperatures or between very sluggish and very fluid steels is ample for testing under the most extreme conditions normally encountered. For a given steel analysis and shop practice, it would be possible to calibrate the spiral directly in temperature units with a probable accuracy of ±25°C. Such calibration would have to be done using a thermocouple maintained in the steel bath and pouring spirals at small increments of temperature. To date no refractory is available which can be used as a sheath for protecting thermocouples from the corrosive action of basic slags and temperature measurements in this way are extremely troublesome. Acid slags present no unusual difficulty, however, when quartz is used as a protecting sheath. Since temperature is not always a true criterion of the casting quality of steel, sole reliance on this quantity would many times be misleading. The more valuable calibration would be in terms of results obtained on the pouring floor — convenient handling, absence of skull in the ladle, and good castings.



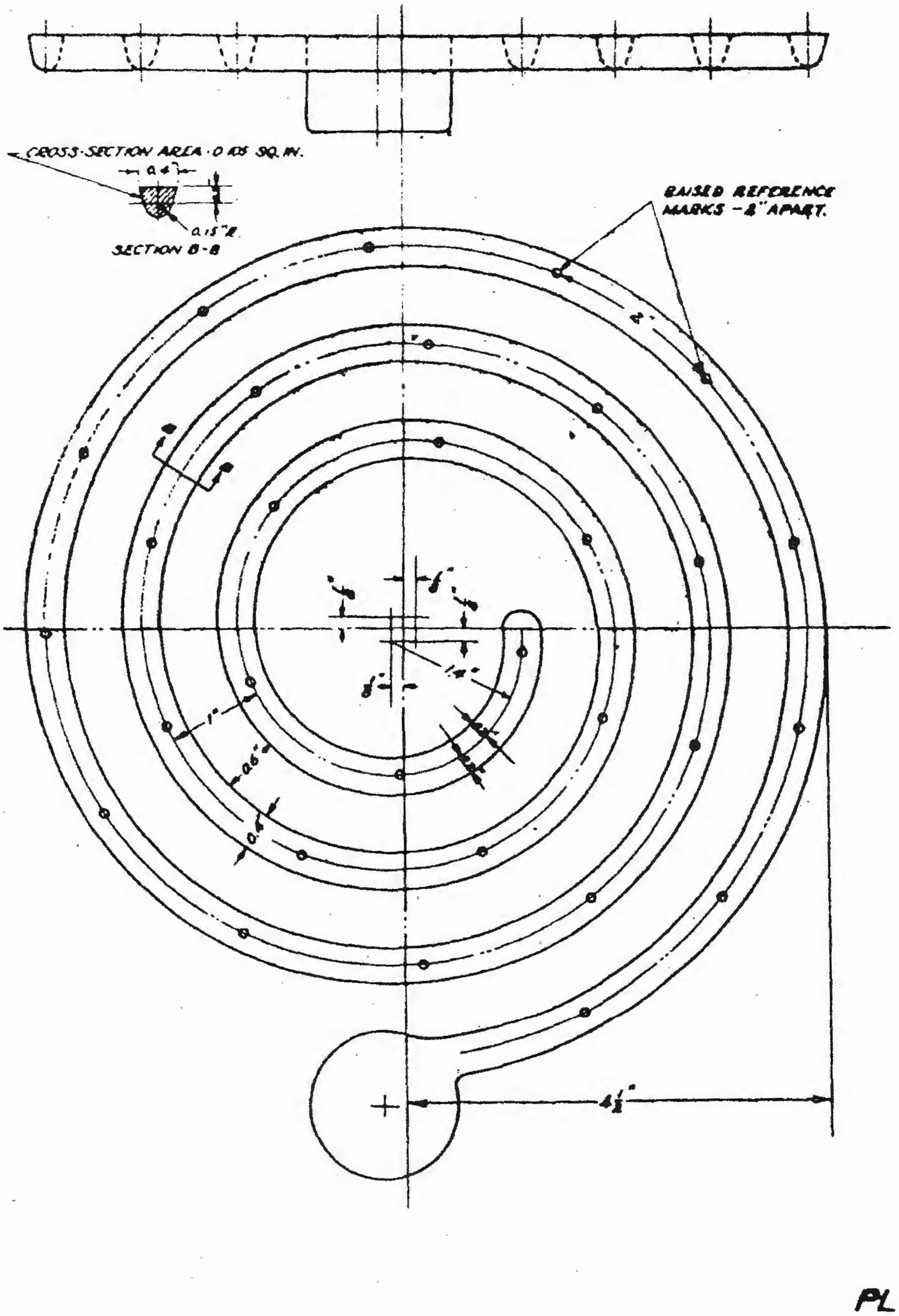
DETAILS OF RUFF, 3/16" DIA, FLUIDITY MOLD FOR COMPARISON TESTS

PLATE I



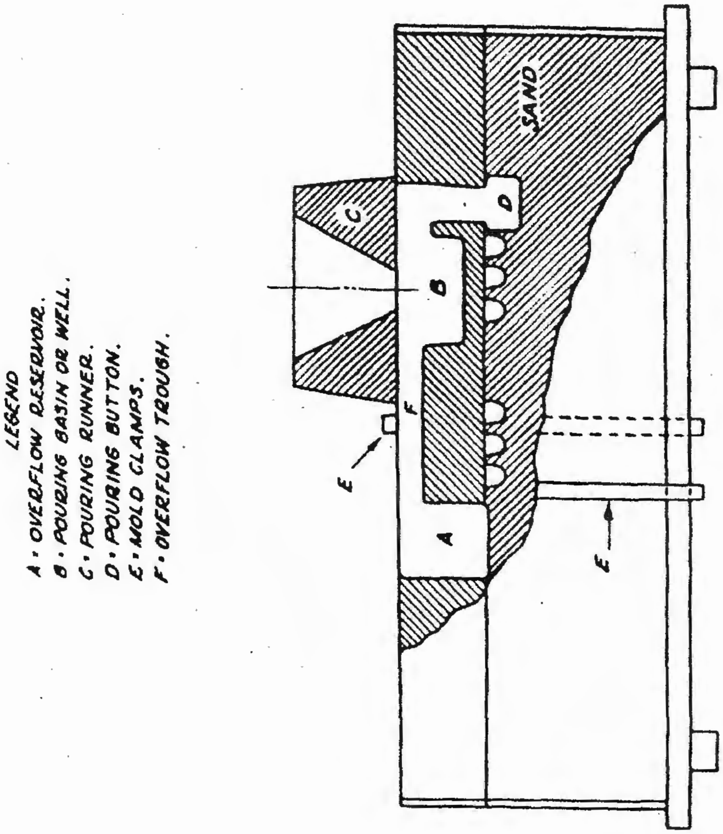
FLUIDITY SPIRAL-STRAIGHT DOWNGATE TYPE
WITH MODIFIED POURING BASIN

PLATE 2

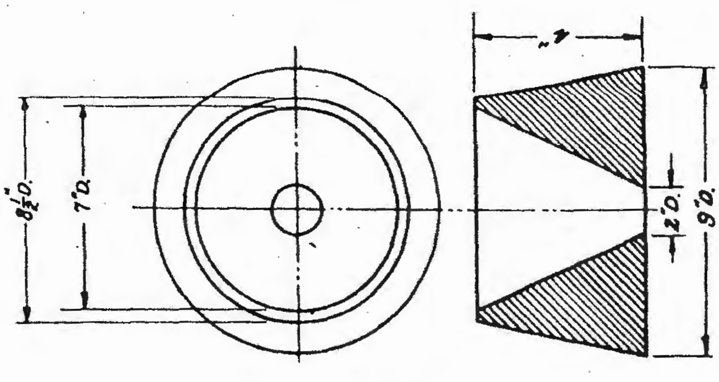


CROSS-SECTION AREA - 0.105 SQ. IN.
SECTION B-B
RAISED REFERENCE MARKS - 2" APART.

PLATE 3

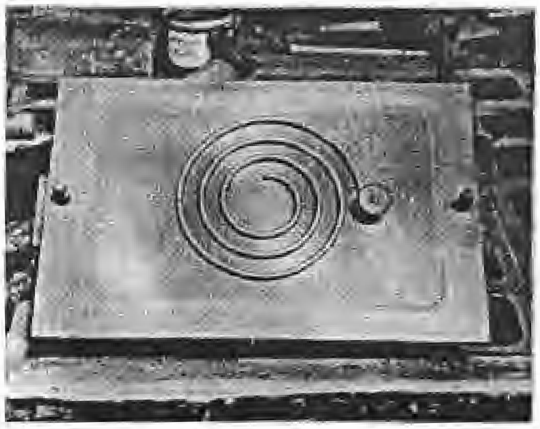


MOLD ASSEMBLY



POURING RUNNER

PLATE 4



23 - DRAG SECTION OF FLUIDITY SPIRAL PATTERN SHOWING BLIND RESERVOIR

FIG. 24 - COPE SECTION OF PATTERN, WITH POURING BASIN PATTERN IN PLACE, AND SHOWING RAISED REFERENCE MARKS.

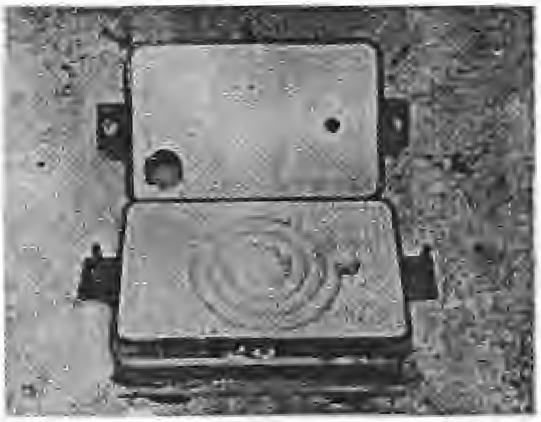


FIG. 25 - SAND MOLD READY FOR CLOSING.

FIG. 26 - ASSEMBLED AND CLAMPED MOLD READY FOR USE.

PLATE 5

FIG. 1–SPIRAL MOLD AND OPERATOR READY FOR MAKING A TEST.

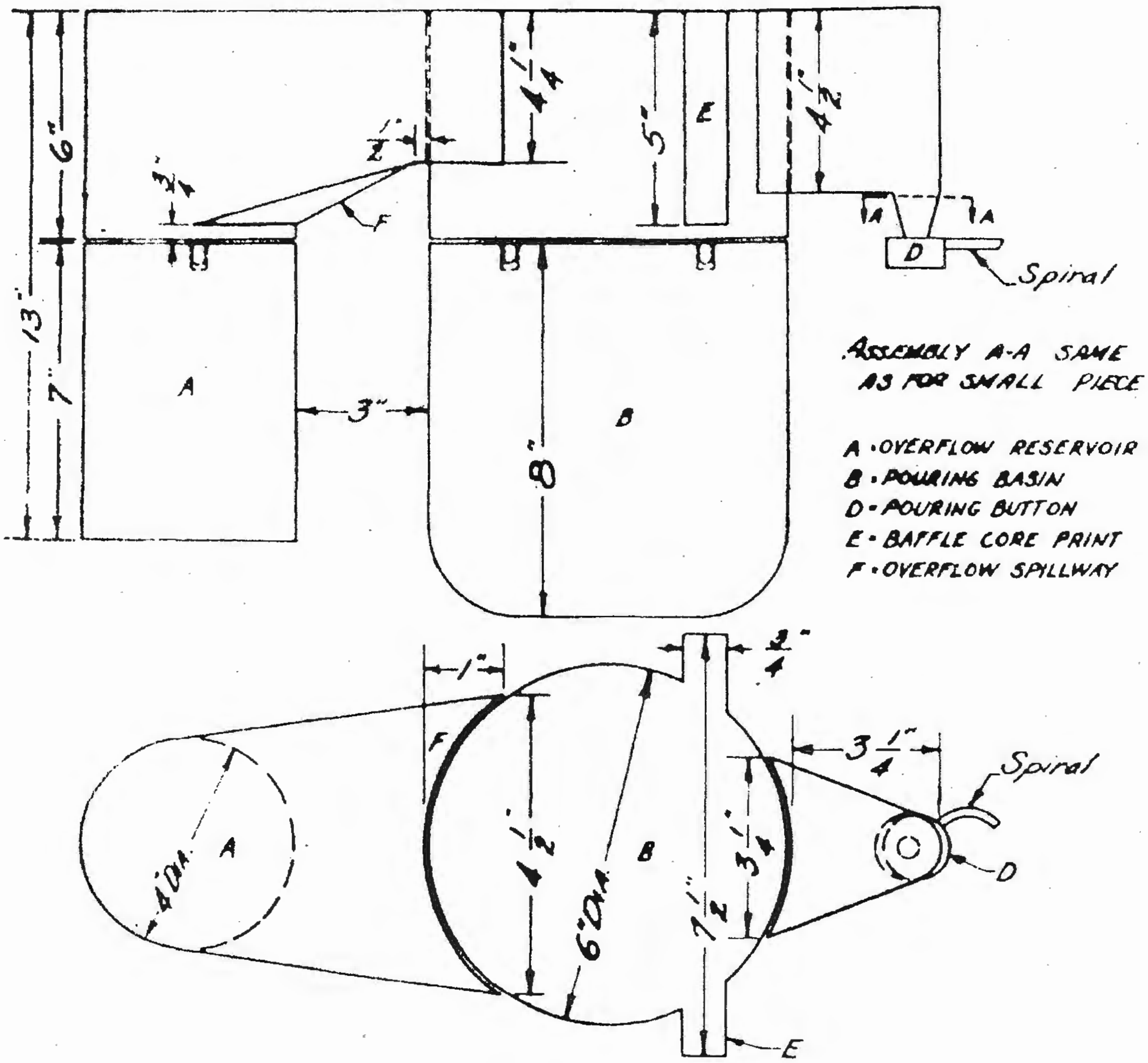
FIG. 2–STIRRING THE ALUMINUM INTO THE SPOON SAMPLE.

FIG. 3–POURING THE SAMPLE INTO THE SPIRAL TEST MOLD.

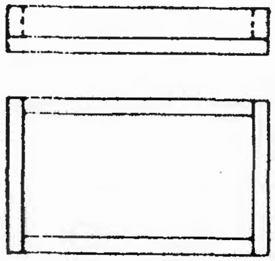
FIG. 4–CHECKING THE LENGTH OF FLOW AS A MEASURE OF THE FLUIDITY.

MAKING A FLUIDITY TEST ON STEEL DRAWN FROM AN ARC FURNACE.

PLATE 6



Details of Fluidity Test Piece
For Use With Large Ladle
On The Pouring Floor



Core Box For
5"x7½"x¾" Plate Core

PLATE 7

FIGURE 1- SPACED PROPERLY FOR RAMMING IN DRAG

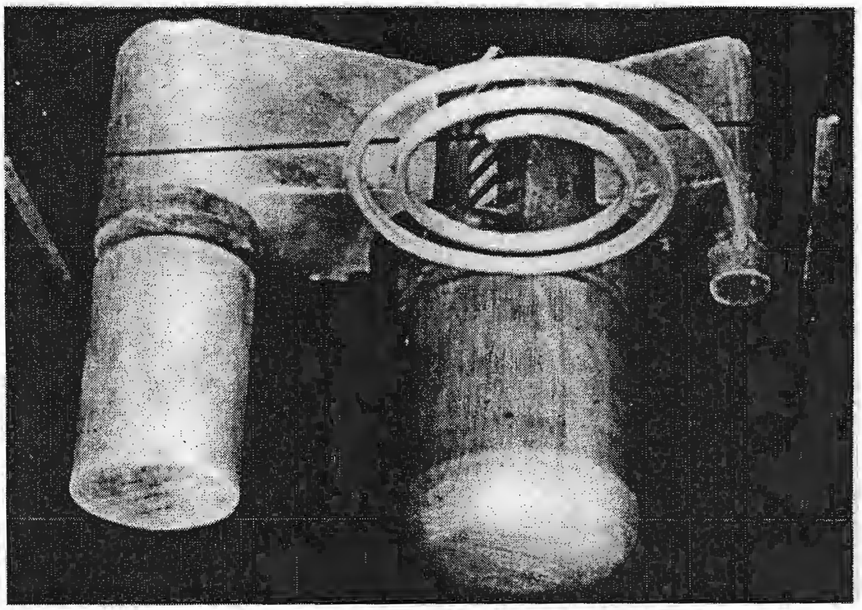


FIGURE 2-INDIVIDUAL PARTS SEPARATED BY GLASS PLATE

PATTERN FOR LARGE FLUIDITY
TEST PIECE

PLATE 8

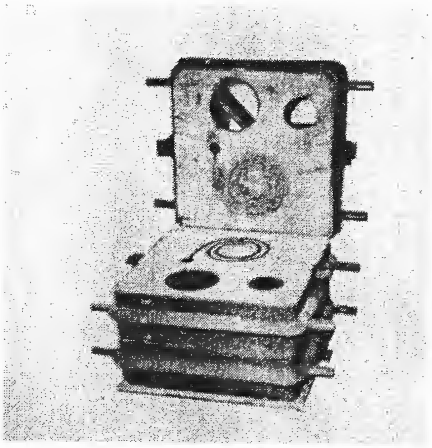


FIGURE 1-MOLD UNASSEMBLED

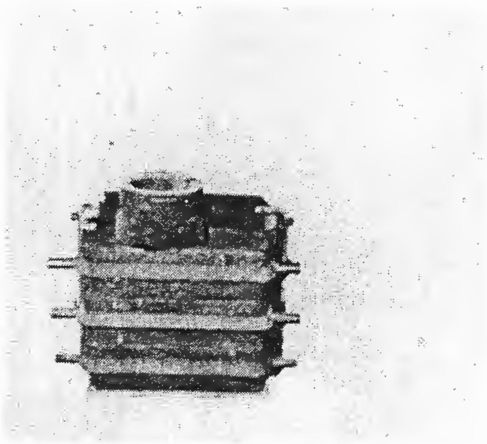


FIGURE 3-MOLD READY FOR POURING

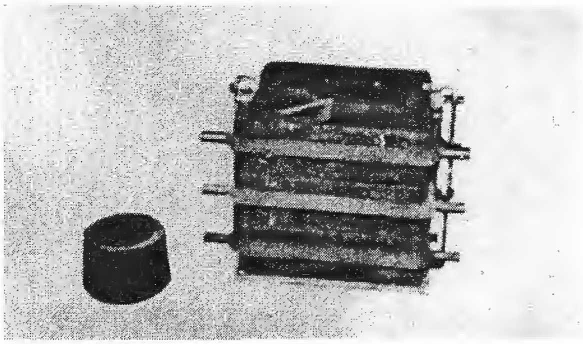


FIGURE 2-MOLD SHOWING BAFFLE PLATE

LARGE FLUIDITY TEST PIECE
DETAILS ON PLATE

PLATE 9