# TESTS ON PERMANENT MOLDS
# FOR LIGHT METAL ALLOYS

by

JACOB JAY SMALTZ

B. S., Bradley Polytechnic Institute, 1939

----------

A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

Department of Shop Practice

KANSAS STATE COLLEGE

OF AGRICULTURE AND APPLIED SCIENCE

1946

# TABLE OF CONTENTS

# INTRODUCTION

Metals have been shaped for many years by means of casting, forging, machining, welding and stamping. Casting, a process of running molten metal into a mold, is said to have been practiced by the ancient Egyptians, Greeks, Romans, and Chinese.

The process of permanent mold casting, or permanent molding consists of pouring molten metal into a cavity surrounded by material of a higher melting point than that poured. The mold is permanent in the sense that it can be used many times, in contrast with a sand mold that is destroyed after a single casting is made.

Early permanent molds were made by forming a cavity of the desired shape in rock. Modern production methods have led to the making of the desired cavity in molds or dies of steel or cast iron.

In holding dimensional accuracy permanent molding lies between the process of sand casting and that of die casting. Permanent mold casting in England is known as gravity die casting, while die casting, as we know it in this country, consists in forcing molten metal into a metal die by means of pressure.

A variation in permanent molding, known as semi-permanent molding, consists of the use of sand cores in conjunction with a metal mold to give the permanent mold a much greater range of usefulness. This process reduces the mold cost by eliminating complicated metal cores and at the same time maintaining desirable metallurgical characteristics of the surfaces cast against the walls of the metal mold.

Medium size permanent mold castings can usually be made in quantity production, 500 or more pieces, at a reduced cost when compared with sand castings.

According to Sugar, (1) "Costs per unit casting, cost of equipment per unit casting, foundry space required, the rate of production per unit, machining time and costs, all favor the adoption of the permanent mold process where volume production is concerned".

The Aluminum Company of America (2) lists the following outstanding features of permanent mold castings:

(1) Low cost and high production.
(2) Mold equipment cost lower than die equipment for die castings, although generally higher than the original cost for pattern equipment for many types of sand castings.
(3) High mechanical properties and greater soundness.
(4) Smoother surfaces, closer dimensional tolerances, and less finish allowance than sand castings.
(5) Permanent mold and semi-permanent mold castings, ranging from .05 to several hundred pounds in weight, have been successfully produced in production quantities. Typical castings made by the permanent mold process are pistons, washing machine agitators, electric flat iron sole plates, ventilating fans, cylinder heads, crank cases, etc.

Other advantages of this method as pointed out by Vickers (3) are:

(1) Greater possible speed of production.
(2) Conservation of raw material.
(3) Reduction of production scrap.

## MATERIALS AND METHODS

The thought of investigating some of the characteristics of permanent molding first occurred during a discussion of the various methods of producing cooking utensils. This led to a search for available literature on the process of permanent molding. It was discovered that a large number of authors mentioned permanent molding and gave a description of the process but that little real information on the subject was available. The best review of the application advantages and design principles to date are found in a manual prepared by Mr. Alfred Sugar (1) (4). After some correspondence with manufactures of aluminum it was found that the nearest permanent mold foundry was Cleveland, Ohio.

There are a number of alloys that can be used in permanent molding. For some years cast iron has been poured into a steel mold in the foundry at Kansas State College. Some of these castings are 3/8 of an inch square in cross section and about ten inches long and have been used as tool bits for lathe work. In some instances they will out perform carbon steel tools. Another permanent mold for cast iron is in use at Kansas State College to form the hub of a spoked wheel. The use of a chill, a steel insert in a sand mold, to produce a smooth hard surface on grey iron castings is also well known.

Aluminum, bronze, magnesium and zinc may also be cast by the permanent mold process. Aluminum is the most widely used of these metals.

The particular alloy to be used depends upon its casting characteristics, whether or not it is to be cast in thin sections, its weldability, machinability, and corrosion resistance. Other factors to be considered are leak tightness, thermal expansion, hardness at elevated temperatures and good physical properties.

The alloy used in this project is one believed to contain four per cent copper, one and five tenths per cent magnesium, two per cent nickel and the remainder aluminum. The source of supply was used automobile pistons. These were first baked in an oven at 1000 degrees F. to burn off most of the oil and other surface impurities. The metal was then melted in an electric furnace, fluxed with Falls "A" and pigged. The pigs were then mixed and remelted so as to produce as uniform a metal as possible throughout the test.

The method finally adopted for the final tests was the result of a series of varied procedures. Problem number one was an attempt to find out what had previously been done in the field. Very little data were available on mold temperatures, but considerable information was found on mold design, based on molds for plastic materials. Due to the great variety of mold cavities, it appeared that most designers developed their own particular method based on experience with the type of casting and alloy used.

From the available information it was decided to design a mold to make a small cooking utensil. This mold was completed on paper but to date has not been made. However, much valuable information was gained in this project, such as means of parting, gating, ejecting the finished casting and the possibility of the use of metal inserts.

Because some of the laboratories at Kansas State College needed some aluminum bars about one inch in diameter and fifteen inches long and wrought bars were not available, it was decided to cast some in a permanent mold.

This mold consisted of two one and one quarter inch plates of hot rolled steel about thirteen inches wide and fifteen inches long. When placed together these plates made five cylindrical cavities one inch in diameter and fifteen inches long. By standing these plates on end and clamping them together, bars of aluminum one inch in diameter and fifteen inches long could be produced. It was found that these cast bars were practically free from porosity and possessed good machinability. The surface finish on these bars was also much better than that on a sand casting. They had a frosty appearance on the surface, however.

It was next decided to devise a better method of opening and closing the mold. One half of the mold was mounted in a vertical position on a stationary framework and the other half was fastened to a rack. By moving a lever which actuated a pinion meshing with the rack the mold was readily opened and closed and needed no clamps to hold it in position. This method speeded up our molding to such an extent that we were limited by the capacity of the electric furnace. The mold could be filled about three times before more metal was required.

The problem of measuring the temperature of the mold was the next one to be solved. Each mold half was divided into six equal areas and a hole drilled in the center of each area. These holes were tapped to receive a one-eighth inch pipe plug. A small hole to receive a chromel-alumel thermocouple was drilled into the top of each pipe plug. The thermocouple was then silver soldered into the plug and a thermocouple plug screwed into each hole. By means of an indicating pyrometer and a specially devised switching arrangement it was possible to measure the temperature at any one or any combination of the twelve areas of the mold.

It was discovered that all areas of the mold could be held within a few degrees of each other and that when all thermocouple leads were brought into the pyrometer at once a good average temperature was determined.

Due to the large radiating area of the mold and the limited amount of metal that could be poured, the highest mold temperature that could be developed by pouring molten metal into the mold was about 300 degrees F.

At this mold temperature the samples still contained cold shuts. This may have been due in part to the method of pouring. As the metal was poured from the ladle, it would run down the sides of the mold and freeze immediately. As the mold was filled, the metal would run around the metal that had already frozen, producing cold shuts. The metal temperature in this case was 1240 degrees F.

A comparatively small gas burner was next made to heat the mold. The highest mold temperature obtained by this method was 500 degrees F. Metal at 1240 degrees F. was poured again. This higher mold temperature gave us a bar that was relatively free of cold shuts in the upper portion.

An attempt was made to heat the mold to higher temperature by means of a 150 ampere D. C. arc welder. The resistance of the mold was so low it could not be heated by this means.

It was then decided to use an A. C. welder and a coil. A coil of 15 turns was wrapped around the mold and the current turned on. The coil heated but the mold did not. The mold might have been heated by means of a high frequency coil, but since equipment was not available this method was not tried.

A special double row gas burner was made to heat the mold uniformly to a higher temperature. Because of the radiation of the mold the highest temperature reached by this method was 660 degrees F.

Due to the fact that the mold was made of hot rolled steel, was machined on one side only, and was heated on the inside portion, some difficulty was experienced in closing the mold after it had been heated. The samples poured still contained cold shuts, some pinholes, and in spots a frosty, corroded appearance. The above samples were poured with a ladle having just enough capacity for one bar. This perhaps contributed to the difficulty of controlling the metal temperature and may have been the source of some of the trouble.

It was thought that a better surface condition might be produced using a teeming ladle, that is, a ladle with a hole in the bottom, and dropping the metal into the cavity rather than pouring it. This did produce a more uniform surface on the casting but the surface was not smooth, possibly due to the turbulence of the metal.

The mold was then tilted from the vertical to various angles and it was found that at 45 degrees the casting was easily poured and produced an excellent finish on the portion of the casting in the top half of the mold.

Up to this point the metal had been poured against the bare surface of the mold. It was thought that a mold paint would help the surface finish. Accordingly a paint was mixed consisting of one quart of water, two fluid ounces of water glass, three-fourths ounce of whiting and one-eighth ounce of graphite. This was then boiled for twenty minutes. The mold was heated to 250 degrees and the paint applied with a brush. This resulted in a very uneven coating of the mold paint so the paint was entirely removed and the application begun again. This time the mold was heated to 500 degrees and the paint applied with a rag. The outcome was a uniform coat of the mold paint on the surface of the mold.

Samples were again poured at various angles of the mold, including one poured in the horizontal position using an elbow shaped pouring funnel, and one poured in the vertical position, using an ogee pouring spout to reduce turbulence. None of these samples had the surface finish desired but they were still much better than those obtained by means of a sand mold.

An experiment was tried to determine the degree of turbulence in the molten metal as it was poured. This was first done by holding a stick of wax in the metal stream as it was poured. Sawing the sample in various portions revealed particles of wax dispersed throughout the sample.

A special ladle was then devised by means of which a stream of aluminum with a core of lead could be poured. When this sample was cut lengthwise, a large portion of the lead surrounded by aluminum could be seen at the bottom of the sample with fine swirls of lead extending upward through the specimen.

This indicated that the sample should be poured down through a gate into a runner, the final specimen being fed from the bottom.

This was tried and the resulting specimen had the desired surface finish but because the runner was small, the metal froze in this portion and the final specimen was much shorter than desired. This led to the design of a new mold which will be described under Test Mold Construction Details.

## TEST MOLD CONSTRUCTION DETAILS

In order to determine the effect of mold temperature upon the casting characteristics, physical properties, and structure of a permanent mold casting it was conceived that a mold which would produce a tensile test specimen, a means of checking on the depth of chill, and some indication of fluidity would be desirable.

After some consultation, the majority were of the opinion that a tensile test specimen could not be cast due to the hot brittleness of the material and the contraction due to cooling. This was sound reasoning. The specimen in order to be tested must have larger diameter ends than the center section, and the mold being made of metal would not yield as a sand mold does. Ideas were then developed concerning the use of sand inserts for the large end of the specimens. It was thought that these would destroy the chilling effect on the specimen so this procedure was abandoned.

"It can't be done" was a phrase that prompted the making of a small mold to cast a test specimen. As was predicted, the first seven samples broke in the mold. The eighth one was a success in the light that it came out of the mold in one piece. Three more were cast after some changes had been made and these too, broke in the mold. The fourth one, however, again came out in one piece. More changes were made and five samples were cast without a failure. Subsequent castings were poured and a sample would break just occasionally.

Another experimental mold for casting test specimens was made which was similar in shape to the one finally adopted. This mold produced a specimen with a half inch diameter center section which increased by a three inch radius to a straight section about 9/16 inch in diameter and 1/2 inch long. The head of the specimen was about 3/4 inch in diameter and connected to the body of the specimen with a 1/16 inch radius.

Knowing the shape of a mold required to produce a satisfactory test specimen, a new mold was designed to incorporate a test specimen, and a sample that would give a rough indication of the metal fluidity and depth of chill. This mold is shown in Plate I. It consists of a cavity as described above for molding the tensile test specimen and another cavity for a cone shaped sample. This cone shaped sample was 2 inches in diameter at the base, tapered approximately 25 degrees to a diameter of 7/8 inch. The sample is cylindrical for 3/8 inch and then again tapered with a 60 degree included angle to a 1/4 inch diameter about 1/4 inch long. If the cavity is filled, there should be a piece 1/8 inch thick and 7/8 inch wide extending from the top of the cone. See Plate I, Figure 2. It will be noted in the photographs that follow that most of these samples were not filled in this portion.

The samples were poured through a 1 inch diameter gate and fed to the specimens through semi-circular rings of eliptical cross section.

The mold itself was cut from pieces of steel of about 50 points of carbon. These were cut with an oxyacetylene cutting torch and machined to final size.

Four separate pieces made up the mold. This was done to facilitate machining. All cavities except the flat portion at the top of the cone were machined on a lathe. Dowel pins held the pieces in alignment and the mold was held together with a clamp. See Plate I, Figure 1. A chromel-alumel thermocouple was fastened into the back of one of the mold halves so that mold temperature could be indicated by means of a pyrometer. Previous experimentation showed that one thermocouple would give a satisfactory temperature indication.

## PROCEDURE

As previously stated, the metal used was pigged and the pigs were mixed before remelting to assure as uniform metal composition as possible.

An electrically heated and controlled furnace was used to melt the metal and another electric furnace was used to heat the mold to the desired temperature. In all the samples poured the metal temperature was kept as nearly as possible to 1400 degrees F. Samples were poured as the metal reached the desired temperature on heating, rather than overheating the metal and allowing it to cool.

Since the melting pot was also used as the pouring ladle it was thought that better control could be obtained in this manner.

Because of the radiation of the mold and the distance from the heating oven to the pouring floor, the molds were overheated and allowed to cool to the desired temperature.

Small pouring ladles of capacity to just fill the mold were tried but it was found that these would not furnish enough head to fill the mold. Hence, a pouring ladle having about five times the mold capacity was used. This also helped maintain better pouring control, which seems to be a large factor in permanent mold casting.

After the mold was filled it was removed from its tilted position to the floor. Due to the contraction of the metal in the mold, it had to be opened with a hammer and cold chisel. The specimen was removed in a like manner. The samples were then cooled in still air at room temperature.

The tensile specimen was removed from the casting and pulled. A stress strain curve was drawn as the sample was tested and these are shown in the section on Photographs and Data on Samples Poured.

The cone shaped portion was then cut lengthwise to expose the central portion. Since a permanent mold has no permeability, venting becomes a considerable problem. In practically all of these specimens cavities will be noted in these sections due to gas inclusions. Those that do not contain these gas cavities have considerable shrink visible on the outside of the casting.

## PHOTOGRAPHS AND DATA ON SAMPLES POURED

The following Plates show photographs of samples as they came from the mold. The cone shaped samples were split and photographs taken to show gas inclusions. A typical specimen was taken from each mold temperature, polished, etched and photographed to show the macrostructure. All macrophotographs are taken at 2 power.

The stress-strain curves shown are photocopies taken of the curve as drawn by the testing machine.

Samples were etched for 20 seconds in the following solution:

HF............ 10 ml.
HCl........... 15 ml.
$H_2O$........... 90 ml.

## Explanation of Plates

### Plate I

Fig. 1. Permanent Mold showing the pouring position and pyrometer for measuring mold temperature.

Fig. 2. Mold in open position showing mold cavities and finished casting. Metal is poured in the center opening.

### Plate II

Fig. 1. Sample poured at 100 degrees F. mold temperature. The tensile specimen was pulled in two in the mold. Note also gas pockets in cone shaped section.

Fig. 2. Macrostructure of cone shaped section of Fig. 1. Magnification 2x.

Fig. 3. Another sample poured at 100 degrees F. mold temperature. Tensile specimen again broke in the mold. Note shrink cavity in cone shaped portion.

Fig. 4. Sample poured at 200 degrees F. mold temperature. Cavity for tensile specimen did not fill. Note also the shrink cavity in the cone shaped portion.

### Plate III

Fig. 1. Sample poured in mold at 200 degrees F.

Fig. 2. Split section of sample shown in Fig. 1.

Fig. 3. Macrostructure of Fig. 2. Note grain size is comparatively small.

### Plate IV

Fig. 1. Stress-strain curve of sample shown in Plate III.

## Plate V

Fig. 1. Another sample poured at 200 degrees F. mold temperature. Here again the tensile specimen was not filled.

Fig. 2. Split section of Fig. 1.

Fig. 3. A sample poured at 300 degrees F. mold temperature.

Fig. 4. Split section of Fig. 3.

## Plate VI

Fig. 1. Stress-strain curve of sample shown on Plate V, Fig. 3.

## Plate VII

Fig. 1. Sample poured at 300 degrees F. mold temperature. Tensile specimen did not fill and broke in the mold.

Fig. 2. Section of cone shaped portion of Fig. 1.

Fig. 3. Another sample poured at 300 degrees F. Tensile specimen again broke in the mold.

Fig. 4. Section of Fig. 3.

## Plate VIII

Fig. 1. Sample poured at 300 degrees F. mold temperature.

Fig. 2. Section of sample shown in Fig. 1.

## Plate IX

Fig. 1. Stress-strain curve of sample shown on Plate VIII.

## Plate X

Fig. 1. Sample poured at 300 degrees F. Note shrink on top of cone portion.

## Plate X (continued)

Fig. 2. Section of Fig. 1. Note absence of gas cavities.

Fig. 3. Macrostructure of Fig. 2

## Plate XI

Fig. 1. Stress-strain curve of Plate X, Fig. 1.

## Plate XII

Fig. 1. Sample poured in mold of 400 degrees F. Note shrink in cone portion.

Fig. 2. Section of Fig. 1.

## Plate XIII

Fig. 1. Stress-strain curve of specimen on Plate XII, Fig. 1.

## Plate XIV

Fig. 1. Sample poured into 400 degree F. mold. Test specimen did not fill. Note shrink cavity.

Fig. 2. Section of Fig. 1.

Fig. 3. Macrostructure of Fig. 2.

## Plate XV

Fig. 1. Sample poured into 500 degree F. mold.

Fig. 2. Section of Fig. 1.

## Plate XVI

Fig. 1. Stress-strain curve of sample on Plate XV, Fig. 1.

### Plate XVII

Fig. 1. Sample poured into 500 degree F. mold.

Fig. 2. Section of Fig. 1.

Fig. 3. Macrostructure of Fig. 2.

### Plate XVIII

Fig. 1. Stress-strain curve of sample on Plate XVII, Fig. 1.

### Plate XIX

Fig. 1. Sample poured into 500 degree F. mold.

Fig. 2. Section of Fig. 1.

### Plate XX

Fig. 1. Stress-strain curve of sample on Plate XIX, Fig. 1.

### Plate XXI

Fig. 1. Sample poured into mold at 500 degrees F.

Fig. 2. Section of Fig. 1.

### Plate XXII

Fig. 1. Stress-strain curve for sample shown in Plate XXI, Fig. 1.

### Plate XXIII

Fig. 1. Sample poured in mold at 600 degrees F.

Fig. 2. Section of Fig. 1. Right hand half macroetched.

Fig. 3. Macroetched portion of Fig. 2. Note that grain size is increasing over that in previous plates.

## Plate XXIV

Fig. 1. Stress-strain curve of sample shown in Plate XXIII, Fig. 1.

## Plate XXV

Fig. 1. Sample poured in mold of 600 degrees F.

Fig. 2. Section of Fig. 1.

## Plate XXVI

Fig. 1. Stress-strain curve of sample shown on Plate XXV, Fig. 1.

## Plate XXVII

Fig. 1. Sample poured in 700 degree F. mold.

Fig. 2. Section of Fig. 1.

## Plate XXVIII

Fig. 1. Stress-strain curve of sample shown on Plate XXVII, Fig. 1.

## Plate XXIX

Fig. 1. Sample poured in 700 degree F. mold. Note shrink in side of cone section.

Fig. 2. Section of Fig. 1.

Fig. 3. Macrostructure of Fig. 2.

## Plate XXX

Fig. 1. Stress-strain curve of sample on Plate XXIX, Fig. 1.

## Plate XXXI

Fig. 1. Sample poured in 700 degree F. mold. Note that tensile specimen did not quite fill. This specimen failed in the head when pulled as is shown in Plate XXXII, Fig. 1.

Fig. 2. Section of Fig. 1.

## Plate XXXII

Fig. 1. Stress-strain curve of sample on Plate XXXI, Fig. 1.

## Plate XXXIII

Fig. 1. Sample poured in 700 degree F. mold.

Fig. 2. Section of Fig. 1.

## Plate XXXIV

Fig. 1. Stress-strain curve of sample on Plate XXXIII, Fig. 1.

## Plate XXXV

Fig. 1. Sample poured in 700 degree F. mold.

Fig. 2. Section of Fig. 1. Right hand half has been etched, revealing the macrostructure.

## Plate XXXVI

Fig. 1. Stress-strain curve of sample shown on Plate XXXV, Fig. 1.

## Plate XXXVII

Fig. 1. Sample poured in mold at 800 degrees F. Note that tensile portion did not fill completely. This is due in part to the tilt of the mold.

Fig. 2. Section of Fig. 1.

## Plate XXXVIII

Fig. 1. Sample poured in mold at 800 degrees F.

Fig. 2. Section of Fig. 1.

Fig. 3. Macrostructure of Fig. 2. Note that grain size is becoming increasingly larger as mold temperature increases.

## Plate XXXIX

Fig. 1. Stress-strain curve of sample shown on Plate XXXVIII, Fig. 1.

## Plate XL

Fig. 1. Sample poured in mold at 800 degrees F.

Fig. 2. Section of Fig. 1. Note pronounced porosity.

Fig. 3. Sample poured in mold of 800 degrees F. Note the misrun in the tensile specimen. This sample was left in the mold for about five minutes. It was thought that gas close to the surface of the mold produced the frosty appearance on the surface of this casting.

Fig. 4. Section of Fig. 3. Note amount of porosity in this sample.

## Plate XLI

Fig. 1. Stress-strain curve of sample in Plate XL, Fig. 1.

## Plate XLII

Fig. 1. Sample poured in mold of 900 degrees F. Sample was difficult to remove from the mold without breaking due to hot shortness.

Fig. 2. Section of Fig. 1.

Fig. 3. Macrostructure of Fig. 2 showing decided increase in grain size over those in the previous plates.

## Plate XLIII

Fig. 1. Stress-strain curve of sample shown on Plate XLII, Fig. 1.

## Plate XLIV

Fig. 1. Sample poured in mold of 1000 degrees F. Sample extremely fragile and difficult to remove from mold at this temperature without breaking. Mold temperature too high for practical purpose.

Fig. 2. Section of Fig. 1. Note solid appearance of this section.

Fig. 3. Macrostructure of sample shown in Fig. 2. Note again the large grain size.

Plate I

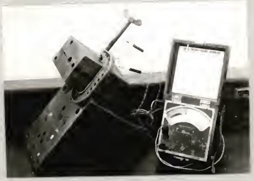

Fig. 1

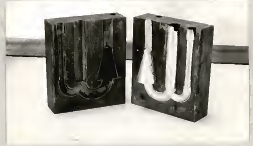

Fig. 2

Plate II

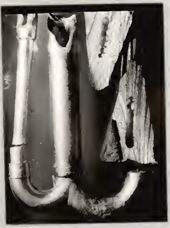

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Plate III

Fig. 1

Fig. 2

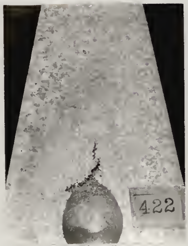

Fig. 3

Plate IV

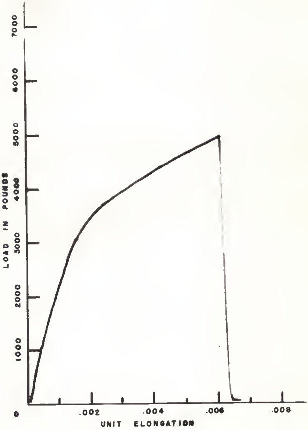

Fig. 1

# Plate V

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Plate VI

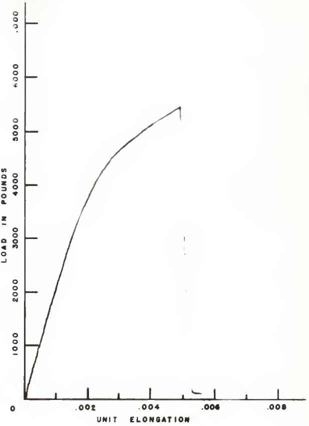

Fig. 1

Plate VII

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Plate VIII

Fig. 1

Fig. 2

Plate IX

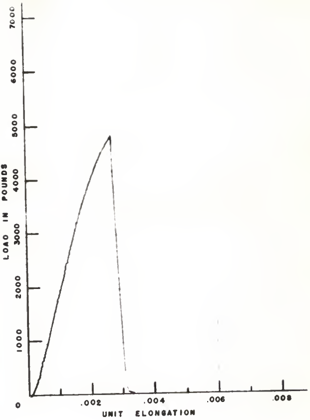

Fig. 1

Plate X

Fig. 1

Fig. 2

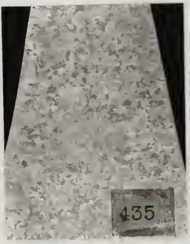

Fig. 3

Plate XI

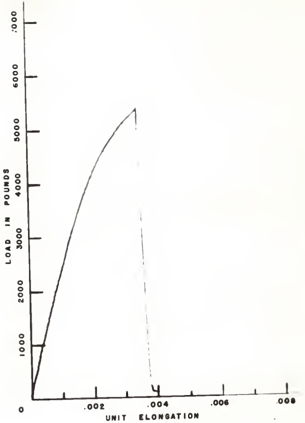

Fig. 1

Plate XII

Fig. 1

Fig. 2

Plate XIII

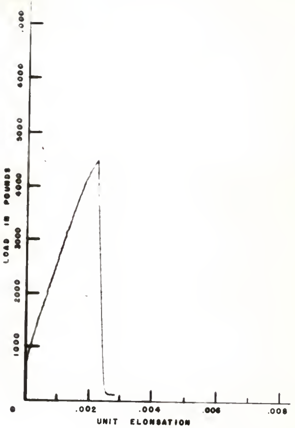

Fig. 1

Plate XIV

Fig. 1

Fig. 2

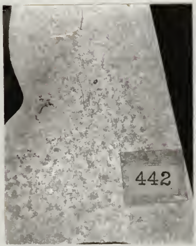

Fig. 3

# Plate XV

Fig. 1

Fig. 2

Plate XVI

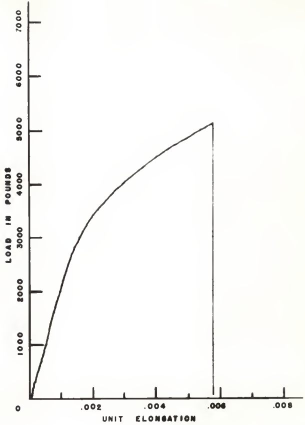

Fig. 1

# Plate XVII

Fig. 1

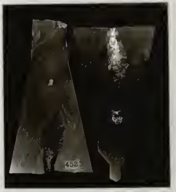

Fig. 2

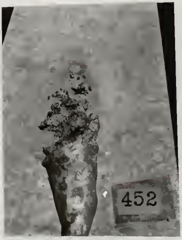

Fig. 3

Plate XVIII

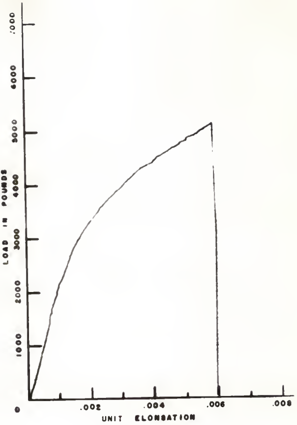

Fig. 1

# Plate XIX

Fig. 1

Fig. 2

Plate XX

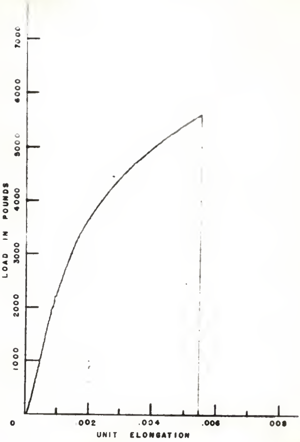

Fig. 1

# Plate XXI

Fig. 1

Fig. 2

Plate XXII

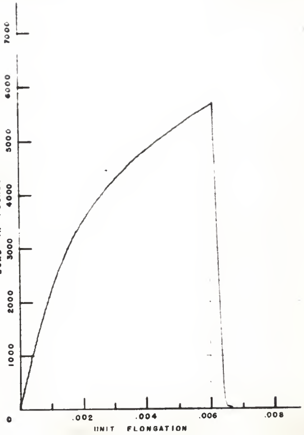

Fig. 1

# Plate XXIII

Fig. 1

Fig. 2

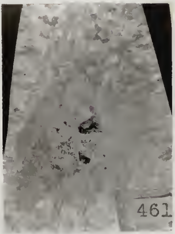

Fig. 3

Plate XXIV

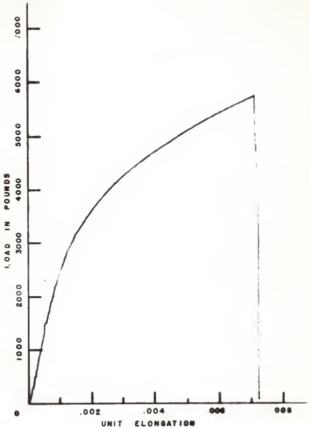

Fig. 1

Plate XXV

Fig. 1

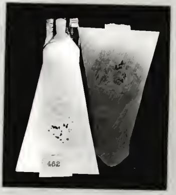

Fig. 2

Plate XXVI

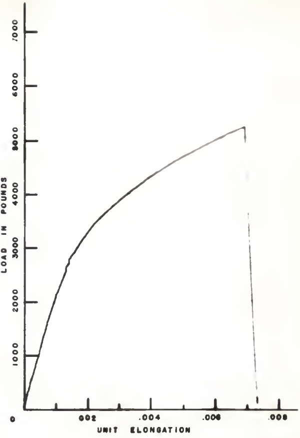

Fig. 1

# Plate XXVII

Fig. 1

Fig. 2

Plate XXVIII

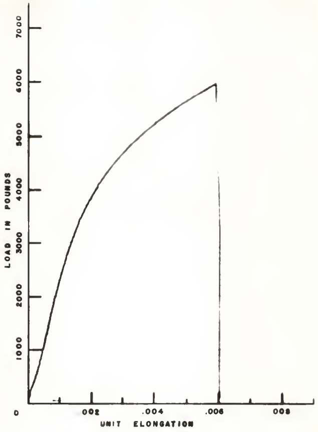

Fig. 1

Plate XXIX

Fig. 1

Fig. 2

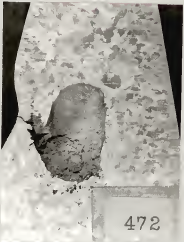

Fig. 3

Plate XXX

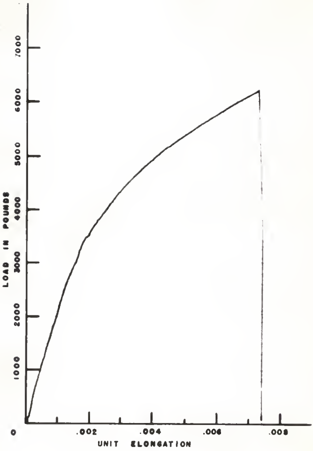

Fig. 1

# Plate XXXI

Fig. 1

Fig. 2

Plate XXXII

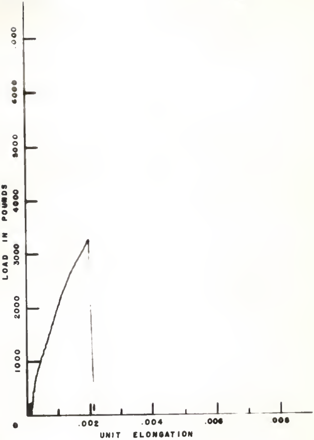

Fig. 1

## Plate XXXIII

Fig. 1

Fig. 2

Plate XXXIV

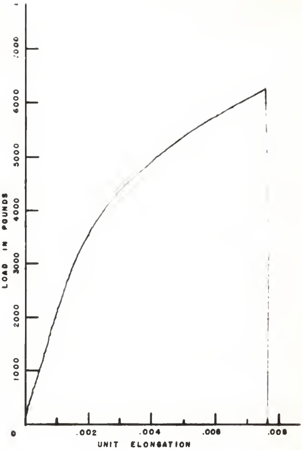

Fig. 1

Plate XXXV

Fig. 1

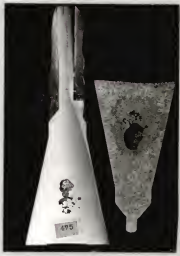

Fig. 2

Plate XXXVI

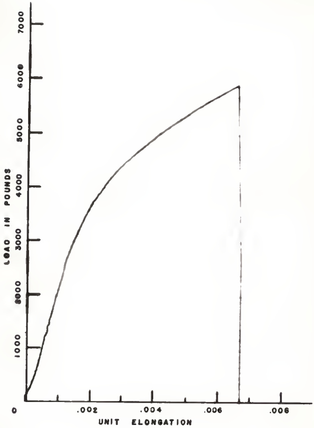

Fig. 1

Plate XXXVII

Fig. 1

Fig. 2

Plate XXXVIII

Fig. 1

Fig. 2

Fig. 3

Plate XXXIX

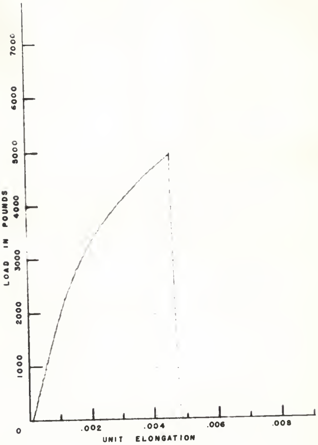

Fig. 1

# Plate XL

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Plate XLI

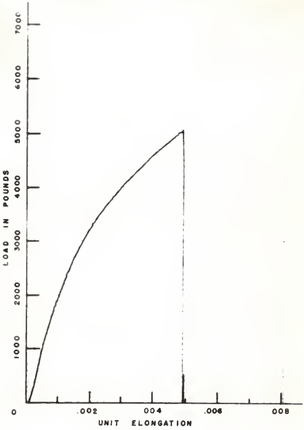

Fig. 1

Plate XLII

Fig. 1

Fig. 2

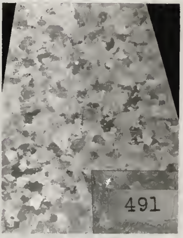

Fig. 3

Plate XLIII

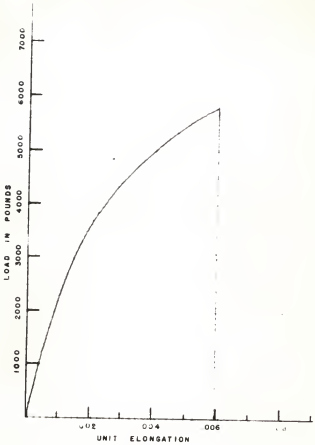

Fig. 1

Plate XLIV

Fig. 1

Fig. 2

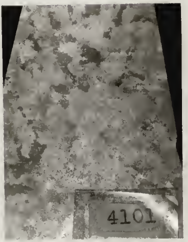

Fig. 3

## EXPERIMENTAL DATA

Before the tensile specimens were pulled the diameters were measured and the areas calculated. Knowing the area of the cross section and the load required to break the specimen the ultimate tensile strength was computed. These values were averaged and plotted against mold temperatures as shown in Plate XLV. It will be noted that there is a slight increase in strength as the mold temperature increases. The experimental samples reached the greatest strength when poured in a mold at 700 degrees F.

It is an interesting fact that all tensile specimens were within a few thousandths of an inch of being the same size. The little variation found was apparently due to shrink.

After the tensile specimens were pulled, Rockwell hardness readings were taken along the length of the samples. Readings were taken in six different positions on each sample and averaged. Readings that varied more than a few points were discarded. The hardness readings thus obtained for each particular mold temperature were averaged and plotted against mold temperature. These results are shown on Plate XLVI. It should be noted that there is not too close a correlation between Rockwell hardness and tensile strength. This may be partially attributed to the fact that the Rockwell penetrator covers such a small area. The depth of chill may also affect the results.

## Table 1

### Data on individual samples

All samples poured at 1400 degrees F. metal temperature.

| Sample Number | Mold Temp. | $R_B$ | Area | Load | Ultimate Strength p. s. i. |
|---|---|---|---|---|---|
| 411 | 100 | 32 | | | |
| 412 | 100 | 49 | | | |
| 421 | 200 | 41 | | | |
| 422 | 200 | 44 | .192 | 5000 | 26000 |
| 423 | 200 | 58 | | | |
| 431 | 300 | 56 | .196 | 5440 | 27800 |
| 432 | 300 | 60 | | | |
| 433 | 300 | 59 | | | |
| 434 | 300 | 51 | .195 | 4800 | 24600 |
| 435 | 300 | 60 | .193 | 5400 | 28000 |
| 441 | 400 | 59 | .191 | 4480 | 23600 |
| 442 | 400 | 56 | | | |
| 451 | 500 | 51 | .197 | 5120 | 26000 |
| 452 | 500 | 51 | .195 | 5160 | 26500 |
| 453 | 500 | 49 | .192 | 5620 | 29300 |
| 454 | 500 | 50 | .192 | 5700 | 29800 |
| 461 | 600 | 48 | .197 | 5720 | 29000 |
| 462 | 600 | 48 | .198 | 5200 | 26200 |
| 471 | 700 | 53 | .199 | 5910 | 29700 |
| 472 | 700 | 52 | .198 | 6200 | 31400 |
| 473 | 700 | 50 | | | |
| 474 | 700 | 52 | .198 | 6310 | 31900 |
| 475 | 700 | 53 | .198 | 5960 | 30000 |
| 481 | 800 | 54 | | | |
| 482 | 800 | 49 | .192 | 5000 | 26000 |
| 483 | 800 | 53 | .193 | 5060 | 26200 |
| 491 | 900 | 50 | .192 | 5800 | 30200 |
| 4101 | 1000 | 46 | | | |

Plate XLV

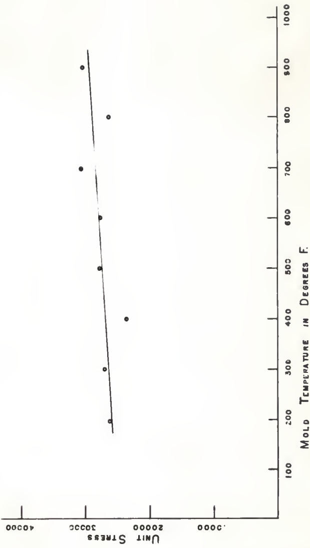

Fig. 1

Plate XLVI

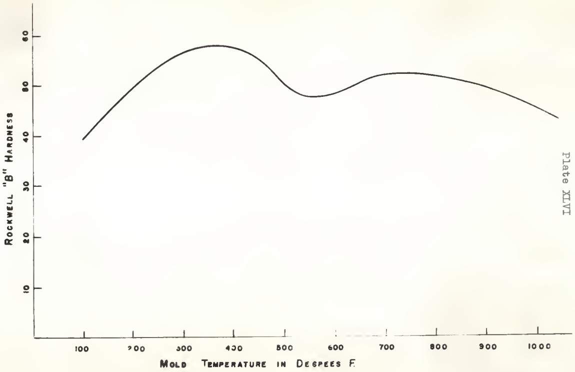

Fig. 1

## SUMMARY AND CONCLUSION

The results of this investigation may be summarized as follows:

1. Permanent molds would be a desirable means of quantity production of castings provided the volume is large enough and the casting not too complicated in shape.

2. The success of using this method for quantity production depends upon the mold design, gating, venting, pour control, temperature control both of the metal and the mold, and the selection of the proper alloy.

3. It was impossible to obtain satisfactory castings from this mold when the mold temperature was around 100 degrees F. due to the rapid chilling and contraction of the metal in a mold at this temperature.

4. Seven hundred degrees seemed to be the optimum temperature to use with this particular mold. At this temperature it would be possible to develop a satisfactory pouring cycle so that the mold temperature could be maintained by the heat of the molten metal.

5. At a 700 degree mold temperature the samples had good physical characteristics as shown by the stress-strain curves for these samples.

6. The grain size of a sample poured in a mold at 700 degrees seems to be fine enough for most purposes. Above this temperature the grain growth is quite rapid.

7. The highest temperature at which this mold may be used satisfactorily is somewhere between 900 and 1000 degrees F.

At any temperature above 800 degrees, external heat would probably have to be added to maintain the mold temperature.

8. Samples poured in this mold at 1000 degrees F. or above would be practically useless due to the difficulty of removal from the mold without damage.

In conclusion it may be said that much scientific data on this subject seems to be lacking. More will undoubtedly be done in this field as the use of permanent mold castings increases.

# ACKNOWLEDGEMENT

Indebtedness is acknowledged to Professor W. W. Carlson, Professor G. A. Sellers and the staff members of the Shop Practice Department for their advice and assistance in carrying out this research program. Their splendid cooperation made the work very enjoyable.

The service rendered by the Department of Applied Mechanics under the direction of Professor C. H. Scholer was also appreciated.

## REFERENCES

(1) Sugar, Alfred.
Permanent Mold Castings. Metals and Alloys, Vol. 21, April 1945, p. 1016.

(2) Aluminum Company of America.
Alcoa Customers Engineering Service--Design Details for Aluminum, 1944, p. 43.

(3) Vickers, John.
Permanent Mold Castings. The Foundry, Vol. 73, February 1945, p. 86.

(4) Sugar, Alfred.
Die Casting and Permanent Mold Casting. The American Metal Company, Limited, 1946.

(5) Fahlman, E. G., Chase, Herbert.
Aluminum Permanent Mold Castings. Iron Age, Vol. 149, April 23, 1942, p. 36.

(6) Chase, Herbert.
Permanent Mold and Die Castings Compared. Metals and Alloys, Vol. 14, Aug. 1941, p. 153; Nov. 1941, p. 699.

(7) Young, J. F.
Materials and Processes. John Wiley and Sons, New York, 1941, p. 351.

(8) Chase, Herbert.
Which Form of Non-Ferrous Casting? Metals and Alloys, Vol. 18, Sept. 1943, p. 496.

(9) Peters, Fred P.
Selecting Production Methods for Small Parts. Metals and Alloys, Vol. 20, July 1944, p. 89.

(10) Swoboda, L. F.
Light Metal Permanent Mold Castings. Iron Age, Vol. 154, Dec. 28, 1944, p. 56.

(11) Vickers, John.
The Mechanized Production of Aluminum Gravity Die Castings. Transactions, American Foundrymen's Assoc., Vol. 52, Sept. 1944, p. 49.

(12) Chase, Herbert.
Handbook of Designing for Quantity Production. McGraw-Hill Book Co., New York, 1944, Chapter 10.