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Report on
Design for Test Coupons
for
Steel Castings

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TABLE OF CONTENTS

<u>Title</u>	<u>Page</u>
Abstract	1
Authorization.	2
Statement of Problem	2
Known Facts Bearing on the Problem	2
Experimental Procedure	3
Use of Necking Cores	6
Conclusions.	7
Recommendations.	8
Bibliography	9

APPENDIXES

<u>Title</u>	<u>Table</u>
Properties of Test Specimens from Pattern Nos. 1 through 6	1
Comparison of the Physical Properties of Steel Castings by Means of Open and Blind Risers	2
Comparison of the Physical Properties of Specimens Cut from Pattern Nos. 3 and 7 with three-inch and six-inch Risers	3
Tensile Tests of Specimens from Heat No. 205 to Compare the Mechanical Properties of Steel Obtained from the Keel Block and Pattern No. 8.	4
Comparison of the Physical Properties of Specimens Taken from the Center of Blanks Cast in one-inch Square and two-inch square Sections	5
Properties of Test Specimens Poured With and Without Necking Cores	6

<u>Title</u>	<u>Plate</u>
Pattern No. 1	1
Pattern No. 2	2
Pattern No. 3	3
Pattern No. 4	4
Pattern No. 5	5
Pattern No. 6	6
Composite Mold.	7
Cope View of Composite Casting.	8
Drag View of Composite Casting.	9
Deep-etched Sections of Castings.	10
Test Coupon Made with Blind Riser	11
Pattern No. 7	12
Sections of Castings from Pattern No. 7 using three-inch and six-inch Risers	13
Pattern No. 8	14
Section of Casting from Pattern No. 8	15
Photograph Showing Pattern Nos. 1 through 6.	16
Front Elevation View - Pattern No. 7.	17
Plan View Drag Section Pattern No. 7.	18
Front Elevation View - Pattern No. 8.	19
Plan View Drag Section Pattern No. 8.	20
Plan View of Mold (drag) with Cores Inserted.	21

ABSTRACT

Several designs of test coupons were cast and their efficiencies in producing satisfactory blanks for tensile tests were compared on the basis of mechanical properties and economy of yield. Coupons of the cloverleaf type in which the tensile blanks are spaced around a central section not only give properties equal to or better than those of other more conventional types, but require much less riser metal per specimen. The blanks may be readily removed by a cold saw or torch.

The use of necking cores for facilitating removal of blanks from coupons was investigated and while not fully satisfactory showed some promise of utility. The meaning and limitations of coupon testing are discussed briefly.

Authorization

1. This work was authorized by Bureau of Engineering letter QP/Castings (6-19-Ds) of July 13, 1928.

Statement of Problem

2. The object of this investigation was to develop a test coupon for cast steel to meet the following requirements:

a. Soundness - the specimen blanks must be uniformly sound without centerline shrinkage and other defects attributable to the mold design.

b. Ease of Molding - the pattern must be simple and readily molded.

c. Ease of Cleaning - the design must be such as to produce a casting which can be easily cleaned and from which the specimen blanks can be readily removed.

d. Metal Economy - the test coupon should contain the least metal compatible with requirements a, b, and c.

Known Facts Bearing on the Problem

3. The chemical composition of a heat of steel may be well within the limits specified but the steel may fail to have the expected physical properties due to the variables of the furnace, deoxidization, and pouring practices. When steel is being made to meet specified physical properties as well as chemical composition, it is always desirable to determine the properties directly; this is done by removing specimens for such tests from so-called coupon castings. Further, several coupons may be taken during pouring of the heat to check the uniformity of the heat during that period.

4. It should be emphasized that the properties of the coupon are not necessarily the same as those of test pieces randomly removed from castings poured with metal from the same ladle (1). Shrinkage, sand spots, surface defects, etc., as influenced by pouring practice, mold design and molding practice, may occur in various locations with varying degrees of severity. The integrity of the castings themselves must be determined by means other than coupon testing; coupon testing answers only the question of metal quality as the metal comes from the ladle.

5. Since coupon testing is a criterion of metal quality only, it is desirable that the design be such that the maximum physical properties of the metal being tested are obtained consistently in the coupon. For example, if the design of the coupon provides only borderline feeding conditions, differences in pouring temperature could result in solid test blanks at one time and porous blanks at another time. Shrinkage not visible after deep etching or detectable by radiography can seriously lower ductility values. Therefore, it would seem desirable that a well designed test coupon be made standard throughout the steel castings industry. Such a coupon should conform to the requirements stated in Paragraph 2. Some work has been done in England in an effort to standardize a suitable rosette type of coupon for sampling cast steel (2).

Experimental Procedure

6. Six different basic patterns were studied and steel of the approximate composition 0.25 percent carbon, 0.60 percent manganese, and 0.45 percent silicon was used for all tests. The steel was melted in a basic-lined high frequency induction furnace and deoxidized with 0.10 percent aluminum before pouring.

7. Patterns for some of the test coupons used in this investigation are shown in the photographs of Plates 1 through 6. Pattern No. 1 is a conventional type and provides only two tensile blanks. Pattern No. 2 is a test piece frequently used at the Naval Research Laboratory in experimental work when a large number of tensile specimens are required. This coupon has fourteen tensile blanks but as many as are required can be added. Pattern No. 3 is somewhat similar to No. 2 but has only eight tensile blanks and a comparatively smaller riser. Pattern No. 4 is a type often used commercially; two tensile specimens and a bend specimen can be obtained from it. Patterns No. 5 and 6 are other designs which depend upon a blind riser to feed the blanks. The latter two patterns are designed for easy removal of the blanks from the coupons.

8. In order to minimize variations in properties arising from pouring the coupons separately the six different patterns were molded in one flask and poured through a single downgate with runners leading to the individual cavities. Plate 7 is the mold incorporating the six test coupons and Plates 8 and 9 are cope and drag views of the castings as removed from the mold.

9. Three specimens were sawed from each coupon except from Pattern No. 1 which provided only two specimens. The specimens were normalized from 1700°F. (925°C.) and tempered at 1200°F. (650°C.) followed by air cooling. After heat treatment standard 0.505 inch diameter shoulder grip tensile test specimens were machined from the blanks.

10. Density determinations were carried out on the machined tensile specimens. After thorough cleaning to remove grease and cutting compound, the specimens were weighed in air and then in water maintained at 20°C. The loss of weight in water, corrected for temperature, gave data for determining the volume of the specimen. The density was then calculated by the equation:

$$\text{Density} = \frac{\text{weight in air}}{\text{corrected volume}}$$

The mean values for the densities of the specimens from each coupon are shown in Table 1 and indicate that Patterns Nos. 1, 2 and 3 produce specimens of the highest degree of soundness.

11. The tensile tests, summarized in Table 1, confirm the values obtained in the density determinations. Coupons Nos. 1, 2 and 3 produce specimens having practically the same yield and tensile strengths, elongation and reduction of area. Specimens from Coupons Nos. 4, 5, and 6 show yield strengths and tensile strengths approximately the same as those of Coupons Nos. 1, 2 and 3 but exhibit a marked decrease in elongation and reduction of area, obviously due, to the presence of minute centerline shrinkage.

12. To show the amount and nature of the shrinkage cavities in the various coupons, the castings were sawed open and deep etched with hot, fifty percent hydrochloric acid after removal of the test specimens. The sectioned coupons are shown in Plate 10. In all coupons except No. 3, the gross shrinkage cavity was confined to the feed head. This is not conclusively significant, however, since upon close investigation, there is an indication of loose centerline structure in the tensile blanks obtained from the Coupons Nos. 4, 5 and 6 whereas those obtained from Coupons No. 1, 2, and 3 were apparently sound. The cause of such a condition is quite obvious from an examination of the coupon designs. In Coupons Nos. 1, 2, and 3, the smallest section (which ultimately becomes the tensile bar) draws its feed metal only a very short distance from the adjoining heavy section whereas in Coupons Nos. 4, 5 and 6 the remote portion of the small section must draw its feed metal a distance of approximately five inches through a one-inch section with very nearly parallel walls. Therefore, the proximity of the gross shrinkage cavity in and under the riser, to the specimen blank is less important than the method of joining the specimen blank to the adjacent heavy section. The shrinkage cavity in Coupon No. 3 extends down into the coupon itself but is concentrated at the center of the block and does not harm the tensile blanks. While the shrinkage in Coupons Nos. 4, 5, and 6 is not readily visible in the tensile blanks, the minute centerline shrinkage due to improper conditions of feeding proved detrimental to ductility.

13. Many practical foundrymen consider that the metal head, i.e., the height of the liquid metal above the location where the tensile specimen will be removed is important to the degree of soundness of the

specimen. From previous and present work at the Naval Research Laboratory the metal head does not appear to be important so long as sufficient metal is available to feed the solidifying specimen.

14. Plate 11 shows sketches of two test coupons. One coupon was cast in the conventional manner with the test blanks at the bottom. The other was cast with the test blanks at the top; feeding in this case was accomplished by the use of a blind riser gated into the heavy section at the bottom of the mold cavity. In the first case, both atmospheric pressure and ferrostatic head acted to force liquid metal into the test blank locations, whereas, in the latter case, only the force of atmospheric pressure acted and even it was diminished by the amount of ferrostatic head (3). Table 2 gives a comparison between the properties of the specimens cut from these coupons. The close agreement between these results indicate that the pressure head of metal is not the important consideration in determining the soundness of the test specimens.

15. Examination of the sectioned casting from Pattern No. 3 (Plate 10) indicated that the six-inch riser of the original design was not needed to produce sound specimens. To verify this assumption, castings were poured using risers six inches and three inches high, respectively. Two test coupons, each designed to provide four tensile test specimens, were also poured from this same heat. A photograph of this new pattern (No. 7) with the six-inch riser is shown in Plate 12. The four castings were poured in less than one minute elapsed time so there was little chance for the composition of the metal to change. The results of the tensile tests after heat treatment are summarized in Table 3, and indicate no significant difference between the properties obtained from coupons with three or six-inch risers. Photographs of the sections of these castings made from Pattern No. 7 are shown in Plate 13. Reducing the size of the riser permits the shrinkage pipe to extend further into the coupon. This is harmless to the tensile blank, as pointed out before, and reduces the amount of metal required. Of course, enough metal must be used to provide a adequate feeding of the blanks, but since they are almost completely surrounded by sand, and cool relatively rapidly compared to the main body of the coupon, a minimum of feed head is required.

16. It was found somewhat difficult to remove the sand from the space between adjacent blanks of the castings made from Pattern No. 3. To improve this condition the pattern design was modified as shown in Plate 14. This modified pattern design (No. 8) permits the casting to shrink away from the sand more readily, provides more efficient removal of heat from the casting, and lowers the amount of metal required per specimen blank. Tensile specimens from this coupon are free from centerline shrinkage and can be easily sawed or torch cut from the casting.

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17. To confirm the belief that the use of Pattern No. 8 produces specimens which have equivalent physical properties with those from proved designs, coupon castings from the same heat of steel were poured in molds made from Patterns Nos. 1 and 8. Blanks cut from these castings were heat treated together, specimens were machined, and tensile tests were made. The results which are given in Table 4 show that the physical properties are equivalent. It is also shown in the same table that only one-fifth of the metal required to make Coupon No. 1 is needed to make Coupon No. 8.

18. Table 1 shows the total weight of each of the coupon castings tested and the weight of metal required for each specimen obtained. Coupon Nos. 7 and 8 which yield four and eight specimens, respectively, require only four pounds of metal per specimen while Pattern No. 1 requires eighteen to twenty pounds and exhibits no better properties. Working drawings for Coupon Nos. 7 and 8 are shown in Plates 17-20.

19. To study the effect of the solidification variable caused by changing the section size of the specimen blanks, two test coupons were cast from the same heat of steel, one from Pattern No. 2, the other from a modification of Pattern No. 2 which was redesigned to produce a tensile blank with a two-inch square cross section. Bars having a one-inch square section were cut from the center of the two-inch square blanks and were heat treated with the blanks cast in one-inch square sections; this procedure eliminated any variable which might be attributed to the effect of section size upon response to heat treatment. Standard tensile bars were then made and tested. Average results are reported in Table 5. There is a definite indication of reduced strength and ductility in the coupon with the tensile blanks of the two-inch cross-section due to mass effect. This supports the theory that test bars indicate only the condition of the metal poured and not the properties to be found in the casting.

Use of Necking Cores

20. To facilitate removal of the specimen blanks from the No. 7 Coupon, and to eliminate the need for a cold saw or torch, necking cores were placed in the mold at the junction between the specimen blank and the body of the coupon. The details of this arrangement are shown in Plate 21.

21. Tests were conducted in one case with the opening between the cores one-quarter inch, and in another three-eighths inch. In a third mold the cores were omitted to provide control specimens for comparison with those made in molds having the necking cores. All three molds were poured from the same ladle of medium carbon steel. The cores provided the desired necking action, were readily removed from the casting, and it was possible to break the blanks from the casting with either the one-quarter inch or three-eighths inch neck.

22. Transverse disk specimens were cut from blanks from each of the coupons. These disks were examined radiographically and by deep-acid etching. No evidence of centerline shrinkage was discovered. Three blanks from each coupon were heat treated and machined into shoulder grip tensile test specimens. The mean values of the tensile tests of the two sets of castings are shown in Table 6. The effect of the necking cores upon the properties is not extremely consistent but does not seem to be markedly detrimental. The test data from Heat No. 401 indicate that there may be imperfect feeding of the blanks when the necking cores are used. This and the extra labor and care necessary in making the mold with the necking cores counterbalance some of the advantage of easy removal of specimen blanks.

Conclusions

23. The following conclusions can be drawn:

a. The cloverleaf type of coupon (Nos. 7 and 8) provides tensile blanks which are completely sound and which exhibit maximum strength and ductility. This type of coupon requires a minimum amount of metal poured per specimen blank obtained, and the blanks may be readily sawed or torch cut from the coupon.

b. Since specimen blanks cut from test coupons do not necessarily reflect the properties of the casting, some standard type of test coupon should be decided upon, and used as an indication of metal quality only.

c. Necking cores can be used on coupons of the cloverleaf type but may cause slightly lowered reduction of area as compared to that obtained in coupons made by the regular method. The specimens can be readily knocked from the coupon rather than sawed or torch cut.

d. Since ferrostatic head does not govern the quality of tensile specimen, considerable economy can be achieved by decreasing the ratio of riser metal to specimen blanks.

e. If a bend specimen is required, this can be obtained by substituting a section of suitable design for one of the tensile blanks.

Recommendations

24. It is recommended that consideration be given the inclusion in specifications for steel castings of a paragraph standardizing methods of coupon sampling and that the cloverleaf type of coupon be adopted as standard.

Unless otherwise instructed by the Bureau with fourteen (14) days from date, this test will be considered closed, and samples will be disposed of as follows: Melting Stock.

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1. C. W. Briggs and R. A. Gezelius, "The Effect of Mass Upon the Mechanical Properties of Cast Steel," NRL Report No. M-1376, July 14, 1937.
2. C. E. Kain and E. W. Dowson, "Design of Test Pieces for Carbon Steel Castings," Institute of British Foundrymen, Proceedings, 1939-40, Volume 33, pp. 61-65.
3. H. F. Taylor and E. A. Rominski, "Report on the Use of Blind Heads in the Manufacture of Steel Castings," NRL Report No. M-1783, September 29, 1941

TABLE 1

Properties of Test Specimens from Pattern Nos. 1 through 6.

Pattern Number	Yield Str. PSI	Ult. Ten. Str.-PSI	Elong.% in 2"	Redn. of Area - %	Density gm./cc.	Weight of Casting-Lbs.	No. of Specimens/casting	Wt. of metal per specimen lbs.
1	48,100	77,100	31.6	47.4	7.819	36-40	2	18-20
2	48,150	77,650	32.7	50.8	7.810	86.0	14	6.1
3	48,050	77,650	32.5	49.6	7.811	48.0	8	6.0
4	49,400	77,500	26.5	36.3	7.801	20.5	3	6.8
5	48,850	77,100	24.0	30.0	7.807	34.0	5	6.8
6	52,300	75,100	18.7	27.2	7.807	23.5	6	3.9

NOTES: Heat No. 203: C - 0.25%; Mn - 0.71%; Si - 0.45%
 Normalized - 1700°F. for 1 and 1/2 hours, A.C.
 Tempered - 1200°F. for 2 hours, A.C.

TABLE 2

Comparison of the Physical Properties of Steel Castings
Fed by Means of Open and Blind Risers. *

Specimen Number	Type of Riser	Yield Str. lb. per sq. in.	Tensile Str. lb. per sq. in.	Elong. % in 1½-in.	Redn. of Area -%
A 1	Open	63,800	78,400	30.2	65.4
A 2	"	63,300	77,000	30.2	66.3
Average	"	63,550	77,700	30.2	65.9
B 1	Blind	64,000	77,600	30.2	68.0
B 2	"	63,200	76,600	32.2	68.0
Average	"	63,600	77,100	31.2	68.0

NOTES: C - 0.13%; Mn - 0.70%; Si - 0.95%; Cu - 1.69%; S - 0.03%; P - 0.03%.
Specimens dead annealed

(*) - This table originally appeared in NRL report No. M-1783, 29 September 1941 by H. F. Taylor and E.A. Rominski.

TABLE 3

Comparison of the Physical Properties of Specimens
Cut from Pattern Nos. 3 and 7 with Three-inch and Six-inch Risers.

Pattern Number	Height of Riser - ins.	Yield Str. PSI	Ultimate T.S.-PSI	Elong. % in 2"	Redn. of Area -%
3	3	40,850	67,100	34.8	53.9
3	6	41,350	66,750	33.7	52.0
7	3	42,900	66,250	35.7	55.2
7	6	43,250	65,350	35.2	54.9

NOTES: C - 0.22%; Mn - 0.47%; Si - 0.47%
Normalized - 1700°F. for 1 and 1/2 hours, A.C.
Tempered - 1200°F. for 2 hours, A.C.

TABLE 4

Tensile Tests of Specimens from Heat No. 205 to Compare
The Mechanical Properties of Steel Obtained from
the Keel Block and Pattern No. 8.

Pattern Number	Yield Str. PSI	Ultimate T.S.-PSI	Elong. % in 2"	Redn. of Area-%	Wt. of Casting - Lbs.	No. of Specimens	Wt. of Metal/Specimen
1 (keel block)	43,650	72,900	31.5	46.4	40	2	20
8	44,650	73,100	32.2	47.6	32	8	4

NOTES: C - 0.23%; Mn - 0.58%; Si - 0.49%
Normalized - 1700°F., for 1 and 1/2 Hours, A.C.
Tempered - 1200°F., for 2 hours, A.C.

TABLE 5

Comparison of the Physical Properties of Specimens
Taken from the Center of Blanks Cast in one-inch
Square and two-inch Square Sections.

Size of Blank	Yield Str. PSI	Ultimate Ten. Str.	Elong. % in 2"	Redn. of Area - %
1" x 1"	58,000	85,000	28.8	49.2
2" x 2"	53,400	83,400	26.5	41.9

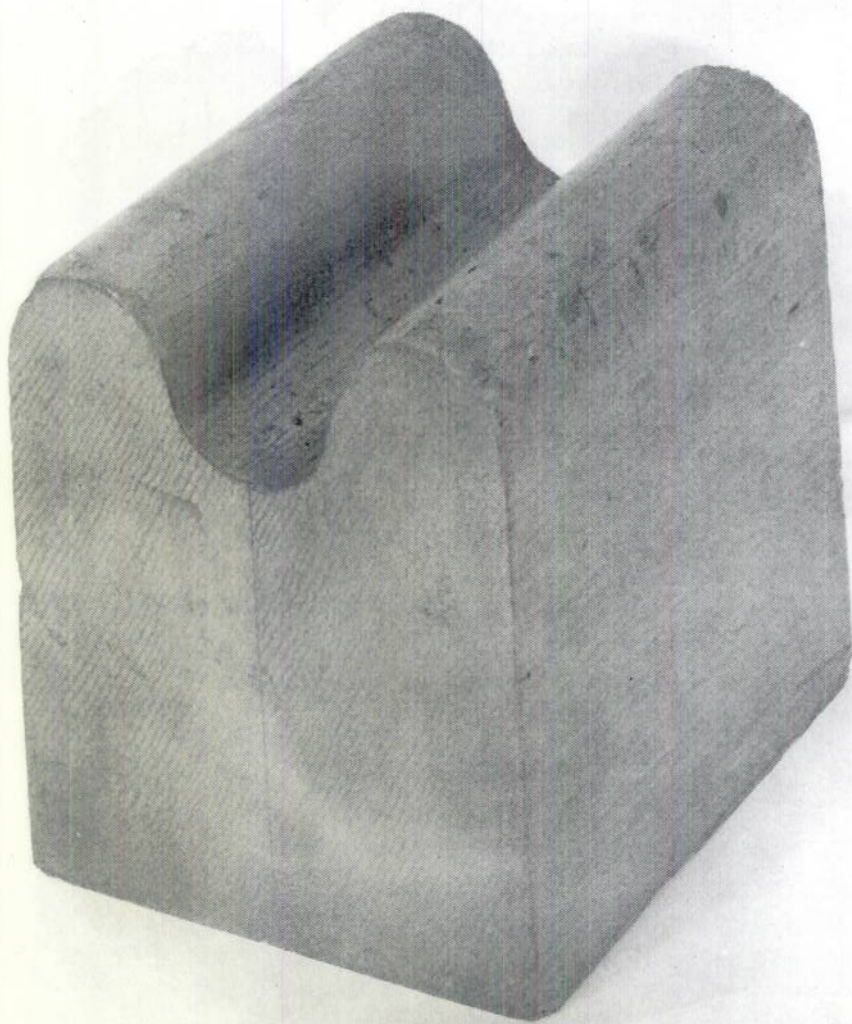
NOTES: C - 0.29%; Mn - 0.73%; Si - 0.49%
Normalized - 1700°F. for 1 and 1/2 hours, A.C.
Tempered - 1200°F. for 2 hours, A.C.

TABLE 6

Properties of Test Specimens Poured With and Without Necking Cores

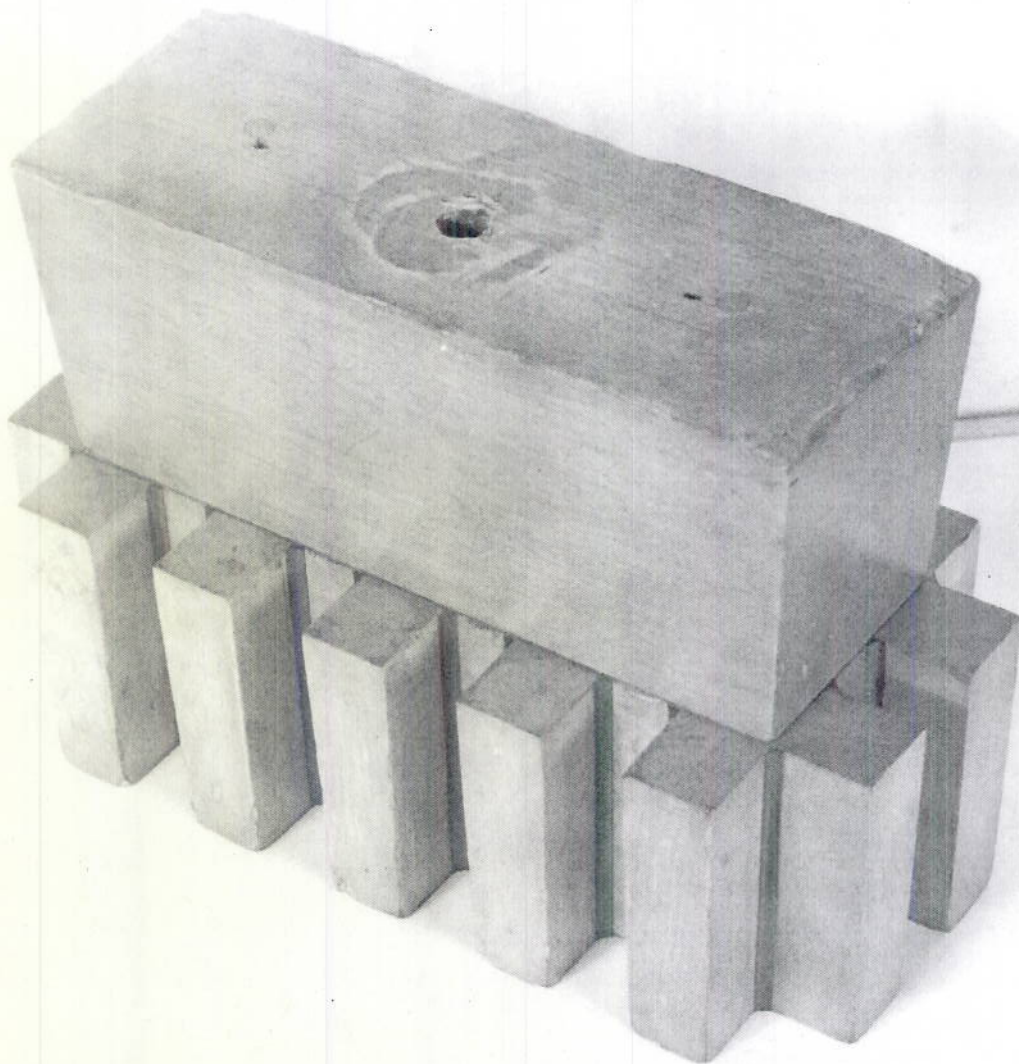
	Yield Str. PSI	Ultimate Ten. Str.	Elong. % in 2"	Redn. of Area - %
* Heat 401				
No cores	50,900	81,350	28.3	48.3
3/8" neck opening	53,100	81,750	27.0	36.5
1/4" neck opening	53,400	81,600	26.8	39.4
# Heat 403				
No cores	46,200	76,000	31.6	50.0
3/8" neck opening	46,150	75,300	32.2	54.3
1/4" neck opening	46,100	75,400	33.5	62.1

NOTES: (*) - C - 0.25%; Mn - 0.63%; Si - 0.53%
(#) - C - 0.31%; Mn - 0.61%; Si - 0.57%
Normalized - 1700°F. for 1 and 1/2 hours, A.C.
Tempered - 1200°F. for 2 hours, A.C.



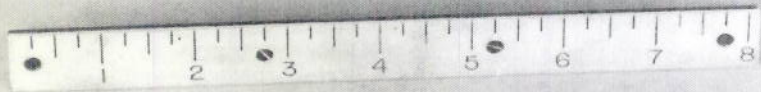
PATTERN NO. 1

PLATE I



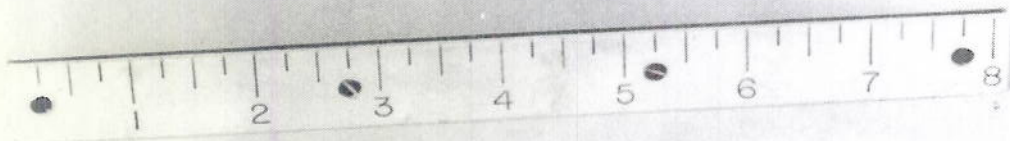
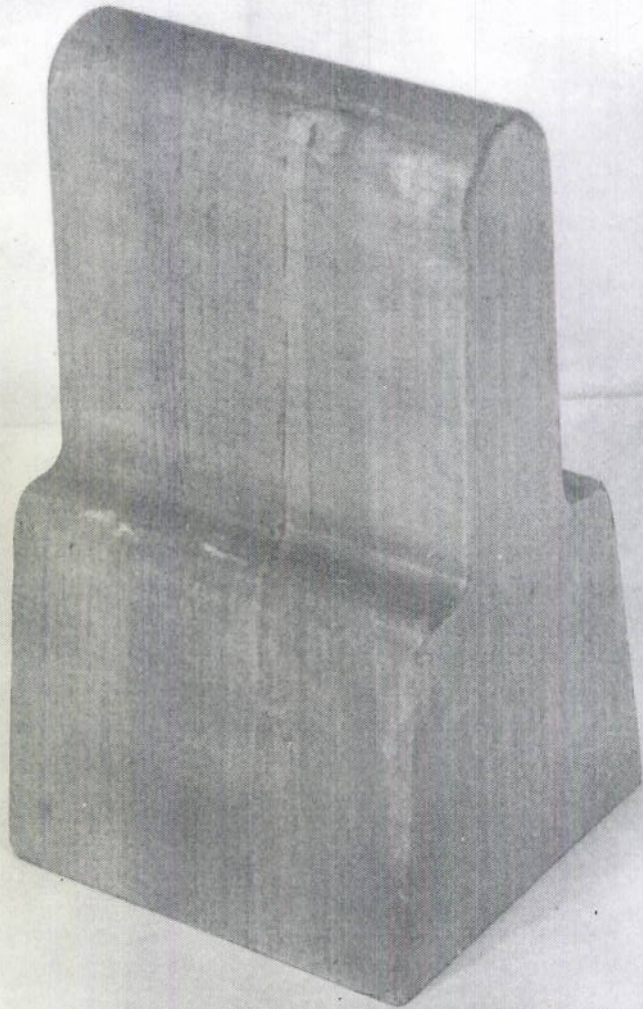
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DIATE A



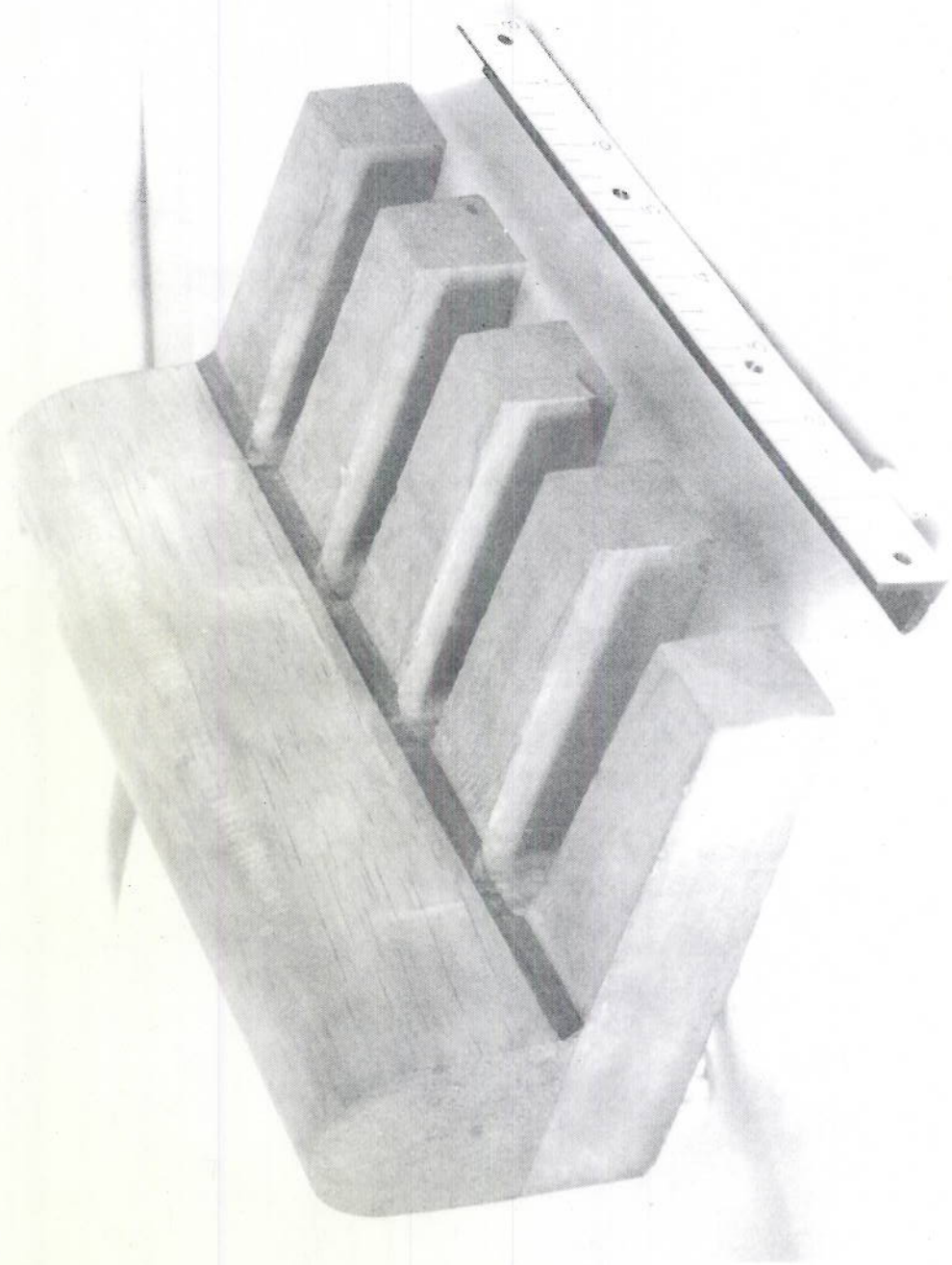
PATTERN NO. 3

PLATF 3

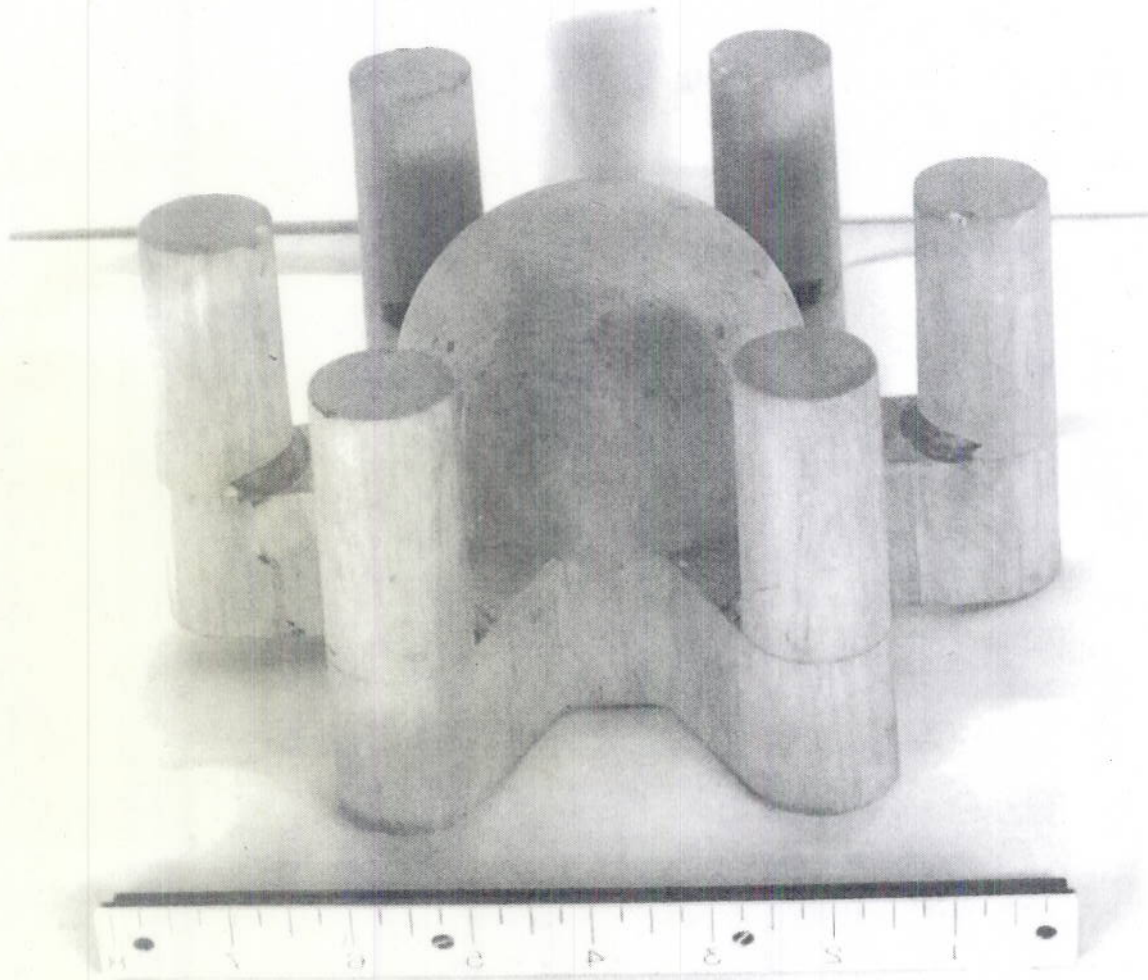


PATTERN NO. 4

PLATE 4

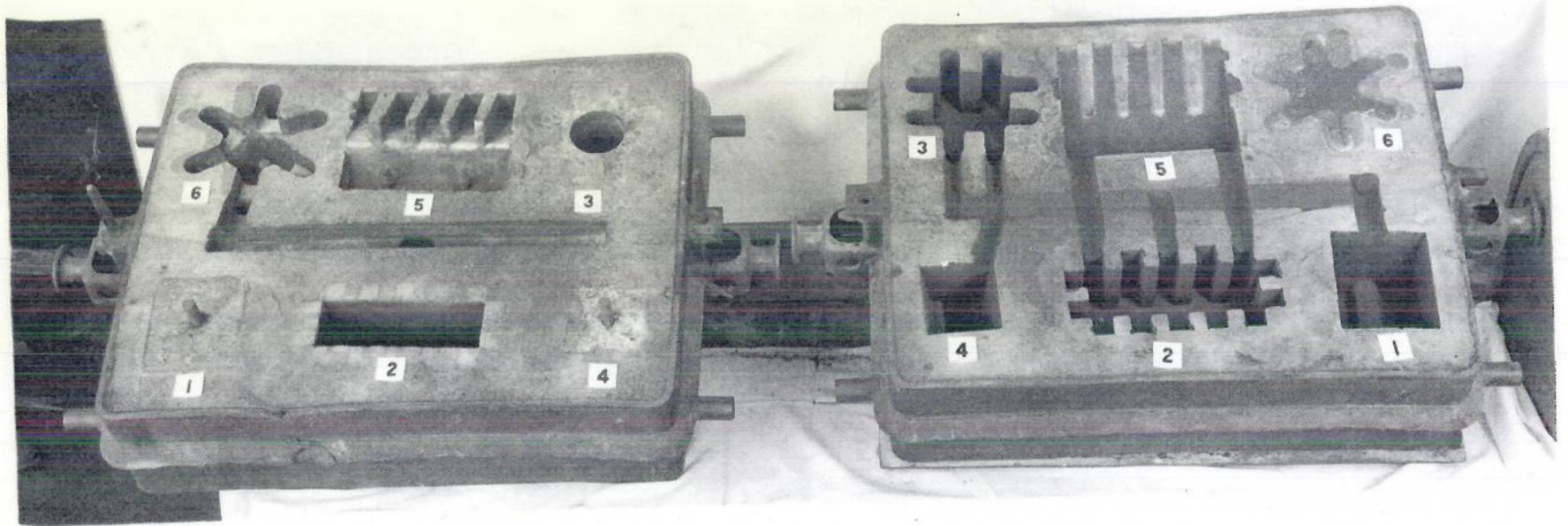


PATTERN NO. 5



PATTERN NO. 6

PLATE 6



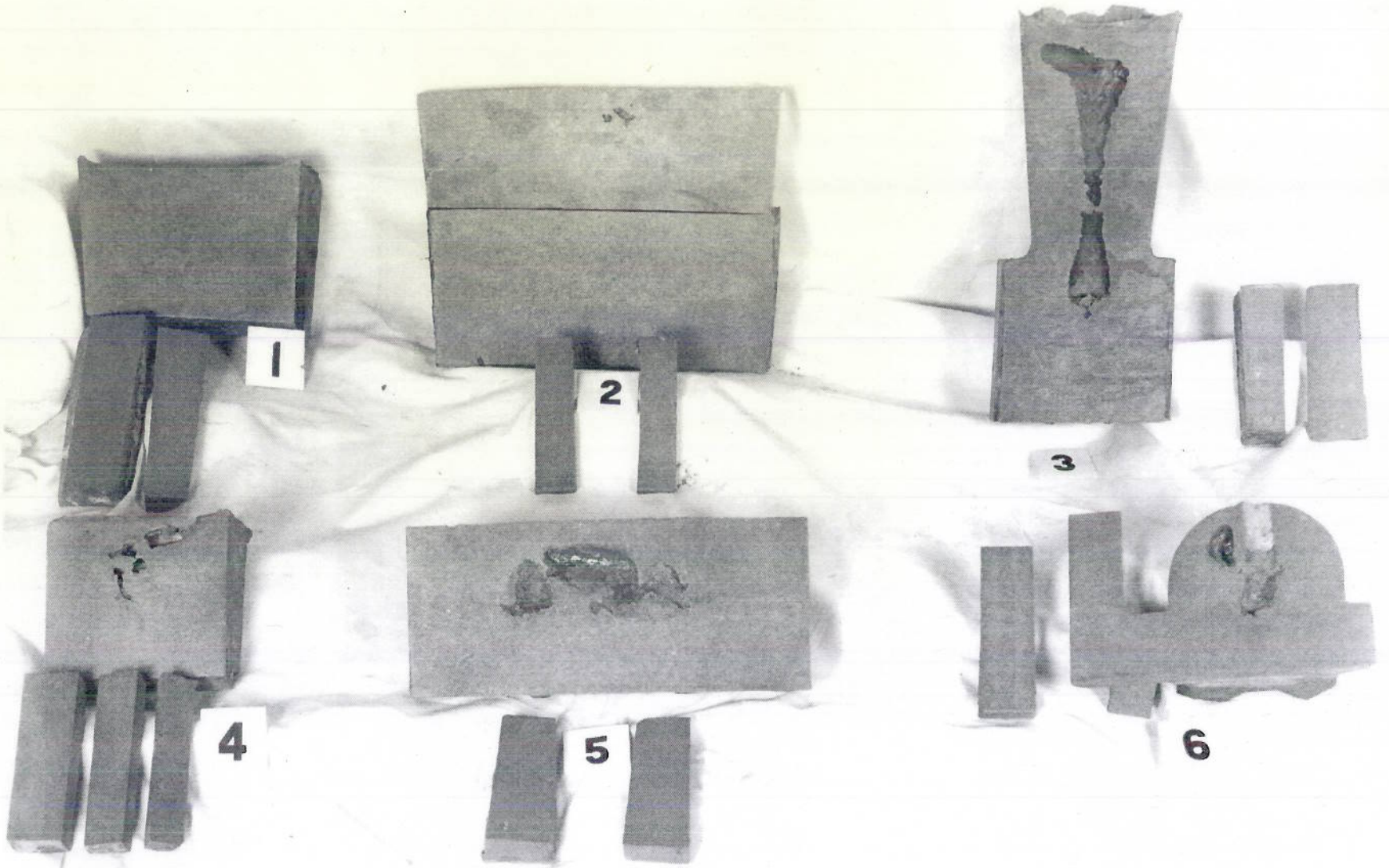
COMPOSITE MOLD



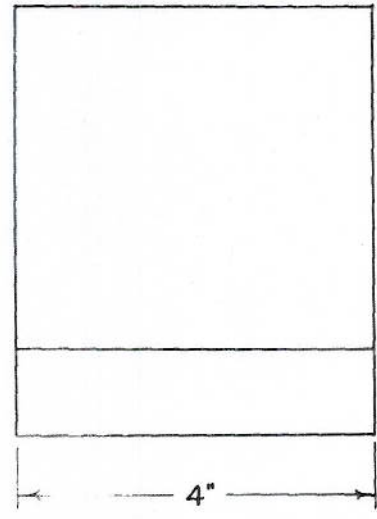
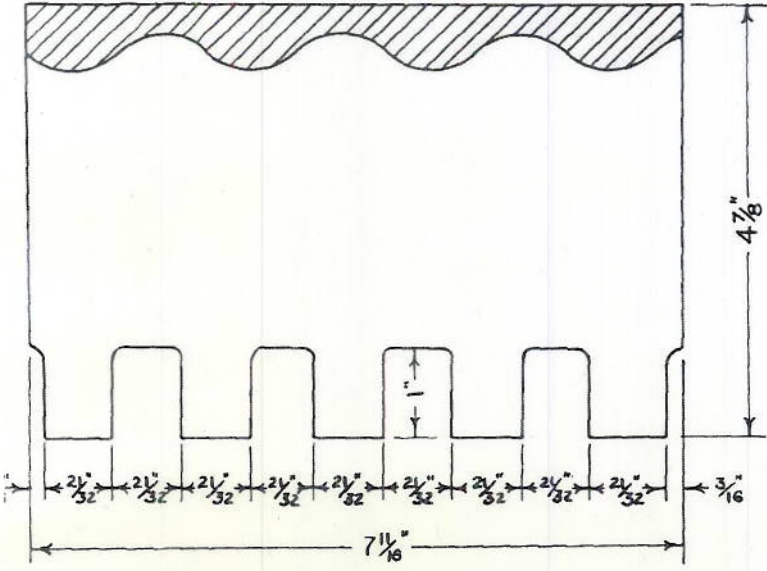
COPE VIEW OF COMPOSITE CASTINGS



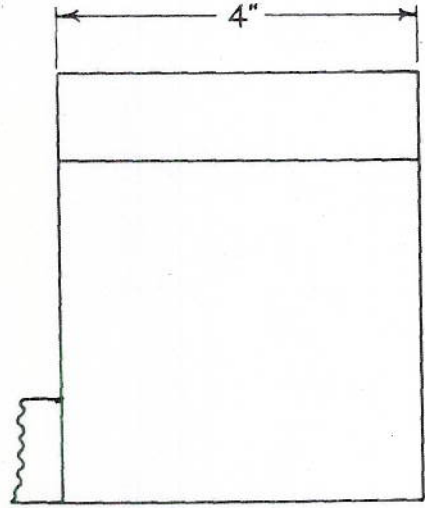
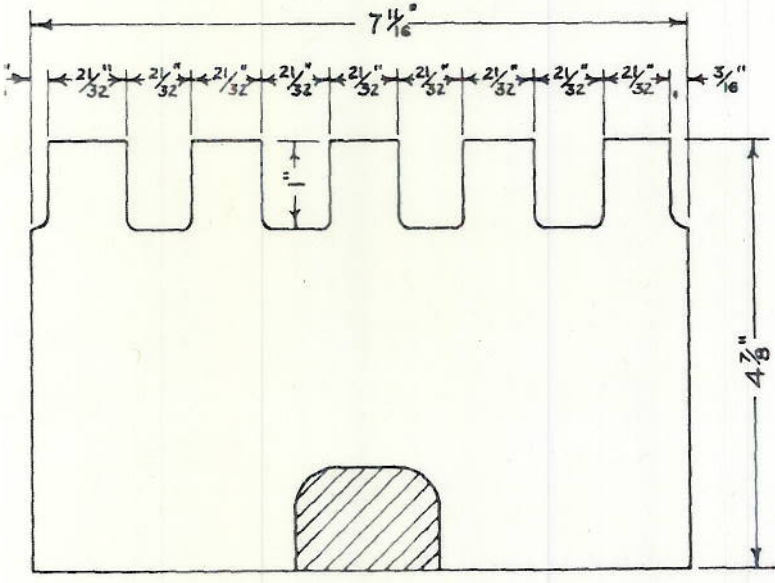
DRAG VIEW OF COMPOSITE CASTING



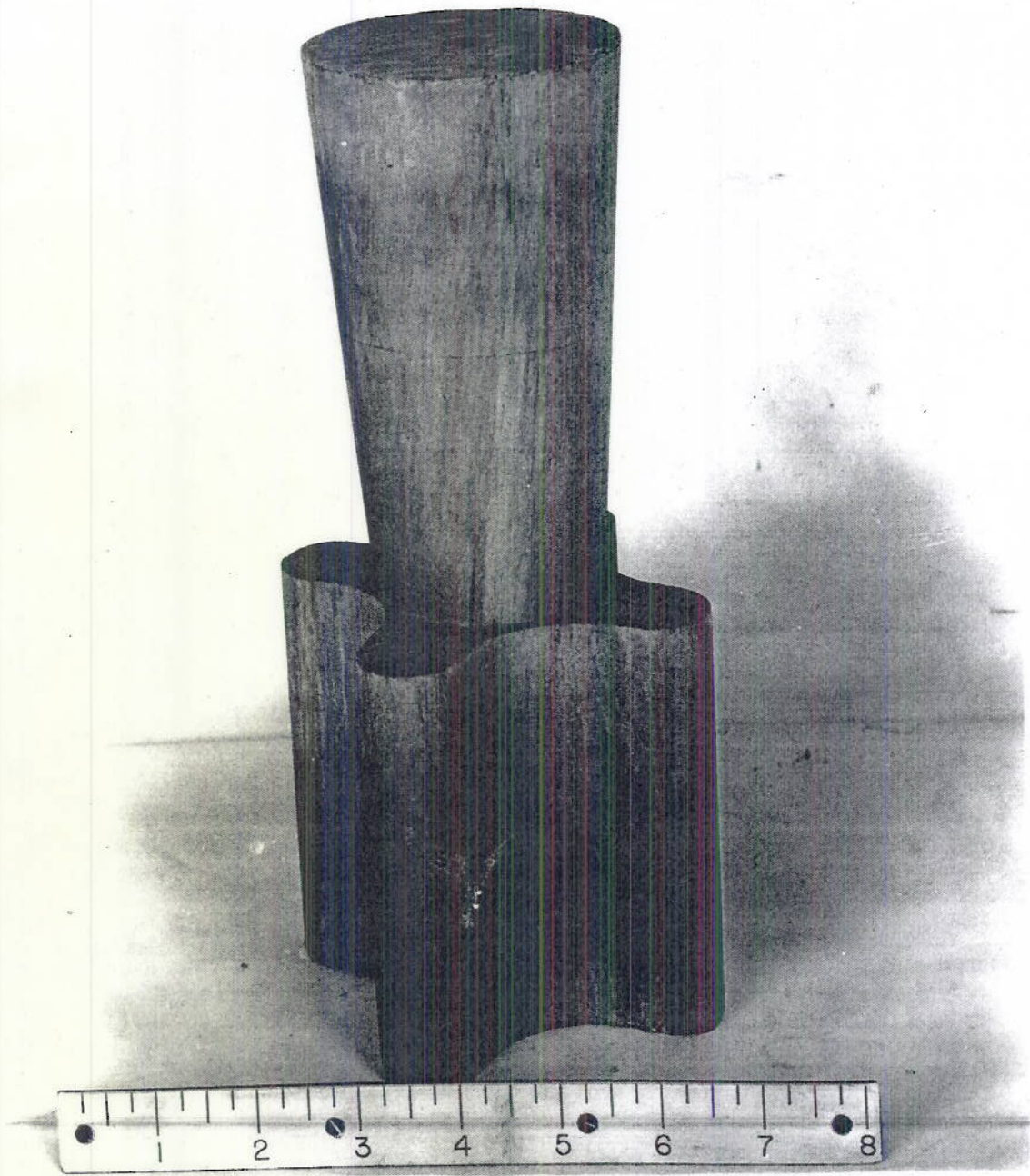
DEEP-ETCHED SECTIONS OF CASTINGS



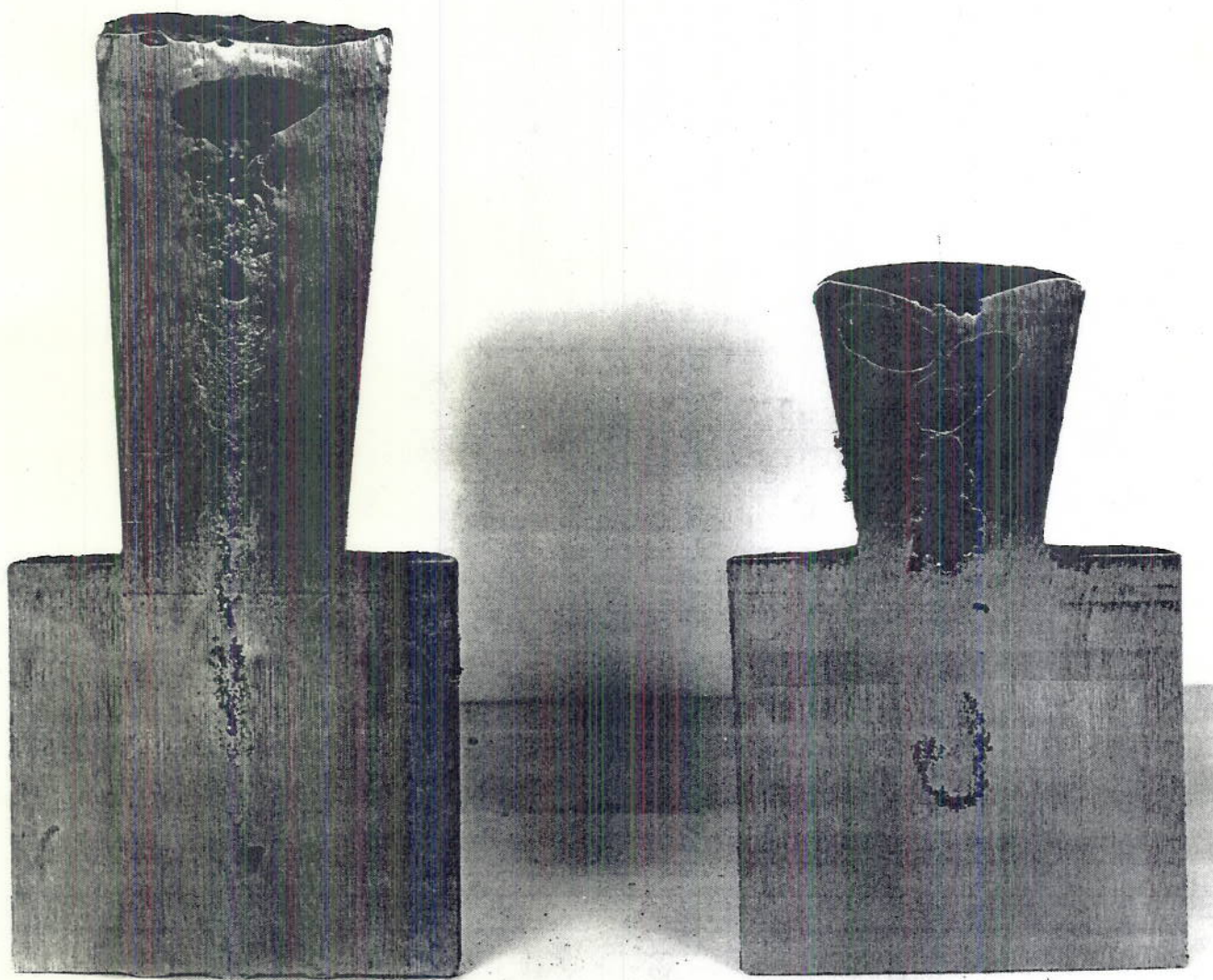
TEST COUPON MADE WITH OPEN RISER.



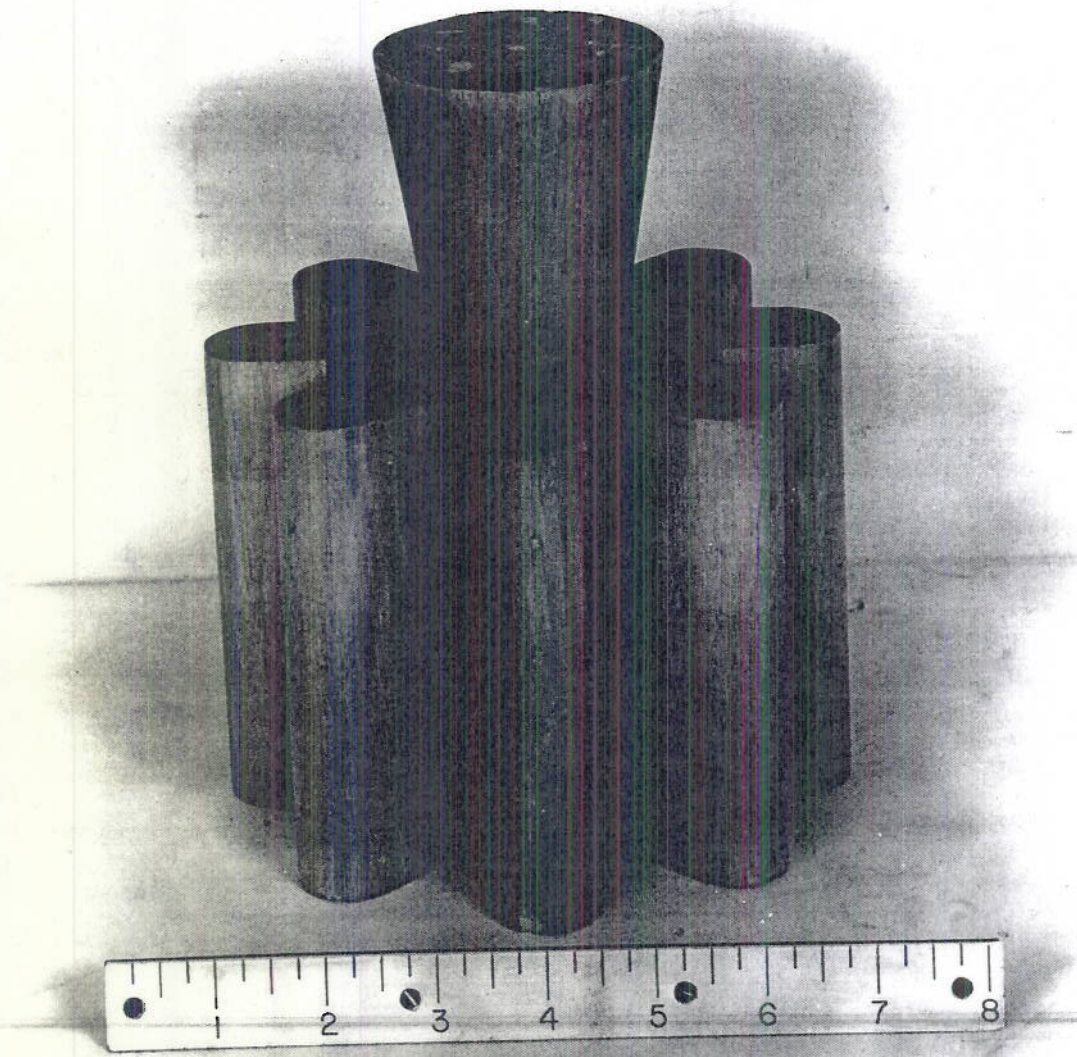
TEST COUPON MADE WITH BLIND RISER.



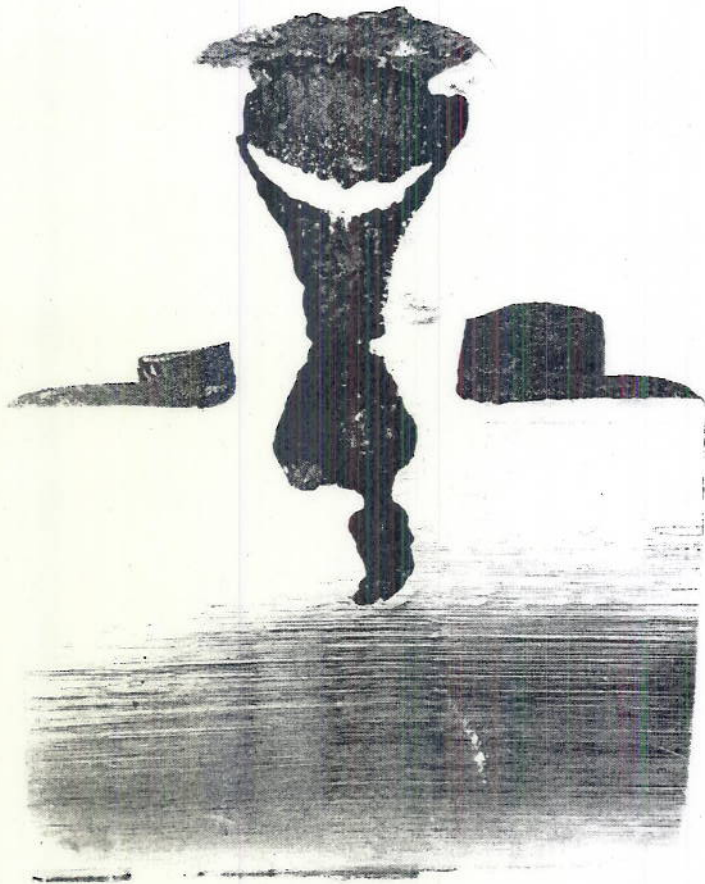
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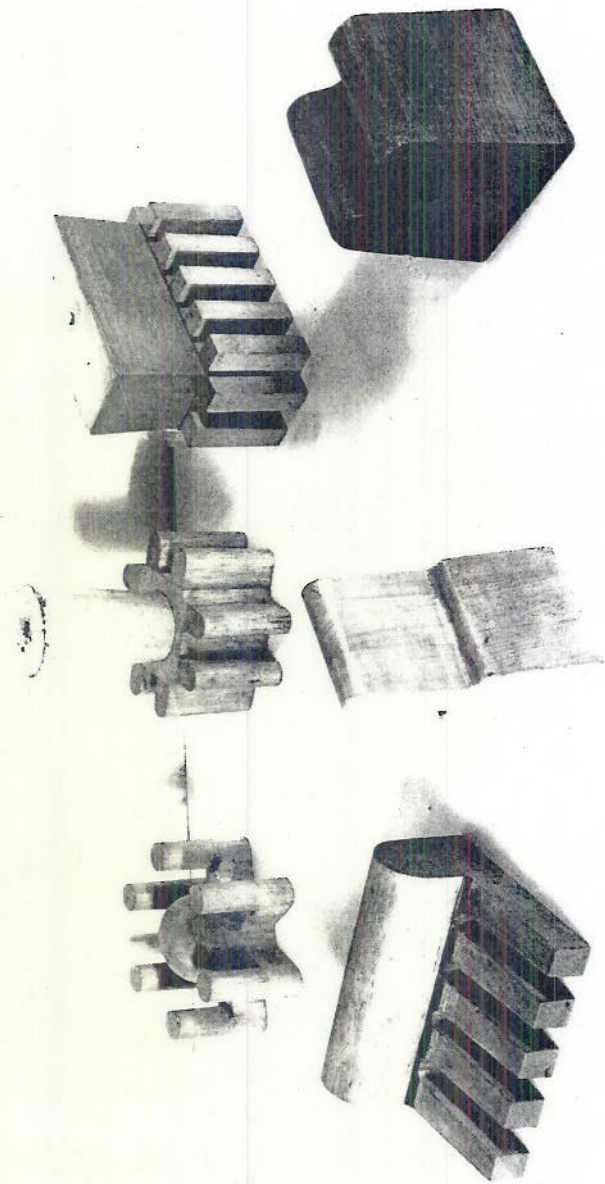
SECTIONS OF CASTINGS FROM PATTERN NO. 7
USING THREE INCH AND SIX INCH RISERS.



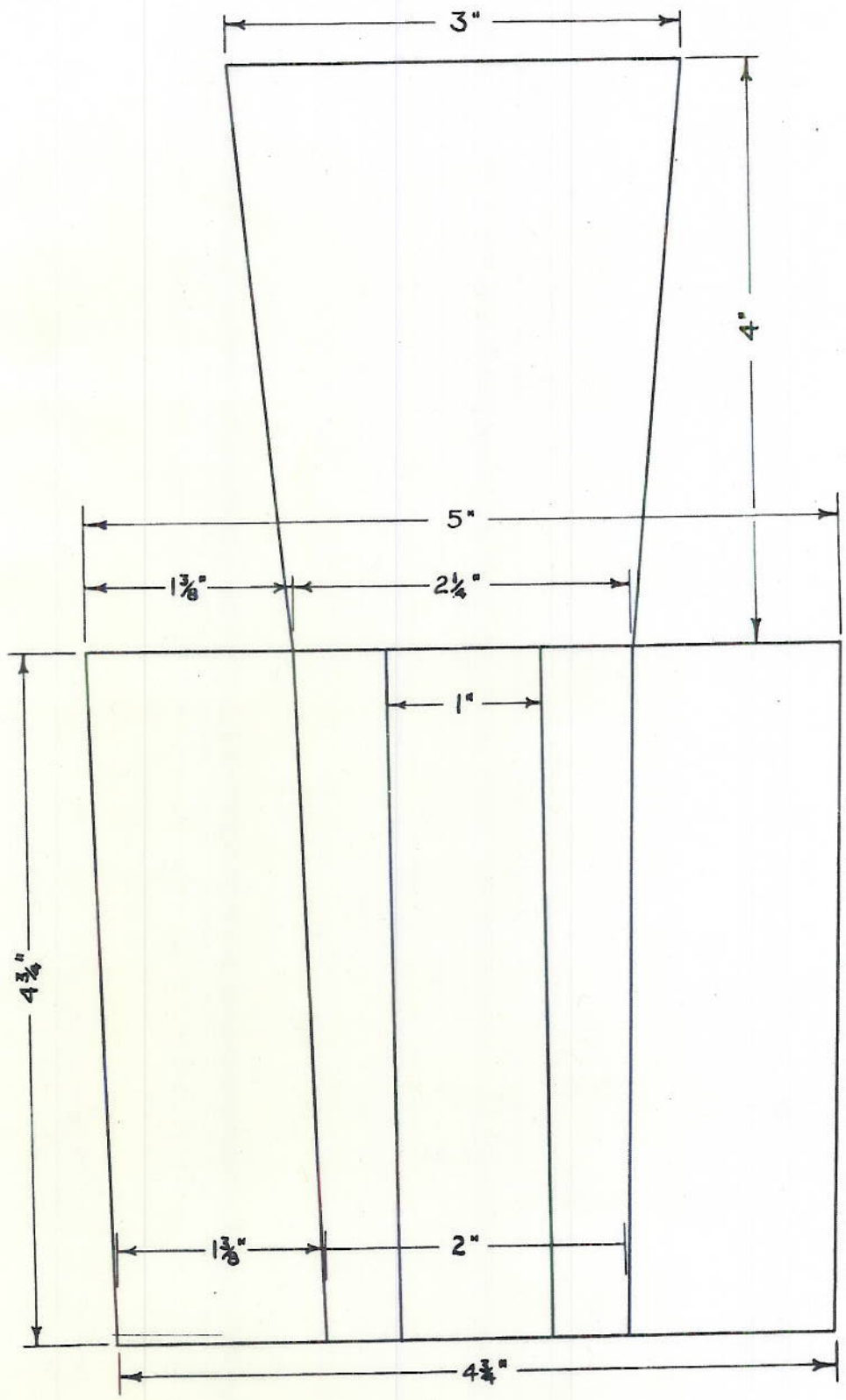
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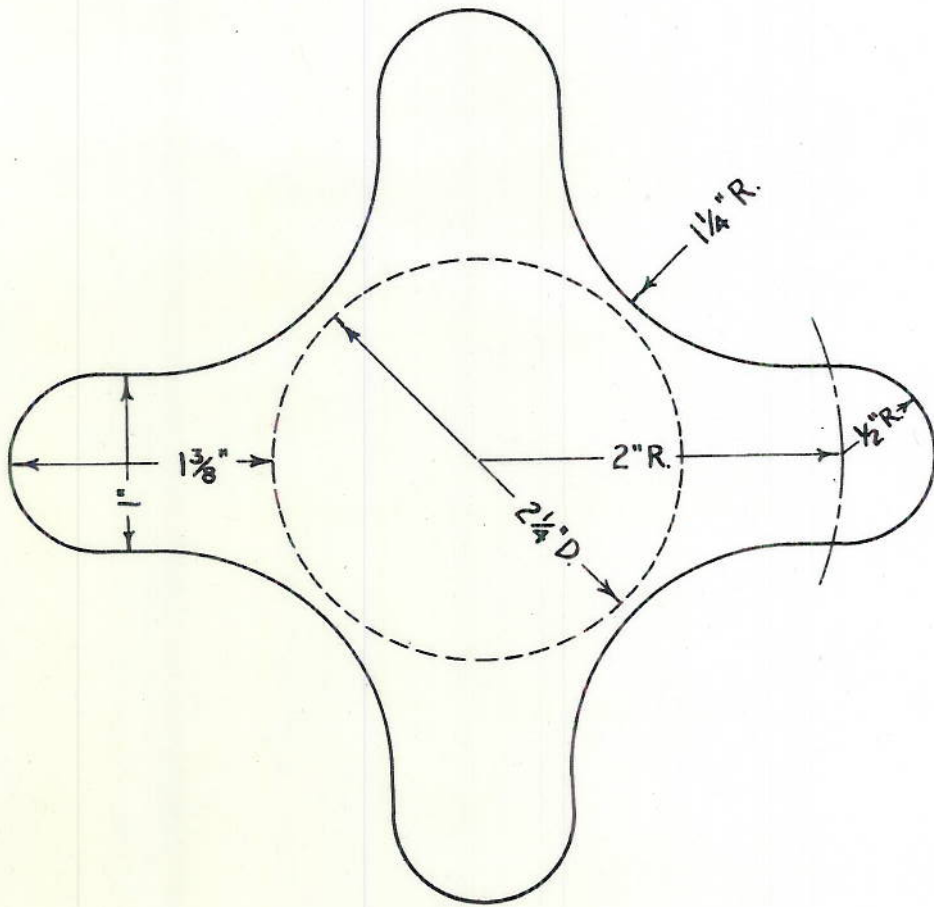
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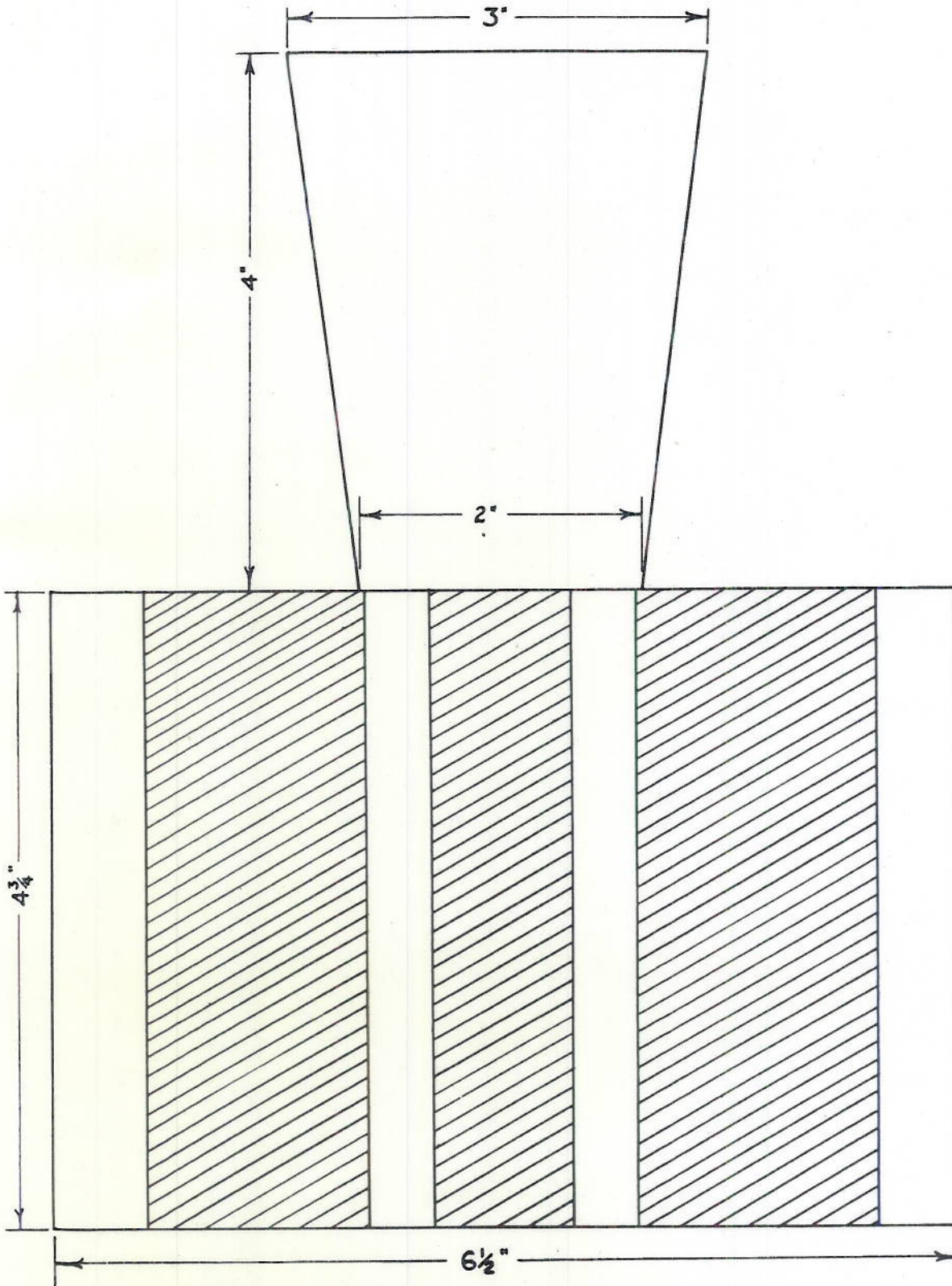
PHOTOGRAPH SHOWING PATTERN NO'S. 1-6



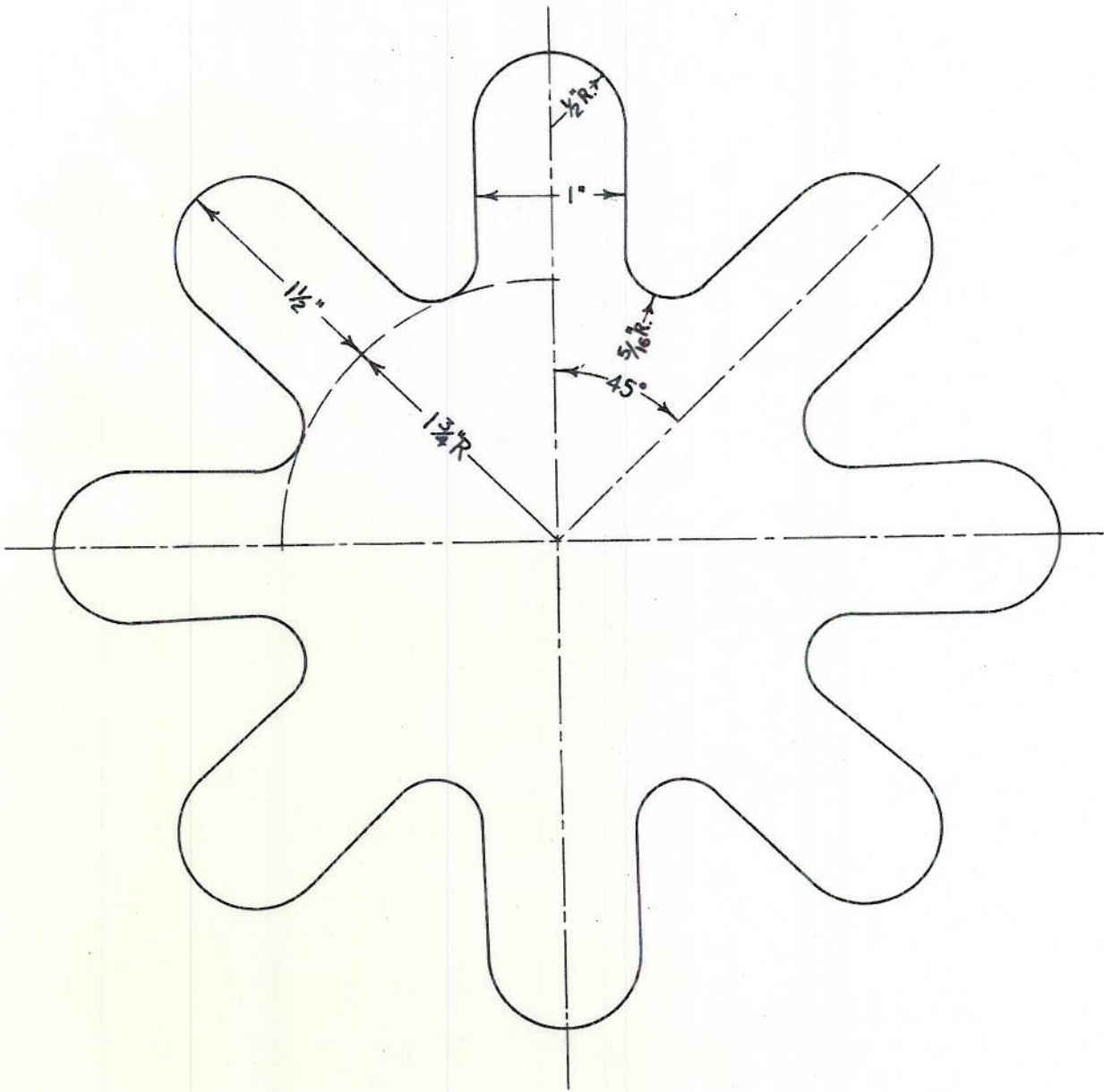
FRONT ELEVATION VIEW - PATTERN N° 7



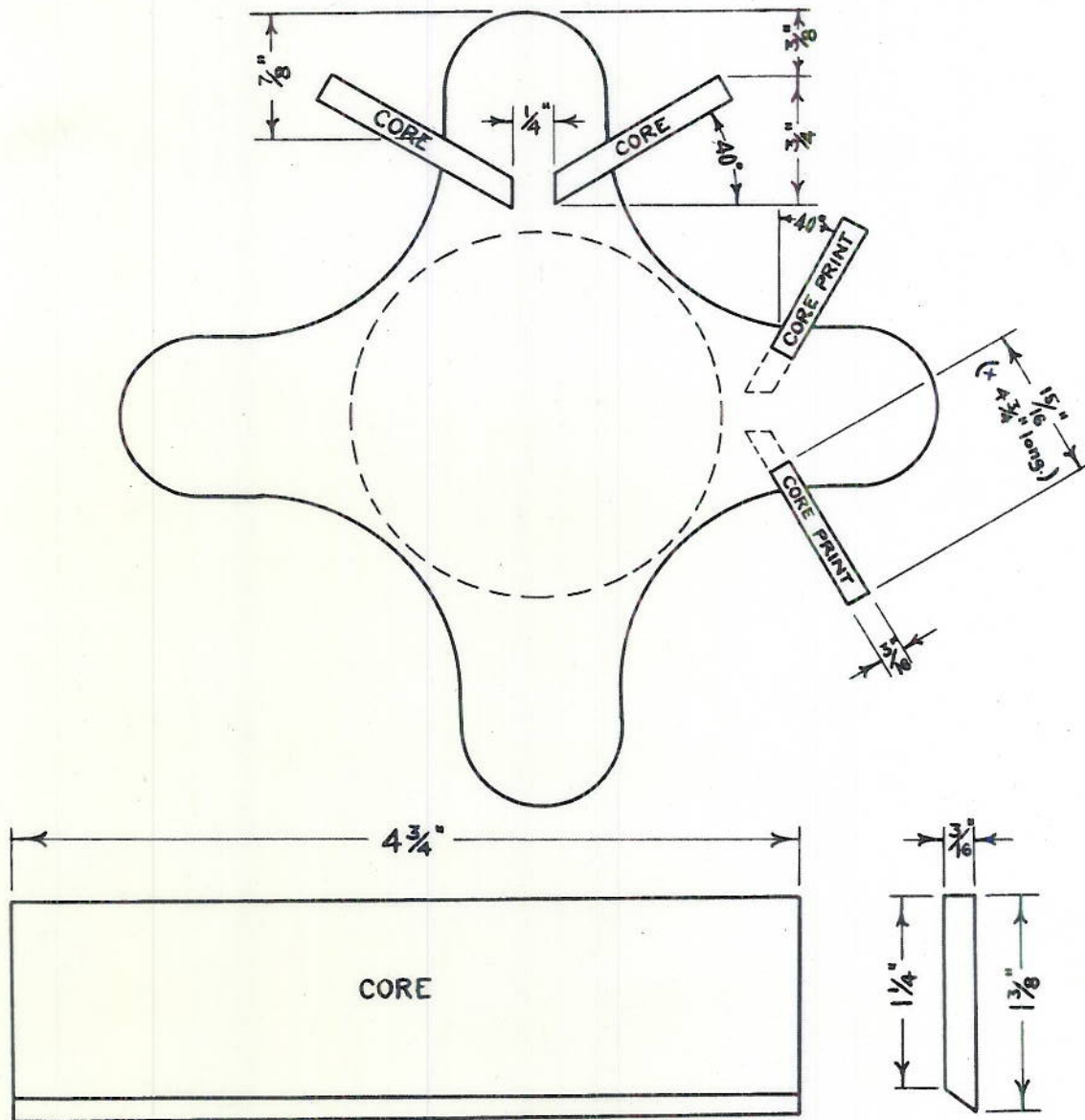
PLAN VIEW DRAG SECTION PATTERN N° 7



FRONT ELEVATION VIEW - PATTERN N° 8



PLAN VIEW DRAG SECTION PATTERN N° 8



PATTERN N° 7

PLAN VIEW OF MOLD (DRAG) WITH CORES INSERTED