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Progress Report on

Use of Chaplets in Steel Castings

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ABSTRACT

The effect of chaplets on the soundness of steel castings is studied using different types of chaplets obtained from a commercial concern. All variables were held constant, the pieces being tested under comparable conditions.

Theoretical considerations are included covering factors which might contribute to lack of fusion at the cast metal-chaplet interface.

A program for future research is included.

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APPENDICES

AUTHORIZATION

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

STATEMENT OF PROBLEM

2. The object of this progress report is to present experimental evidence of some of the defects which may result in steel castings through improper selection and/or lack of care in the use of chaplets. Certain theoretical considerations will be included as well as a program for future work based on these considerations.

KNOWN FACTS BEARING ON THE PROBLEM

3. A great many chaplets of a variety of sizes and designs are used regularly wherever castings are made which necessitate internally supported cores. A chaplet is a spool shaped piece used in a mold for supporting or spacing cores. Some examples are shown in Figure 1 of Plate 3. Many castings are rejected daily because of defects occurring immediately adjacent to, or in the near vicinity of those chaplets, either because of lack of fusion at the chaplet-cast metal interface or as a result of porosity caused by any of several factors. Such defects become especially deleterious if the casting is to be used in some type of pressure installation, as in the case of valve bodies. Any defective areas must be chipped or ground out and replaced by weld metal, necessitating considerable expense and loss of time. The indication is clear that too little attention is ordinarily given to the many factors which influence the successful application of chaplets. Altogether too often a stock supply is furnished upon which every molder draws regardless of any consideration other than the initial necessity of supporting a core.

4. Some of the factors affecting chaplet reactions may be listed as follows:

- (a) Diameter of chaplet supporting rod.
- (b) Temperature of the cast metal surrounding the chaplet.
- (c) Design of chaplet, especially the supporting rod.
- (d) Material of the chaplet.
- (e) Composition and quality of plated, dipped, or alloyed exterior chaplet covering.
- (f) Cleanliness of surface both before and after coating.
- (g) Mold conditions

5. It is common among practical foundrymen to regard strength and rigidity as chief criteria in choosing chaplet material for a certain job. As a result many types are employed daily which are unnecessarily large for the weight of core supported and which are too large to be properly fused with the cast metal at normal pouring temperatures. The ratio of cold chaplet volume to the available heat content of the molten metal surrounding it is often so large as to preclude any possibility of fusion. This would indicate that a

certain rather critical chaplet diameter might exist for a particular metal temperature, but for reasons disclosed later it appears that a fairly large latitude exists. It would be illusory to attempt to prescribe specific metal temperatures for any particular application since control is not normally practiced within very close limits. However, many castings have been noticed in which not only were chaplets unfused, but large open gaps were present for a radius of two or three inches around the chaplet stem. This could only result from too low pouring temperatures or to the metal having to run too far in the mold. With present improvements in fluidity tests and optical and photoelectric pyrometers this extreme condition should conveniently be obviated. Thin walled castings are the chief offenders in this regard, and from the standpoint of proper fusion the mass of metal surrounding the chaplet must be considered as well as metal temperatures. When it is known that metal temperatures will be unavoidably low, some type of chaplet should be chosen which has a lower fusion point than those normally provided. Such a type is the silicon impregnated variety to be discussed below.

6. It often happens that chaplets are chosen with a stem too small for the weight of core supported and the temperature of metal poured. This causes premature melting and complete fusion to the extent that the core shifts before the metal has solidified enough to support it. This occurs with less frequency than the selection of an oversize type because of the desire of a molder to be on the safer side, knowing that unfused chaplets or porosity caused by them is repairable by welding, whereas a shifted core automatically destroys further use of the casting. However, this is a point worth bearing in mind. Certain low melting point chaplets to be put on the market might give trouble if used with the same judgment as plain low carbon steel types. Core supporting properties, from the standpoint of rigidity alone, might be equal in each case, or even better in the alloyed chaplets, but the lowered melting point of the one would cause trouble unless used with care.

7. Chaplets are made in a variety of designs, examples of which are given in Figure 1. Types A and C are designated by the manufacturer as patented superstem, B and D as threaded stem styles. There seems to be a definite trend toward the making of chaplet stems into some form of corrugated, rather than plain, surfaces. No doubt this is done with the expectation that the roughened, or irregular, surfaces are an aid to fusion, and possibly to a certain extent as being more appealing to a buyer. It is logical to assume that sharp points and patterns in relief may fuse more readily than a plain surface, but experimental evidence to be presented does not always bear this out. What advantage might be gained in promoted fusion may be nullified by the formation of gas pockets in the sharp corners and depressed sections.

8. The material from which the chaplet is made should be a point for consideration. Variations in carbon, manganese, sulphur and phosphorus will all influence the mechanical strength as well as

the temperature of fusion, the latter being perhaps the more important. Chaplets are ordinarily made of low carbon steel with the stems stamped, rolled, or machined into the desired shape. The end pieces are stamped, placed on the stem, and pressed into a tight fit to make a rigid assembly. The relatively high melting point of the low carbon steel prevents too rapid melting and is cheap, conveniently shaped, and easily made. Some high alloy chaplets are on the market in which fusion results in an alloying action in the cast metal for a considerable distance around the chaplet-cast metal interface. This would affect the properties of this region according to the nature of the element and might be advantageous in some cases and bad in others.

9. In regard to special preparation of chaplet surfaces many different methods have been tried and some are listed and discussed below. Special treatment is necessary for a variety of reasons. If the plain, low carbon steel chaplets were left exposed to the air without any protective covering, they would rust and accumulate moisture. Upon use in a casting, excessive porosity would result at the fusion zone and for considerable distances into the body of the metal. This would be caused by the reaction between the carbon of the steel and the iron oxide of the scale with the formation of carbon monoxide. Also any moisture present as such in the scale, or on the surface of the chaplet, would cause defects and retard satisfactory fusion. The surfaces of uncoated chaplets could be cleaned in acid or sand blasted immediately prior to use, but this would be both inconvenient and subject to lack of care. To obviate this, chaplets are coated and prepared in several ways, some of the more popular types discussed below.

10. Electroplated surfaces include nickel, copper and cadmium in thicknesses from 0.0005 inch to 0.01 inch. In a series of tests conducted by cooperating industrial foundries, the copper plate was found to give the most consistently good results of any tried. Included in the work was a tin dipped series, but none of the silicon impregnated variety. What type or how extensive the investigation was is not known.

11. So-called "dipped" chaplets are prepared by dipping the cold pieces into a bath of molten metal, such as tin or zinc, and allowing a thin layer to adhere, after which they are removed and cooled. Opinion varies greatly among foundrymen as to the relative merits of this type.

12. Silicon impregnated chaplets are prepared in several ways, the chief function of the process being to cause silicon to alloy with the iron by diffusion at some temperature below the melting point of either one. So far as known, impregnation of chaplets has only been tried with silicon, and these are of very recent origin and are not marketed commercially. The most popular process of silicon impregnation consists of heating iron or steel to 1700-1850° F in the presence of silicon carbide and chlorine. Forged, rolled, or cast

low sulphur, low carbon steel is preferable for the process. Ferro-silicon can be satisfactorily substituted for all or part of the silicon carbide. Ordinary carburizing equipment can be used and chlorine is added after the parts are at temperature. Rotary or pot type furnaces are equally applicable. The carbide should be in contact with the metal and, while the mechanism of the process is not clearly understood, it is believed that nascent silicon is liberated which diffuses readily into the metal. Cases from 0.005 inch to 0.1 inch can be obtained. The silicon rich iron case, containing as much as 14 per cent silicon, has a relatively low melting point and would fuse, or perhaps completely melt, very readily. Such being the case, fusion would result at a specific temperature with considerably larger impregnated chaplets than plated or dipped types.

12. Cleanliness of chaplet surface, both before and after coating, merits much greater consideration than is commonly given. Any scale or dirt present prior to coating will be covered up by a thin layer of deposited metal and is a potential source of porosity in the casting. Also a very thin or loose layer, or at worst none at all, might adhere in the vicinity of the scale, allowing more oxide to collect. In impregnated varieties this is not so important and the corrosion resistance of this type is excellent.

13. Rust is only one of many forms of uncleanliness that may lead to poor chaplet fusion. Any oil or moisture present would cause porosity, the former being spilled accidentally or rubbed from the hands of any person handling the material. Moisture could result from water spilled over the chaplet or by condensation from the atmosphere before being put in the mold. Fine dust often collects in irregularities or often on flat surfaces if chaplets are stored in open containers on the foundry floor and may account for some pin hole formations and much of the slag sometimes noticed in unfused specimens.

14. Conditions of molding have an important influence on the satisfactory functioning of chaplets. If a green sand mold containing chaplets is allowed to stand for a very long interval before pouring, moisture from the humid atmosphere of the mold condenses on the cold metallic surface and either remains as water or promotes rusting, each capable of causing faulty castings. In cases where green sand molds are oven dried with cores in place, very favorable conditions for rusting are presented, and any spot of porous or discontinuous coating would be readily attacked. The flaky nature of silicon impregnated chaplets present good possibilities for the absorption of moisture and the collection of dust.

EXPERIMENTAL PROCEDURE

15. Four different styles of chaplets were obtained from the Fanner Manufacturing Company, of Cleveland, Ohio. These are shown in Figure 1, Plate 3, and are designated as follows:

A. 1/4" Dia. x 1" High x 1-1/4" Sq., Superstem
B. 1/4" Dia. x 1" High x 1-1/4" Rd., Coarse Thread
C. 3/16" Dia. x 1" High x 1-1/4" Sq., Superstem
D. 3/16" Dia. x 1" High x 1-1/4" Rd., Coarse Thread.

16. Copper plated, tin dipped and silicon impregnated types were obtained in each of the above designs and tested as received from the factory without any further preparation. Table 1 explains the features of each chaplet and the specimen number corresponds to the number shown on one corner of the piece in the photographs of Plates 1 to 6, inclusive.

17. The 24 pieces were placed in green sand molds without supporting any cores, and held in place by the pressure of the cope bearing on the flat upper plate of the chaplet. It was not thought necessary to use a core since the main aim of the investigation was the adaptability of the three different series from the standpoint of satisfactory fusion. Plate 1 illustrates the casting design and the position of the chaplets in the cast piece. The design of the test piece was considered to furnish uniform conditions for each specimen tested.

18. The molds were made of a synthetic sand mix consisting of washed and graded silica sand, bentonite and water. They were made up approximately three hours before pouring and left open for about two and a half hours.

19. The six molds containing the 24 chaplets were placed in order on a long truck of the small gauge railroad type which could be pushed along in front of the melting unit for more rapid pouring of the successive castings. The furnace used was an induction, tilting type, of 300 pounds capacity and lined with a fused silica crucible. The metal was an average analysis of 0.21 per cent C, 0.78 per cent Mn, 0.32 per cent Si, and 0.45 per cent Ni. As soon as the metal was melted the final addition of ferro-manganese and ferro-silicon was made and the temperature raised to 2925° F. The temperature was measured with an optical pyrometer of the Pyro type, calibrated against a thermocouple in previous baths of steel. At this point the power input was decreased slightly to hold the steel at this temperature while each of the six molds were poured in rapid succession.

20. Figure 2 of Plate 3 shows the castings after being shaken from the molds and indicates that each was poured to the same height in the riser. Figures 3 and 4, of Plate 3, show an individual casting from the cope and drag side respectively. The round catch basin was placed directly under the pouring gate to allow a reservoir of metal to build up and equalize the flow into the four arms. The position of the chaplet is clearly seen, as well as the method of marking their identity.

21. After cooling, the castings were sawed into specimens 1-1/2 inches square around the region of the imbedded chaplet as shown in

Plate 2. This piece was then cut in half to give a section across the chaplet stem and the second half cut lengthwise through the rod. The resulting specimens are as shown in Plates 4 to 6, inclusive. The cut surfaces of the specimens were ground flat and finish polished on coarse metallographic emery paper. This was considered satisfactory to give the general information desired in the initial investigation. For the more precise metallographic analysis, discussed later, considerably more care was taken in preparation. For the etched specimens a 3 per cent solution of nitric acid in ethyl alcohol was used. A hardness survey was made across the face of one of the pieces in which a silicon impregnated chaplet had been used. This was done with a Vickers-Brinnell machine using a diamond pyramid.

DISCUSSION OF RESULTS

22. The macrographic analysis of work done to date is presented in Plates 4 to 6, inclusive. The duplicate series of Plate 4 were made to check the ability to reproduce results in subsequent castings not poured in order. Plate 5 presents a duplicate set cast in order as shown in Table 1, while Plate 6 includes the hot tin dipped and silicon impregnated series. The photographs of the unetched specimens give a much clearer indication of the degree of fusion in each case than do the etched pieces. What appears to be a clear line of demarcation between chaplet material and the cast steel is often only a film of impurity deposited at the interface during etching and accentuated in photographing. A micro-examination revealed this to be the case.

23. In Plates 4 and 5, it is evident that the degree of fusion desired has not been obtained. Such porosity and lack of fusion as indicated therein might enable a casting to pass an initial test, but if the piece is destined for service under steam or hydraulic pressure, failure would ultimately result in many of the cases. Porosity is evident both at the fusion zone and for some distance into the metal. How far away such spots occurred from the region of the chaplet was not determined in the present investigation, but radiographs of many castings indicate that they can be very widespread. This is undoubtedly the result of any dust, oxide, or volatile substance on the chaplet surface which can wash into the metal stream. In some cases localized fusion has occurred in portions of the chaplet while others show no fusion whatever.

24. The sections showing the cut taken longitudinally through the chaplet rod is placed directly above the corresponding transverse section. From a comparison of each it is clear that by using only the latter a mistaken conclusion could be drawn. If the cut was made presenting the sharp points of a thread, as in specimen 14, it would appear that fair fusion was obtained. However, if the cut showed the bottom of the "V" as in specimen 2, an entirely different interpretation would result.

25. It does not appear from Plates 5 and 6 that threaded stems

give any greater assurance of fusion than the superstem type. It should be noted here that by an error in arrangement the longitudinal cut corresponding to specimen 4 appears over specimen 3. More information will be required before any definite conclusions can be drawn regarding chaplet design. It is felt that a plain type with a smooth fillet at the juncture of the stem and plate might be superior to any of the present types.

26. From the present work little can be said regarding chaplet size. In certain specimens, differing only in size, about the same degree of fusion is evident in each. In specimens 17 and 19 the larger even showed the better fusion, indicating that the latitude of chaplet size is wide enough for practical purposes.

27. Plates 4 and 5, showing copper plated series differing only in thickness of coating, indicate no constant difference in fusion. The tin dipped series of Figure 9, Plate 6, show very good fusion and little porosity. Specimen 17 is a nearly perfect example of the type of union desired. Any of the four specimens of this series would function properly under pressure. The silicon impregnated chaplets of Figure 10 show satisfactory fusion but also a slight amount of porosity, especially in specimen 21. These would undoubtedly give satisfactory service from the standpoint of leakage due to porosity. The dark areas around the chaplet, shown in Figure 10b, are silicon rich base metal into which the silicon from the chaplet has diffused. These regions would be very brittle and the casting might crack under sudden, localized shock. In the majority of installations danger from this source is probably slight since the usually more ductile material surrounding these areas would absorb most of the shock in isolated cases where it might occur. No actual measurement of brittleness was made, but a hardness survey was taken across specimen 24 in the manner indicated in Plate 1. The increase in hardness can be taken as a rough criterion, together with the well known embrittling action of silicon. The results of the hardness measurements are given in Table 2. In forming conclusions from Figures 10a and 10b, it should be noted that the longitudinal cut of specimen 23 does not show any chaplet material. This was accidentally removed by the saw cut.

THE MECHANISM OF FUSION

28. It is commonly believed that fusion between chaplet and cast metal is a case of simple melting, enough superheat existing in the melt to raise the temperature of the chaplet above its melting point. This is a fair belief since most steel is poured at relatively high temperatures. However, cases are known where cast iron has fused soundly with low carbon steel chaplets, the temperature never reaching the fusion point of the latter. This leads to the necessity for considering some other phenomenon than that of simple melting.

29. Considering the case of cast iron and turning to the iron carbon diagram, it is obvious that chaplet metal containing 0.10 per cent carbon and no other alloying elements would have a melting point higher than that normally reached by the cast iron poured around it.

In order for fusion to result some means must be provided for a lowering of the fusion point. When immersed in molten cast iron, it is known that chaplet material will absorb carbon by diffusion and the carbon content of the surface will rise progressively to a high figure. This carburization will go on until the melting point of the chaplet surface has been lowered to correspond to the temperature of the surrounding cast metal. It is obvious that unless some such mechanism exists fusion in the above instance would be impossible unless the cast iron were held at the fusion point of iron containing .05 to .15 per cent carbon, i.e., 1490-1500° C., a temperature too high for the production of sound iron castings. It is known that satisfactory fusion has resulted in cases such as the above and a micrographic examination revealed a very definite carburization for a considerable distance into the body of the chaplet.

30. Since the above mechanism prevails in the case of cast iron, it is logical to expect that a similar phenomenon exists in the operation of chaplets in steel castings. Steel is poured with enough superheat to melt a low carbon chaplet material but in cases of thin sections or when the metal is forced to run long distances a large amount of this heat is dissipated to the sand. As a result, many borderline cases exist where temperatures are possibly too low to effect satisfactory fusion unless some carburization operates jointly to raise the surface carbon content of the chaplet material. That a certain amount of carbon penetration does take place is shown clearly in Plate 8. The composite photograph shows the polished and etched surface from the center of a chaplet outward into the body of cast metal. The increasing amount of pearlite from the center of the chaplet to the interface is an indication of the carbon penetration, as is the increasing ferrite noticed from the unaffected cast metal toward the fusion line. The carburization in the present case is of a low order and the difference in melting point between the original compositions of chaplet and casting is slight. In cases of low or medium carbon castings little advantage from the standpoint of a lowered melting point would result. In higher carbon castings, however, it is probable that the influence of carburization would operate to advantage.

31. Specimens selected as representative of good and poor fusion, threaded and superstem types, both in longitudinal and transverse cuts were carefully polished and etched and examined under high magnifications to see if any conclusions made from the macrographic study should be modified or changed.

32. Considering the design of the coarse thread type of chaplet stem it can be said that there is a definite trend toward increased porosity at the base of the "V" or in other designs at any indentation or sharp internal angle. This is probably the result of dust or moisture having collected at these points before use. Some cases of good fusion showed no apparent difference between the points or bottoms of the "V's", but there is no doubt that a definite keying action takes place in porous specimens. The sharp points of the threads fuse into the cast metal and appear perfectly sound under pressure tests.

Radiography will reveal the porosity if carefully done.

CONCLUSIONS AND RECOMMENDATIONS

33. Many generally ignored factors operate jointly or individually in causing unsatisfactory operation of chaplets.

34. Threaded stem chaplets do not present any added assurance of fusion and may, in some cases, be deleterious by presenting spaces at the bottom of threads for the accumulation of gases.

35. More consideration should be given to the preparation and care of chaplet surfaces both before and after plating or processing.

36. More information is necessary for a more judicious choice of chaplet material and coating.

37. Threaded stem chaplets serve to promote a keying action by fusing at the points of the threads. This may be an aid in passing an initial test, but without complete fusion at the base, as well as at the point, the casting may fail in service.

38. Alloyed chaplet material fuses readily but may sometimes melt too easily for suitable core support.

39. Occluded gases during electroplating may be deleterious.

40. A good grade of low carbon steel is well chosen for chaplet material to be used in steel castings.

41. Fusion is ordinarily the result of carbon diffusion from the higher carbon base metal into the chaplet material at the interface. This diffusion lowers the melting point of the chaplet and promotes satisfactory fusion at a clean surface.

42. Silicon impregnated chaplets fuse readily. A certain amount of embrittlement results in the casting for a small distance around the imbedded chaplet.

43. The tin dipped chaplets of the present investigation gave the best results.

44. The duplication of test results indicates the suitability of the test procedure used.

45. More experimental work is necessary before definite changes in chaplet preparation and handling can be prescribed.

FUTURE RESEARCH

46. The results of the present fundamental investigation disclosed the defects which may result from the use of chaplets. Several more test pieces will be made varying such factors as appear to be operative in causing faulty fusion.

47. A number of different coatings, both dipped and plated, will be tried to determine the superiority of any particular type. All popular coatings, including tin, copper and nickel, will be tried with possibly a chromium and cadmium series.

48. The effect of cleanliness of chaplet both before and after plating will be ascertained as will the possible effect of gases occluded during electroplating.

49. The design of the chaplet will be varied to determine more fully the possible deleterious influence of sharp corners and depressions.

50. A series of alloyed types will be studied, including calorized, aluminized, carburized and silicon impregnated types. These will be prepared under carefully controlled conditions. An effort will be made to determine why the silicon series of the present investigation caused porosity. It is believed that a thin case of silicon rich iron would be advantageous rather than the thick case of the series used in this work. Fusion should be effected satisfactorily, less embrittlement would result, and there would be less danger of premature melting with consequent shifting of the core.

51. Sand blasting of chaplet surfaces before use will be tried to determine the effectiveness of this method of cleaning.

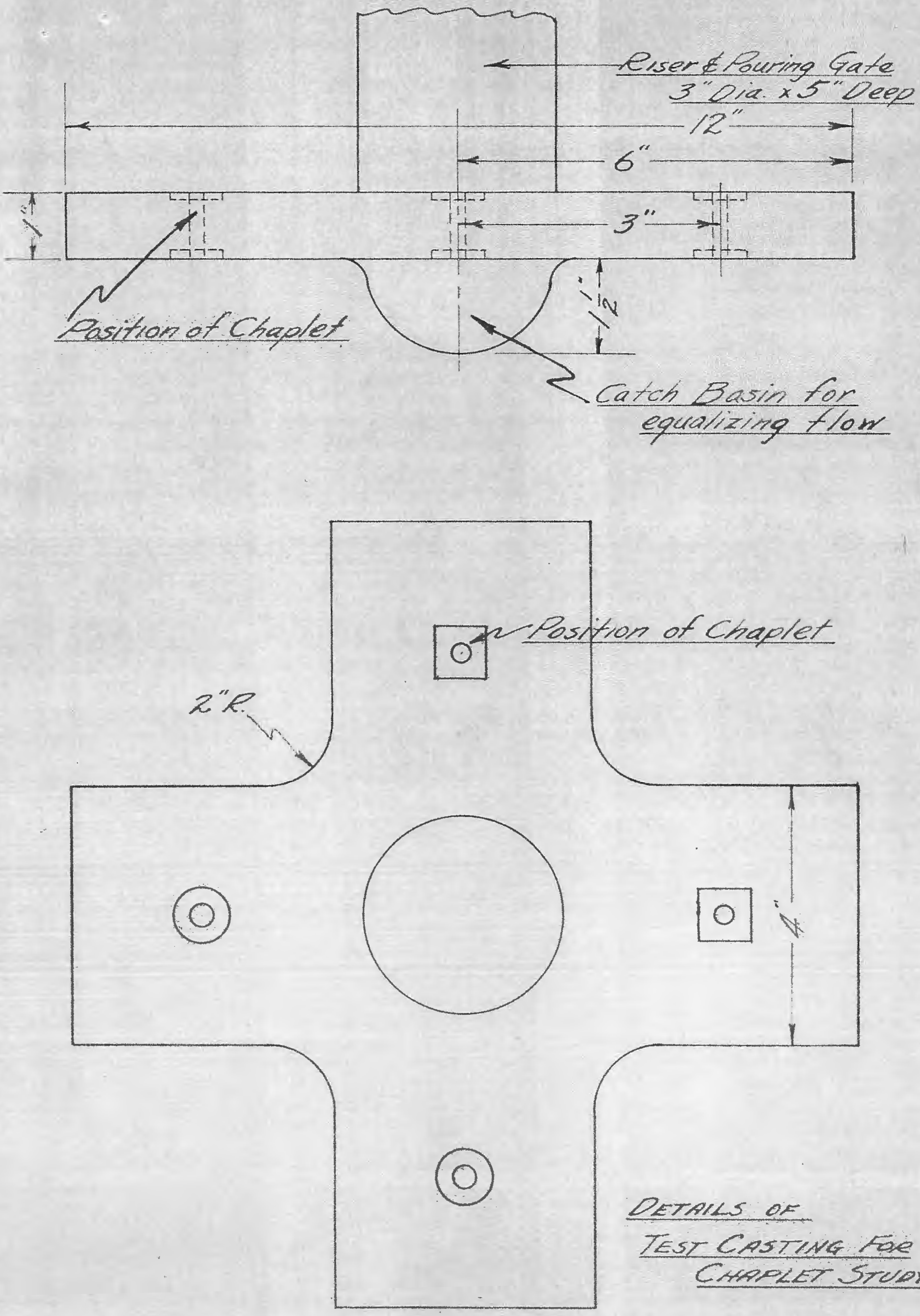
52. Besides the chaplets prepared at this Laboratory, a set will be procured from an active foundry and included in the program.

Table 1

No. of Specimen	Type of Stem	Type of Surface	Diameter of Stem
1	Superstem	Barrel plated copper .0005" thick	1/4"
2	Coarse Thread	"	1/4"
3	Superstem	"	3/16"
4	Coarse Thread	"	3/16"
5	Superstem	Barrel plated copper .001" thick	1/4"
6	Coarse Thread	"	1/4"
7	Superstem	"	3/16"
8	Coarse Thread	"	3/16"
9	Superstem	"	1/4"
10	Coarse Thread	"	1/4"
11	Superstem	"	3/16"
12	Coarse Thread	"	3/16"
13	Superstem	Barrel plated copper .0005" thick	1/4"
14	Coarse Thread	"	1/4"
15	Superstem	"	3/16"
16	Coarse Thread	"	3/16"
17	Superstem	Hot tin dipped	1/4"
18	Coarse Thread	"	1/4"
19	Superstem	"	3/16"
20	Coarse Thread	"	3/16"
21	Superstem	Silicon impregnated	1/4"
22	Coarse Thread	"	1/4"
23	Superstem	"	3/16"
24	Coarse Thread	"	3/16"

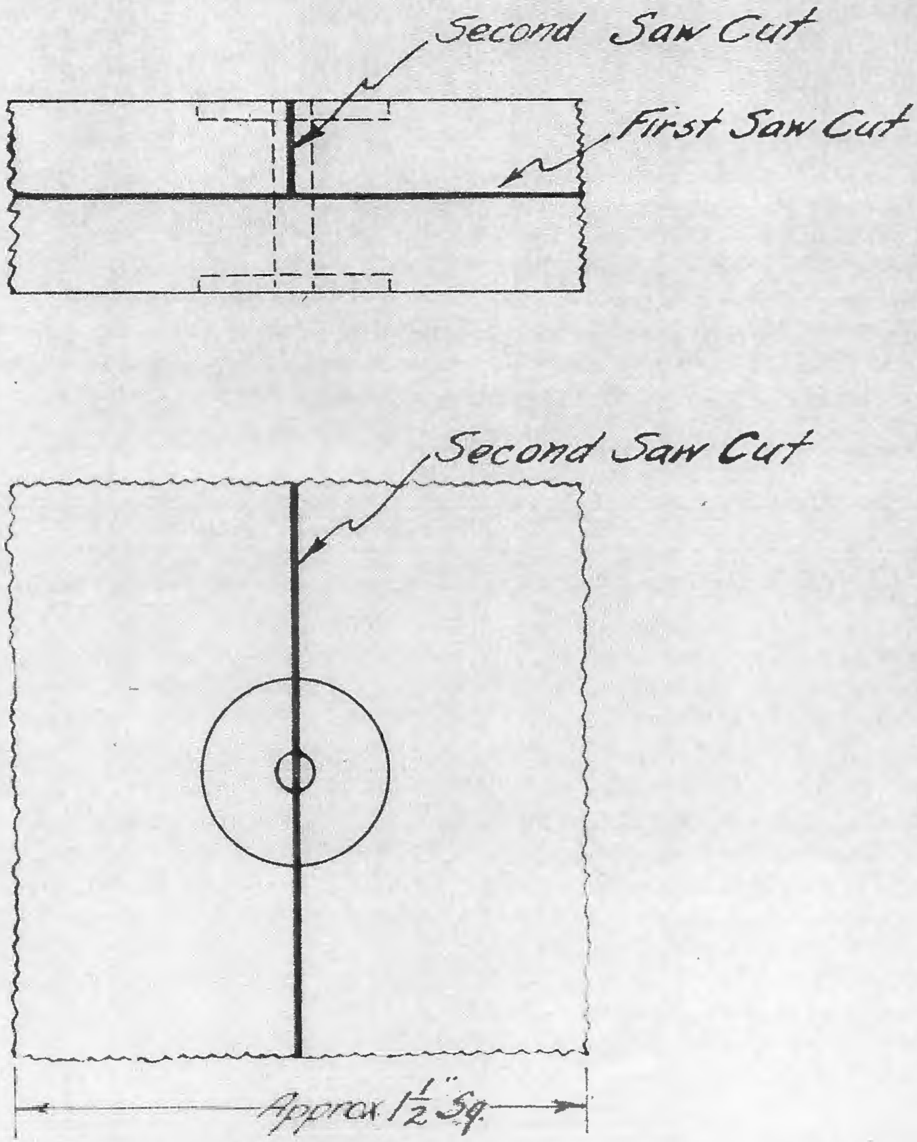
Table 2

Position of Indent as shown on Plate 7	Hardness in Vickers Brinell units
1	215
2	228
3	311
4	309
5	145
6	302
7	318
8	238
9	226
10	219



DETAILS OF
TEST CASTING FOR
CHAPLET STUDY

PLATE I



METHOD OF CUTTING SPECIMENS
FOR EXAMINATION

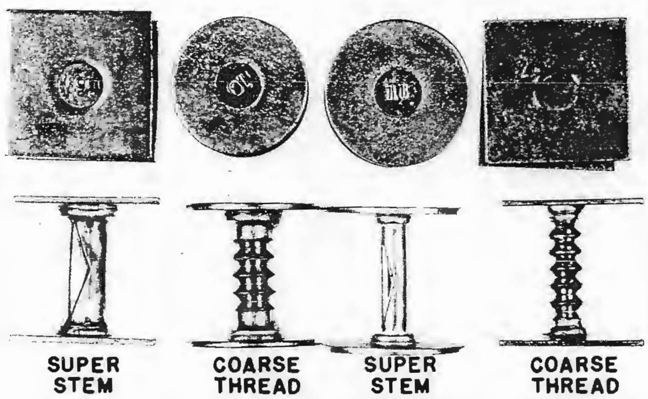


FIG. 1 – TYPES OF CHAPLET

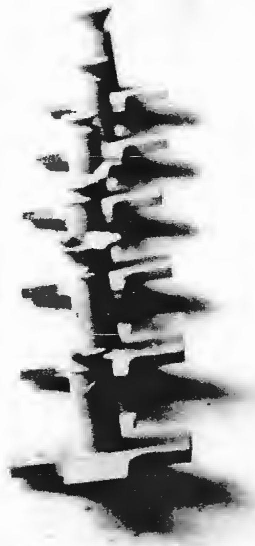


FIG. 2 – TEST PIECES AS CAST.

FIG 3. – TEST PIECE - COPE SIDE

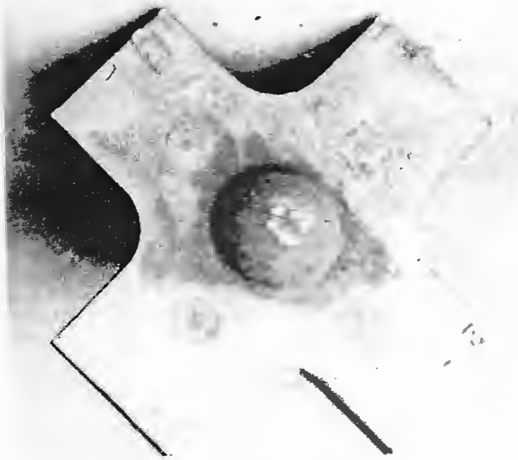


FIG. 4 – TEST PIECE - DRAG SIDE

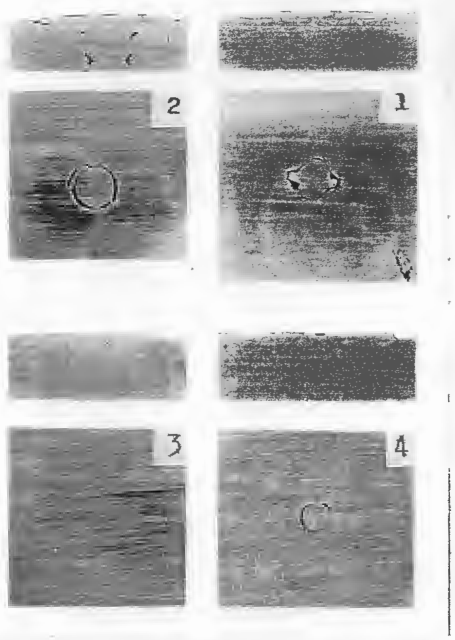


FIG. 5A

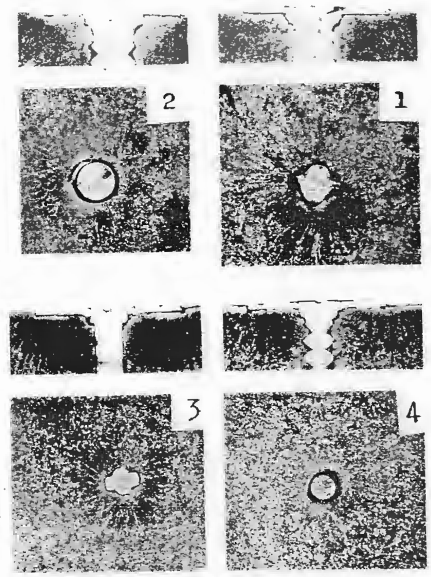


FIG. 5B

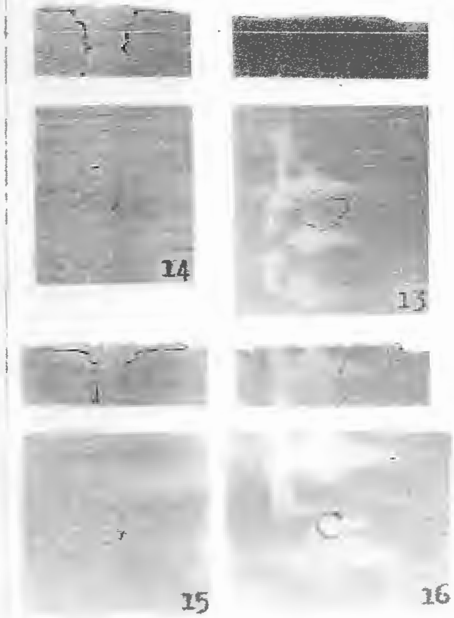


FIG. 6A

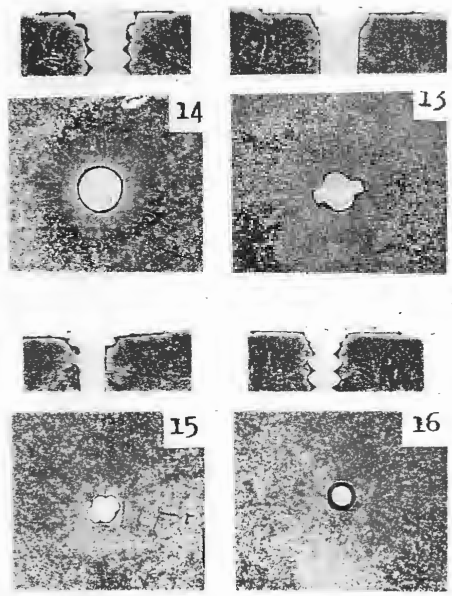


FIG. 6B

COPPER PLATED SERIES
PLATE 0."0005 THICK

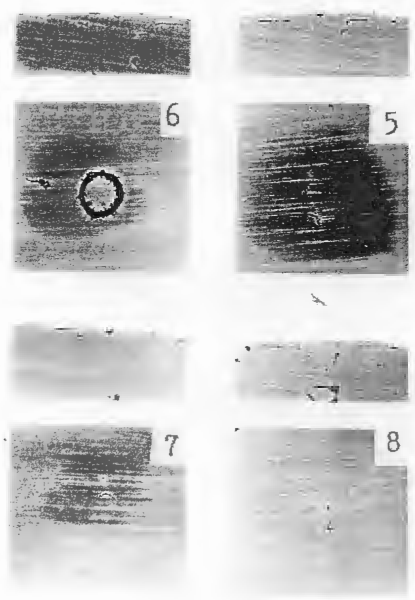


FIG. 7A

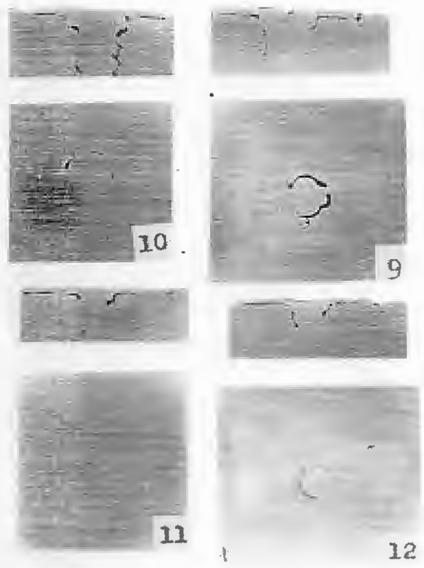


FIG. 8A

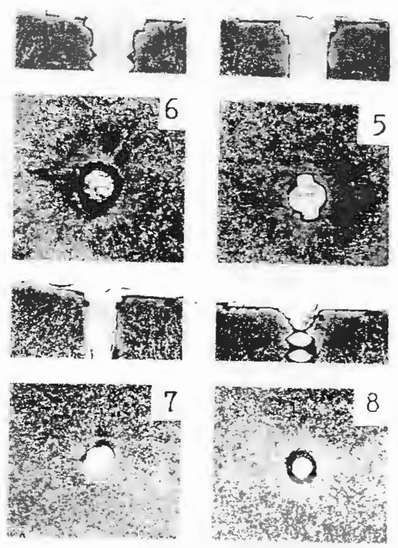


FIG. 7B

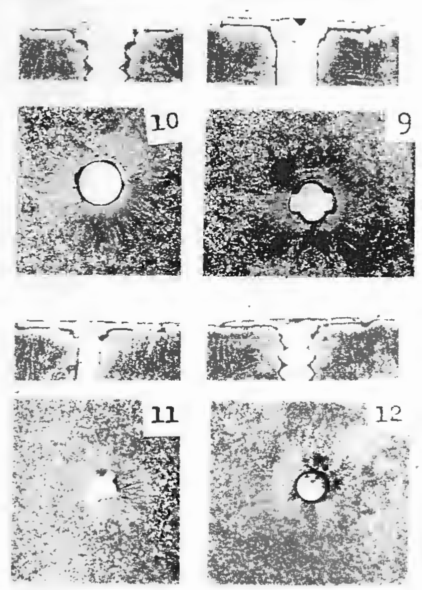


FIG. 8B

COPPER PLATED SERIES
PLATE 0."010 THICK

Plate 5

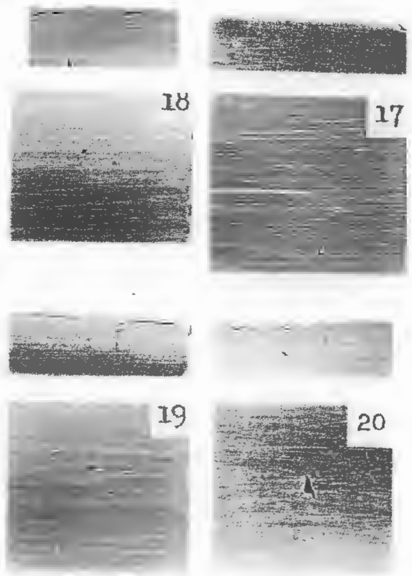


FIG. 9A

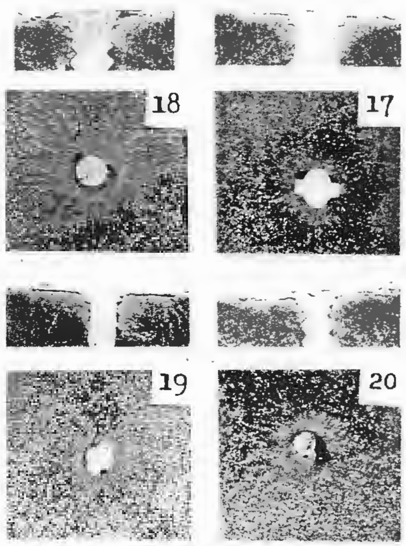


FIG. 9B

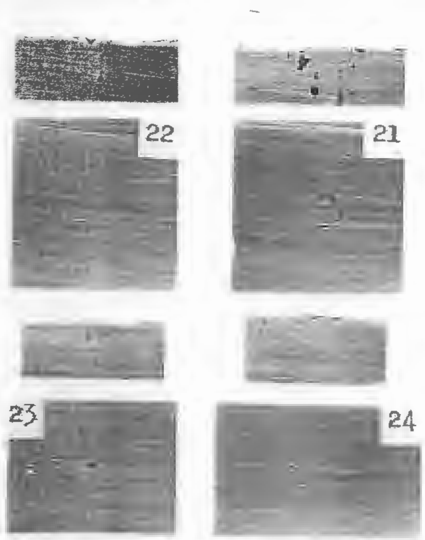


FIG. 10 A

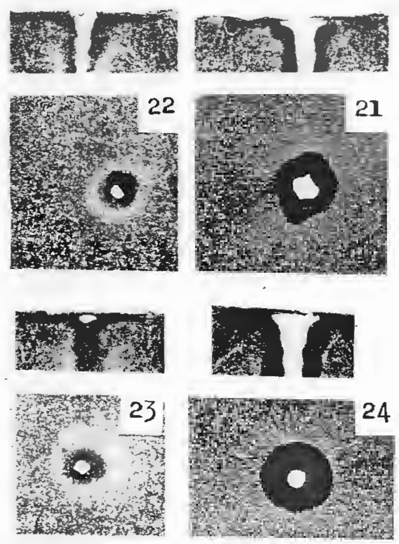
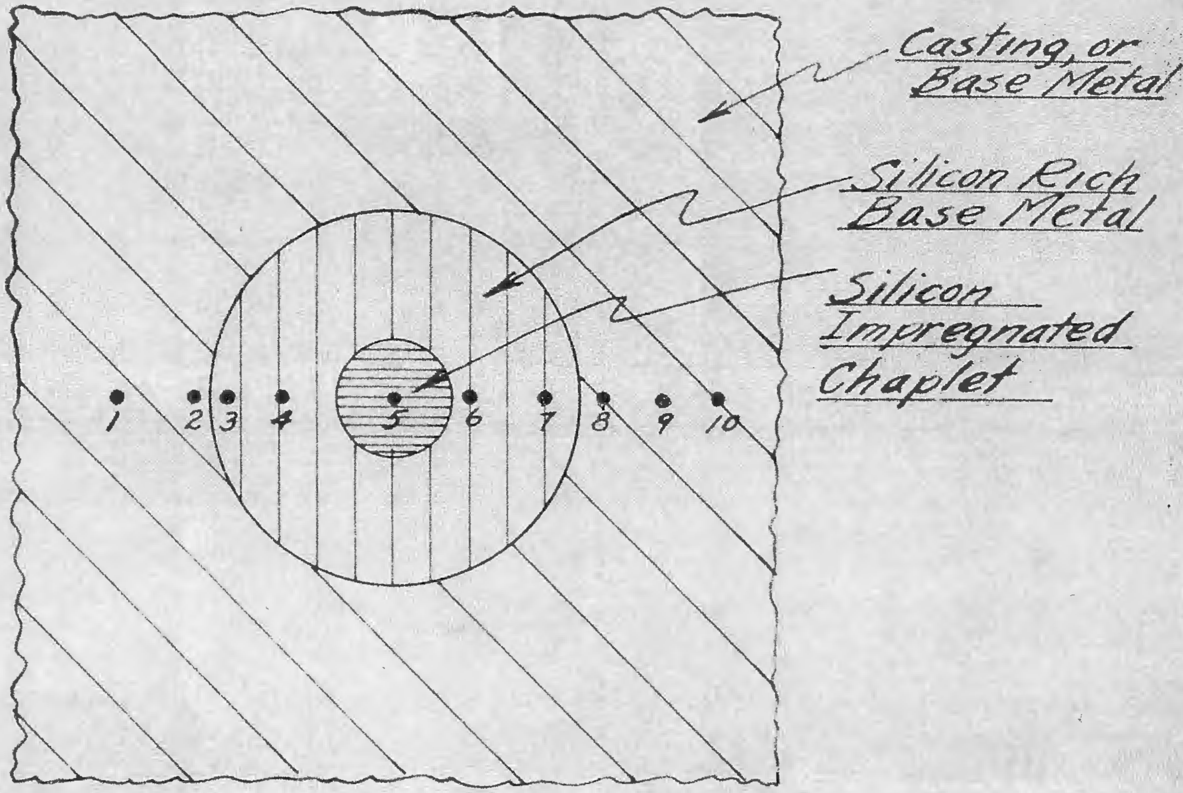


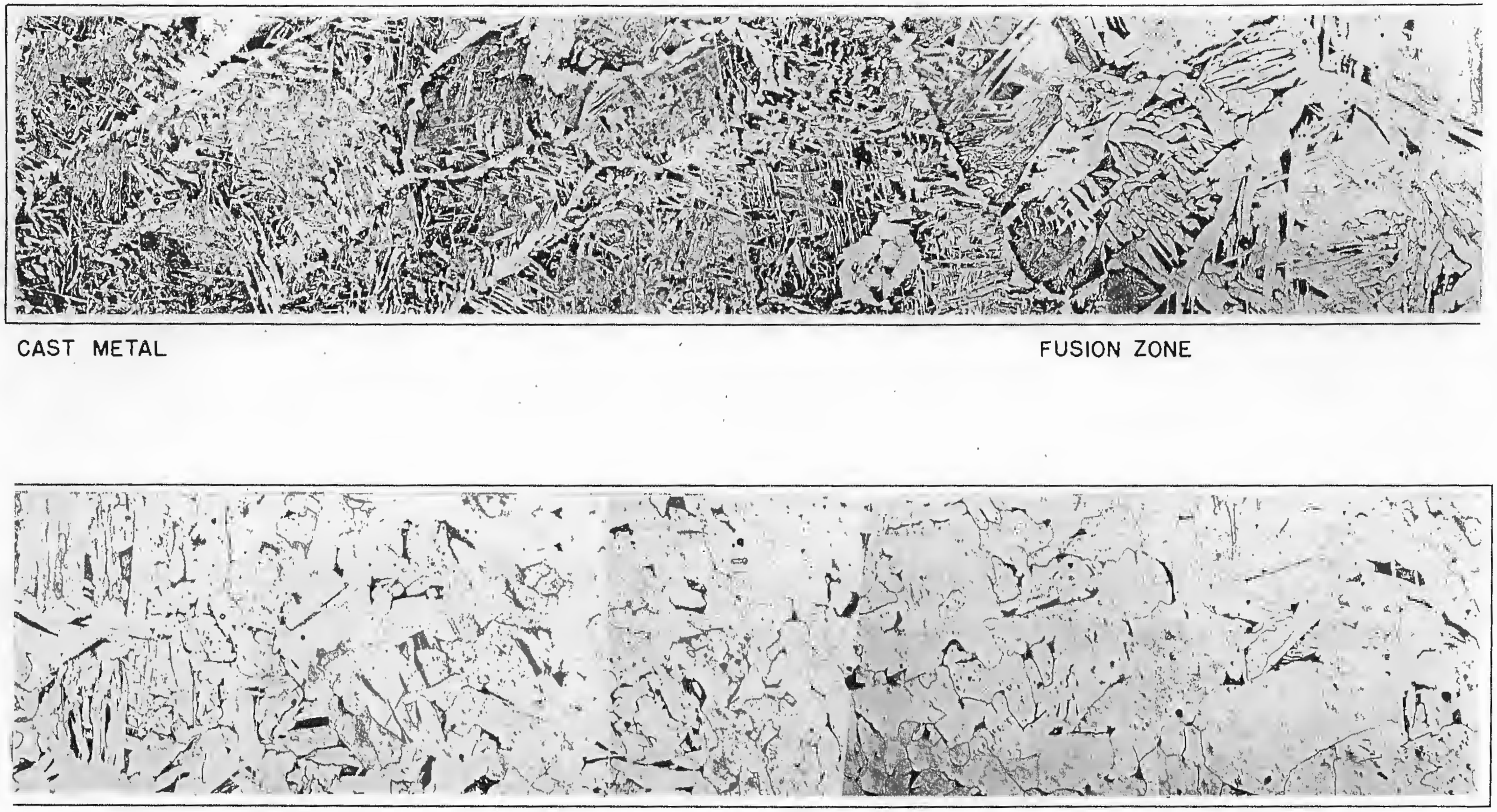
FIG. 10 B

SERIES 9 — TIN DIPPED
SERIES 10 — SILICON IMPREGNATED

Plate 6



Position of Hardness Indents Across Specimen 24



CAST METAL FUSION ZONE

CHAPLET MATERIAL

STRUCTURE FROM CENTER OF CHAPLET INTO THE CAST METAL