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A STUDY OF THE CAUSES AND METHODS OF PREVENTING VEINS AND PENETRATION IN SAND CAST METALS

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Report M-2757

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ABSTRACT

Veins and penetration are surface defects which frequently occur on castings produced in synthetically bonded sand. They are frequently found on lead and tin bronze castings and occasionally on cast iron and steel castings. In order to find methods for preventing their formation an investigation was made to determine the mechanism of veining and penetration. Phosphor bronze was used in all experimental work because the defects are most prevalent in castings made from this alloy.

Veining of bronze castings is caused by (1) sweating of the metal, which is an extreme case of inverse segregation, and (2) cracking of the mold or core. In the late stages of solidification dissolved gases come out of solution and force the low melting point constituent of the alloy toward the surface of the casting through interdendritic passageways. Frequently this constituent exudes from the surface of the casting and enters cracks in the mold or core to form veins. Cracking of molds and cores is believed to be caused by the thermal expansion characteristics of silica. Penetration defects occur when the exuded metal enters intersticies among the sand grains.

The elimination of most veining and penetration on bronze castings can be accomplished by proper melting practice because this tends to reduce the amount of dissolved gases in the molten metal. Sand techniques which help to eliminate veining by preventing the mold from cracking were developed. Washes containing finely divided refractories stop penetration by filling intersticies in the surfaces of mold and cores.

The mechanism of veining on gray iron castings is believed to be similar to that of veining on bronze castings, but it is believed that veins on steel castings form only at locations where hot tears occur.

A STUDY OF THE CAUSES AND METHODS OF PREVENTING VEINS AND PENETRATION IN SAND CAST METALS.

Authorization

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

Statement of Problem

2. The increased use of synthetic sands throughout the foundry industry is a convincing indication that their advantages over natural sands are widely recognized. In order to fill the need of advanced bases, repair ships, and other naval establishments for simplicity in sand practice, a synthetic molding sand and a core sand were developed at the Naval Research Laboratory and recommended for use in making molds and cores for most of the commonly used foundry alloys. The molding sand mixture consists of washed silica sand with a median size of 180 microns (corresponding approximately to A.F.A. grain size of 80) plus additions of 3.0 per cent bentonite, 1.5 per cent dextrine, 0.5 per cent corn flour, and 3.5 per cent moisture. A core sand employing the same base sand bonded with 1.0 per cent core oil, 1.0 per cent corn flour, and 4 per cent moisture was recommended.

3. With few exceptions, sound engineering castings of all the commonly cast metals except magnesium have been consistently produced in these sands. Difficulty, however, is often experienced in producing bronze castings free of a surface defect known as veining. This flaw is rarely found when natural sands are used. Veins are extraneous fins of metal which sometimes protrude at various places on the unfinished casting. Preventing their formation is a matter of importance since castings must be scrapped because of them or, at best, time and equipment are required to remove them.

4. The problem, therefor, was one of investigating veining in order to find, if possible, means of preventing its occurrence.

Known Facts

5. While veining has been known to occur in many of the sand casting alloys, the most serious cases are found in certain lead and tin bronzes. Of the ferrous metals, gray cast iron has the greatest tendency to vein, but veins are occasionally found on steel castings. Aluminum and magnesium alloys have the least tendency to form veins.

6. Veining is often confused with penetration because the two defects frequently occur simultaneously. Differences, however, have been noted at the Naval Research Laboratory and also have been recorded in the literature (1). That molds and cores crack when suddenly heated is a fact known to most foundrymen. This is attributed to dimensional instability caused by thermal stresses in the sand which form as a result of temperature gradients. Veins form when molten metal flows into such cracks. They form most frequently at "hot spots" in the sand such as reentrant angles, but are occasionally found on flat surfaces. Penetration occurs when the metal is fluid enough to flow into intersticies which form in the mold or core surface of the sand as it is rammed. Coarseness, soft ramming, and poor flowability of the sand are the main causes of penetration. In most cases it may be eliminated by the use of a wash in which a refractory of fine

particle size is used as the base This prevents penetration by filling the intersticies between the sand grains but it does not stop the mold from cracking when hot metal is poured into it and hence has little influence on veining. Plate 1, Figure 1 shows a phosphor bronze casting which illustrated this fact. Half of the mold for this casting was painted with a silica flour wash and the other half was untouched. The line of demarcation can clearly be seen where penetration is prevented by the wash. but veining is not retarded.

Suggested Mechanisms of Veining

7. No satisfactory explanation of the mechanism which causes veining has ever been proposed. For a crack or fissure to be produced into which metal can flow, the surface of the sand must be in tension. A compressive stress only tends to bond the sand into a more compact mass. When a specimen of sand is heated in a furnace a temperature gradient exists from the surface to the interior of the body and the surface expands more rapidly than the interior to produce compression in the surface and tension in the interior. If the furnace is controlled at some constant temperature below 573°C (1063°F) which is the inversion point of alpha quartz to beta quartz, the surface of the specimen comes to the furnace temperature and is expanded a definite amount. At some later time, the center of the specimen also reaches the furnace temperature an amount equal to the expansion at the surface of the specimen. When this condition is reached, the temperature gradient is gone and the stress gradient also disappears. Simple heating, therefore, will not produce the necessary tensile stress to cause veining. Conditions existing during cooling can be neglected because it has been observed that, at elevated temperatures, cracks develop in test specimens during the heating period. These facts indicate that some other conditions must exist for veining to occur.

8. Since the sand is a granular material of low strength it is conceivable that some adjustment takes place in the grain positions or the clay layer which relieves the compressive stress at the surface during the early stages of heating. A temperature gradient then exists in the absence of a stress gradient as shown in C of Plate 2, Figure 2. This condition persists as long as the temperature continues to rise provided the surface does not reach 573°C (1063°F). As the temperature rises, however, the sand is developing hot strength to become a unified mass instead of a granular material. Then when the sand at the surface reaches a temperature of 573°C (1063°F) it suddenly stops expanding and begins to contract very slightly, as shown by the expansion curve for sand in Plate 4, while the sand in the interior of the specimen is still expanding because it has not reached the inversion temperature. The slight contraction at the surface accompanied by expansion in the center tends to set up extreme tensile stresses at the surface. This is believed to be the condition which initiates the cracks which, in a mold, permit the molten metal to enter the sand and form a vein. As the isothermal surface at 573°C (1063°F) progresses inward, the depth of the crack is gradually increased.

9. Another suggestion which has been made is that the organic material in the sand mixture burns and the sand mixture contracts in a manner similar to that in which a piece of paper contracts when it burns. If a specimen is exposed to an elevated temperature in the dilatometer for a period of not over four minutes and is then removed and broken open it will be found that there is a burned or black layer of sand on the surface of the specimen while the

center remains unchanged. This might be expected to cause a change in length of the surface layers and cause some tension which would produce cracking. This theory is discredited, however, by tests upon sillimanite and periclase refractories which indicate that the nature of the refractory as revealed by its characteristic expansion curve is probably responsible for the forces which start cracks in the specimen.

Experimental Procedure

10. Experience in pouring all types of metal at the Naval Research Laboratory has shown that the worst instances of veining are consistently found on phosphor bronze castings. This alloy is known to foundrymen for its property of "attacking the sand". Veining and penetration ofter disfigure the castings beyond repair. The use of phosphor bronze in experiments on veining produces the most severe test of the sands used; therefore, any means of stopping veining in this alloy would do at least equally as well on other copper base alloys. For this reason phosphor bronze of the following composition was used in all tests: 89.5 per cent copper, 10 per cent tin, and 0.5 per cent phosphorus.

11. A simple test block (illustrated on Plate 3, Figures 3 and 4) was designed so that three different sand mixes could be tested in one casting. Three standard 2-X 2 inch test-specimens, made from three different mixes, were inserted into the bottom of the mold so that one half of each specimen projected into the molten metal. This type of test is one of the most severe possible, since the sand under test is nearly surrounded by metal and the heat flow is restricted.

12. Most mixes tested were mulled in 2000 gram batches in a 15 pound capacity laboratory mullor. The regular molding sand and core sand, which were used for the purpose of comparison, were taken from sand bins in the foundry after they had been mulled in the 200 pound production muller. Specimens made of clay-bonded molding sands were dried at 105°C (220°F) and those made of core sands were baked at their normal baking temperatures before being placed in test molds.

13. All heats were melted in an induction furnace. After the results from each heat were recorded, the same metal was remelted for use in subsequent tests.

Test Results

14. If the first possible mechanism stated above is a valid explanation for the cracks which form on mold surfaces as their temperatures are raised, refractories which have smooth expansion curves should be free from cracks and thus prevent veining when used as molding materials. Two such materials, namely periclase (MgO) and sillimanite ($AL_2O_3 \cdot SiO_2$) were tested. Their expansion curves are shown in Plate 4. Samples of sand and of these materials having equivalent particle size were bonded similarly and tested in experimental castings. Plate 5, Figure 5 shows the results obtained. From left to right the cores were periclase, sillimanite, and sand. Both periclase and sillimanite stopped veining completely; thus the above theory is given support.

15. The ability of periclase and sillimanite to undergo shock heating without cracking is illustrated in Plate 5, Figure 6. These three dilatometer specimens were subjected to a temperature of 1093°C (2000°F) for a period of

three minutes. Both periclase and sillimanite maintained smooth continuous surfaces but large cracks were developed in the sand. The specimens had all been coated with silica wash in order to show the cracks more clearly. Most of the sand mixtures used in these experiments were subjected to this test. It was found that, in general, the degree of veining was related to the amount of cracking.

16. Previously in this report it was stated that veining is most serious in lead and tin bronzes, while other metals show much less tendency to form veins. Some heats of the lead and tin bronzes produce castings which are free from veins, although the chemical composition and pouring temperature are apparently the same as those which form many veins. This indicates that there is some property characteristic of each heat which determines whether or not veining occurs.

17. Early in these experiments it was noted that in most heats the phenomenon of tin sweating occurred. Sweating is an extreme case of inverse segregation in which the low melting point constituent of an alloy exudes from the surface of the casting late in solidification. Plate 6, Figure 7, shows a typical example of tin sweat which has exuded from the top of a riser. The fact was soon established that the serious cases of veining are associated with this phenomenon because invariably the heats that sweated were the ones in which the bad cases of veining occurred. Two castings which illustrate this fact are shown in Plate 7, Figures 8 and 9. In both cases the chemical compositions of the heats, pouring temperatures, and type of molding sand were the same. The tin sweat in the casting shown in Figure 8 was very pronounced, while in the casting shown in Figure 9 it was completely absent. It will be noted that veining in the casting which sweated is many times worse than in the one in which sweating did not occur.

18. In order to further associate veining with sweating, a sample of material which was exuded from the top of a riser and actual veins which were chipped from castings were analyzed. The results, shown in Table 1,

Table 1

	Veins	Exuded Material	Body of Casting
Copper	84.2	79.0	89.8
Tin	14.3	17.3	10.3
Phosphorus	1.5	2.0	.6

show that both the veins and the exuded material are high in tin and phosphorus and, therefore, are low melting point constituents.

19. As a final experiment to prove that sweating is responsible for veining, two identical castings were poured from the same heat. One was

shaken out four minutes after pouring, and the other was allowed to cool in the mold. The one that was removed from the mold while hot had solidified sufficiently to retain its shape, but no veins had formed. Shortly thereafter, however, sweating began to take place with liquid metal exuding from numerous places on the casting. The casting that cooled in the mold formed many veins. These castings are shown in Plate 8, Figures 10 and 11. Many beads of sweat are visible on the casting shown in Figure 10 which was shaken out while hot. The obvious conclusion may be drawn that metal also exudes from the casting shown in Figure 11; but having no other place to go was forced into cracks in the sand and thus formed veins. It may be noted that the surface of the bottom casting is much rougher than that of the top casting. Thus it appears that the exuded metal also enters intersticies among the sand grains and causes penetration.

20. Many theories which have been proposed to explain inverse segregation have been published (6) (7) (12). Data obtained in these experiments on phosphor bronze support that of Gender (7), who states that gases which are dissolved in the liquid metal come out of solution during the later stages of solidification and force the low melting point constituent toward the surface through interdendritic passageways. Density determinations were made on six test castings from different heats, three of which sweated and veined whereas the other three did not. The chemical composition, pouring temperatures, and positions of the samples for density determinations were the same for each. Results are shown in Table 2.

Table 2

Density Determinations

Castings with tin sweat	Castings with no tin sweat
7.974 grams per cc	8.351 grams per cc
8.165 " " "	8,375 " " "
7.975 " " "	8.329 " " "

The castings which sweated and veined are considerably less dense. This can be attributed only to entrapped gases; therefore, it appears that at least for the extreme case of inverse segregation known as sweating, Gender's theory is valid.

21. The fact that the severe cases of veining are generally found on lead and tin bronze castings can be readily explained by the theory of sweating. These alloys have wide freezing ranges which is a condition that must exist in order for sweating to occur. This condition promotes the type of freezing in which coring and dendritism are prominent. When freezing progresses in this manner, numerous interdendritic passages

form, through which the low melting point constituent can flow to the surface.

Veins on Gray Iron and Steel Castings

22. It is possible that the theory of sweating also explains the veins which are frequently found on gray iron castings. This alloy has a wide freezing range, and research conducted at the Naval Research Laboratory indicates that its manner of freezing is similar to that of tin bronzes; i.e. during the initial stages of solidification, many dendrites form throughout the casting with liquid metal filling the intersticies. Although the amount of gas dissolved in cast iron is negligible, a phenomenon occurs which might have a similar effect in causing sweating. This is the formation of graphite flakes. It is concievable that the growth of these flakes forces liquid metal to the surface in the same way that expanding gases cause sweating in bronzes.

23. Veins occasionally occur on steel castings but they differ from those found on bronze castings in both appearance and location. They are small and seldom occur at reentrant angles. Because of the narrow solidification range of steel, its manner of solidification differs from that of tin bronzes and cast iron. Instead of the formation of dendrites throughout the casting, the solidification of steel begins with the formation of solid skin of metal in contact with the mold and progresses inwardly with a relatively sharp division existing between the solidified layer and the liquid metal. For these reasons sweating and inverse segregation do not occur in steel, and veins must form by some other mechanism. Studies on bore cracks, a specific type of external hot tears in cast steel fittings and valve bodies (11) have produced results showing that veins on steel castings are frequently found following the contour of bore cracks. Experimental observations led to the explanation that hot tears form in the solid skin of metal while the interior of the casting is liquid. The sand adjacent to the casting adheres to the metal and also tears. Molten metal from the interior of the casting flows through the crack in the solid skin and into the adjacent crack in the sand to form a vein. The problem of eliminating veins on steel castings, therefore, is secondary to the problem of eliminating hot tears. If the proper precautions to prevent hot tears are observed, no veining occurs.

24. There is no evidence to indicate that this theory of veining is applicable to bronzes. The experiment in which a test casting was shaken out four minutes after being poured precludes this possibility. One of the necessary conditions for the formation of hot tears in steel castings is friction between the sand and the casting. There were no exudations from the surface of this casting until it had been out of the mold for a minute and, therefore, the casting was free of any frictional stresses imposed by the sand, It is, therefore, reasonable to conclude that the cause of exudations was not the formation of bore cracks. The

exudations, which took place in this experiment, occurred at numerous scattered points, and it is not likely that they were connected by cracks. Microscopic and macroscopic examinations revealed no cracks in the vicinity of veins on bronze castings.

Prevention of Veining by Proper Melting

25. The evidence indicating that veins on bronze castings are one of the effects of sweating and that this is caused by gassiness makes it apparent that melting practice is an important factor to be considered. If gases can be excluded from the melt, veins are seldom formed.

26. Melting practice and gas porosity of cast bronzes have been the subjects of much research (8,9,10). Although there was no systematic investigation of them, made during these experiments, the results obtained suggest a few of the principles that should be followed to obtain good castings:

1. Virgin heats should be melted, allowed to solidify, and then remelted before being cast. In general, heats made from pigs or scrap are less gassy than those melted from virgin metals.

2. The use of clean, high grade raw materials is desirable.

3. An oxidizing atmosphere is best for melting.

4. If deoxidation is necessary, the minimum amount of deoxidizer should be used and it should be added just before pouring.

5. The temperature of the melt should be kept as low as is practical. The maximum temperature reached rather than the pouring temperature is most critical. Gas solubility increases with temperature, therefore the highest temperature attained determines the amount of gas dissolved. As the temperature falls, dissolved gases do not come out of solution until sufficient time elapses for equilibrium to be established. Most of the gas dissolved during melting is retained in the metal until solidification is in progress.

Influence of the Sand Mixture on Veining

27. Although it has been shown that sweating is responsible for the serious cases of veining, it is also true that the mold or core must crack before veins can form; therefore, the condition of the sand is an important factor in veining. Numerous sand mixtures were tested with experimental castings. It should be remembered that the test was one of the most

severe possible. The metal used has a greater tendency than any other to form veins; no attempt was made to employ the best melting procedure, and the shape of the test casting is one with which veins may be formed very easily. Any conditions which are effective for preventing the formation of veins should be even more effective under less severe conditions. Most of the test cores were painted with silica wash in order to eliminate penetration so that the veining could be clearly seen. The pouring temperature in all tests was 2000°F.

28. Ramming - The effect of different amounts of ramming is negligible. This is illustrated in Plate 9, Figure 12 which shows a casting in which 3 cores of molding sand were rammed differently. Cores No. 4 and 5 (as marked on the casting) were rammed 10 times and once respectively, while No. 6 was made by ramming 3/4 of its length 9 times, then adding the remainder of the sand and ramming once in order to form an unevenly rammed specimen.

29. Grain Fineness and Distribution - Veining can be decreased by the use of fine sand. This is shown in Plate 10, Figure 13. The 3 cores used in this casting were molding sands with median sizes of 187, 145, and 109 microns respectively from left to right. These sizes are approximately equivalent to A.F.A. grain fineness numbers of 80, 108, and 135. Core No. 10 in Plate 10, Figure 14 was a fine synthetic molding sand with a wide grain distribution. No. 11 was the regular molding sand which has a well sorted grain distribution, and No. 12 has the same median size but a wide grain distribution. The wide distribution gives slightly better results. Cumlative curves for these sands are shown in Plate 11.

30. Facing Materials - Numerous facing materials and binders were tested. No correlation could be made between any of the ordinary physical properties of molding sands and the degree of veining. One elevated temperature property which has a great influence on veining, however, was discovered. This is the property of plasticity. Certain materials, when added to the sand mix, render a rammed body of the sand capable of being deformed at high temperatures without breaking. This enables the thermal stresses in the sand to relax by plastic deformation rather than cracking, and hence prevents veining.

31. The best material which was found for imparting this property is wood flour, but it is useful only when employed in conjunction with a clay such as bentonite. It can not be used with success in core sands. Apparently, there is a fluxing reaction between the wood and the clay which produces plasticity. Wood flour increases collapsability and ease of shake out, but it creates gas and lowers dry strength.

32. Other materials which furnish this property to sand are ordinary fluxes such as borax or sodium carbonate. These materials, however, flux directly with the sand producing a hard glass which makes shakeout and cleaning difficult. They also increase penetration. In Plate 12, Figure 15, the left hand and center cores consisted of regular molding sand with additions of 5 per cent wood flour and borax respectively,are compared with one made of regular molding sand with no additions. Some penetration can be seen where the

core mixture containing borax was used but veining was stopped completely by both wood flour and borax.

33. The property of plasticity can best be investigated by means of the ordinary dilatometer compression test. This consists of compressing the dilatometer specimen after soaking at temperature for twelve minutes. Ordinarily the specimen remains relatively rigid until a certain load is reached and then collapses into 2 or more pieces. Mixes containing wood flour, borax, sodium carbonate or other fluxing materials, however begin to flow plastically when a small load of a few pounds per square inch is reached. Thereafter the load remains constant while the specimen is compressed to a shape with shorter length and increased diameter. The load required to produce plastic flow and the extent to which the specimens can be compressed without cracking or breaking depends on the type of flux, soaking time, and temperature. If specimens made from mixes containing five per cent borax or wood flour are heated to 2000°F or above for 12 minutes, they can be compressed to less than three quarters of their original lengths without cracking. Other organic materials such as activated charcoal and sea coal were tested. Their influence on the sand mixture is similar to that of wood flour in that they make it possible for the dilatometer specimen to be compressed without complete failure, but they did not maintain smooth, uncracked surfaces. These materials were not as effective in preventing veining as those mentioned above.

34. Low Fusion Point Washes - Experience in casting steel has shown that a thin layer of the mold directly in contact with the metal becomes viscous within a few seconds after pouring and, upon cooling, forms a glaze. When properly controlled, this glaze may be peeled easily from the casting and is instrumental in producing a smooth surface. This condition is not achieved in nonferrous castings because of the wide difference between the pouring temperature of the metal and the fusion point of sand.

35. As a possible means of preventing the formation of veins, such glazes were produced with bronze castings by the use of low fusion point washes. These washes were made in three ways; frits of ceramic materials, combined in such a way to have a fusion point of 1800°F, were employed as the base material in a wash; silica flour wash was adulterated with fluxes such as sodium carbonate, borax, and potassium nitrate in order to lower its fusion point; and plain water solutions of such fluxes were applied to the surface of the mold. The ceramic frits were only slightly beneficial. Adulterated silica washes did not stop veining entirely, but were superior to the washes which contained ceramic frits. Only the method of applying water solutions of fluxes to the mold was completely effective in eliminating veining. The reason for the superiority of this type of a wash over the adulterated silica wash is its ability to penetrate further into the mold. If the water to silica ratio of the adulterated silica wash is increased it is more effective for preventing veins since it penetrates more deeply into the sand.

36. In Plate 12, Figure 16, the left and center cores were molding sand, painted with a 12 per cent water solution of sodium carbonate. The center core had, in addition, a covering of silica wash applied after the sodium carbonate solution was dried. On the right is the same sand covered only with silica wash. No veins were formed in the core washed with a plain sodium carbonate solution. On the core which was coated with silica wash in addition to a solution of sodium carbonate a smoother surface was produced, but a small

vein was formed. The core at the right shows the normal condition of veining for the sand.

37. All of the low fusion point washes formed glazed coatings on the casting; but, rather than peel off easily as with steel castings, they adhered tightly to the castings and were difficult to remove.

38. Clay Content of Molding Sands - Veining occurs more readily in sands bonded with both cereal and clay binders than it does in sands bonded with clay alone. For this reason and because of the fineness, wide grain distribution and low fusing point of natural sands, the occurrence of veins in such sand is rare. Plate 13, Figure 17 shows a casting in which the regular 180 micron base sand was bonded only with water plus one per cent, three per cent and ten per cent bentonite respectively from left to right. The veining is decreased as the bentonite is increased.

39. Core Sands - The information obtained on core sands used in these experiments show that a minimum of veining occurs when the more collapsable cores are used. It is believed that veining will not occur in cores which collapse before sweating begins because cracks in such cores are filled with loose sand. Evidence to support this theory is shown in Figures 17, 18, and 19. In Plate 13, Figure 18,a photograph of a casting is shown in which all cores were bonded with core oil and corn flour. No. 1 contained 0.5 per cent of each, No. 2 was the regular core sand with 1.0 per cent of each, and No. 3 had 2.5 per cent of each binder. Core 1 apparently had collapsed before sweating commenced, while the other two had not. Two cores bonded with a collapsable resin binder are compared with one containing the regular binders in Plate 14, Figure 19. Core No. 7 contained 1.0 per cent resin; core No. 8, 1.0 per cent resin plus a half per cent dextrine; and core No. 9 was composed of regular core sand. It is well known that quick collapsability is a characteristic of all resin binders. This property is probably responsible for the appreciable reduction in veining which results from the employment of resinous core-binders.

40. A final illustration of the effect of collapsability is shown in Plate 14, Figure 20. All of the cores used in this casting contained the ingredients of regular core sand, but they were mixed differently. The one on the left was mixed in 200 gram batches by hand and the one in the center by means of a mortar and pestle, while the right hand core was made from a batch mixed in the production muller. In both of the poorly mulled cores veining was eliminated probably because they were loosely bonded and collapsed soon after pouring.

Conclusions

41. Severe cases of veining in bronzes are caused by cracking of the mold due to thermal stresses and sweating of the metal. The elimination of either of the two causes is sufficient to stop or greatly reduce veining. Sweating is caused by gassiness and may be eliminated by proper melting practice. The best methods found for reducing cracking of the mold are the following:

a. The use of fine sand with a wide grain-size distribution.
b. The addition of wood-flour to molding sands.
c. Washing of molds and cores with a water solution of a flux such as sodium carbonate.
d. The use of as small amount of organic binder as is practical.
e. The use of as collapsable cores as is possible.

42. Veins on gray iron castings are believed to form in a similar manner to those on bronze castings except that the internal pressure is produced by the growth of graphite flakes instead of gases evolved from the metal.

43. Veining defects on steel castings are less prevalent than on bronze castings. They occur as a result of hot tears which are caused by stress-conditions within the mold. Elimination of veining under these conditions is primarily a problem of preventing the formation of hot tears.

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"	Pearl Harbor	(1)
"	Philadelphia, Pa.	(1)
"	Portsmouth, N.H.	(1)
"	Portsmouth, Va.	(1)
NavShpYd	San Francisco, Calif.	(1)
"	Terminal Is., Calif.	(1)
NGF	Washington, D. C.	(1)
EES	Annapolis, Md.	(1)
NAB	San Diego, Calif.	(1)
NOB	San Diego, Calif.	(1)
NBS	Washington, D.C.	(1)
USCG Yd	Curtis Bay, Md.	(1)
NAMC	Philadelphia, Pa.	(1)

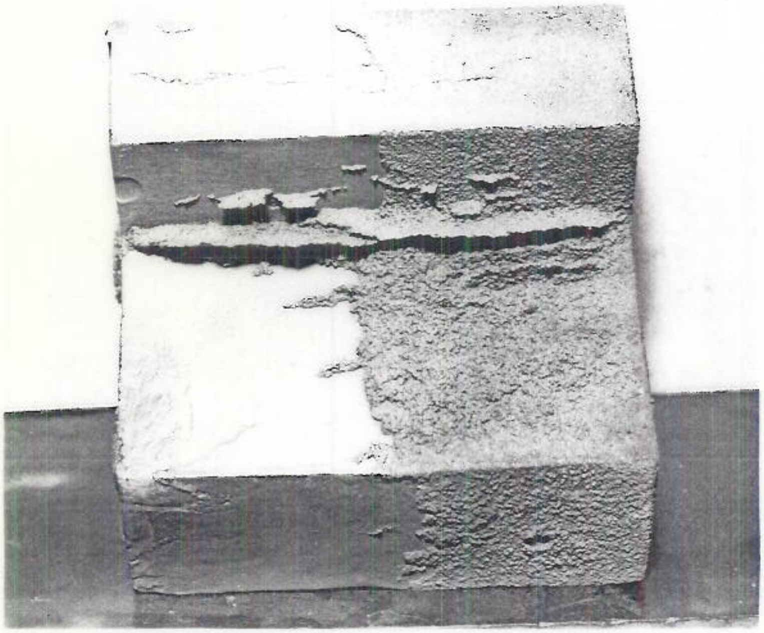


FIG. 1 PHOSPHOR BRONZE CASTING. ONE HALF OF THE MOLD WAS PAINTED WITH A SILICA FLOUR WASH WHILE THE OTHER HALF WAS UNTOUCHED.

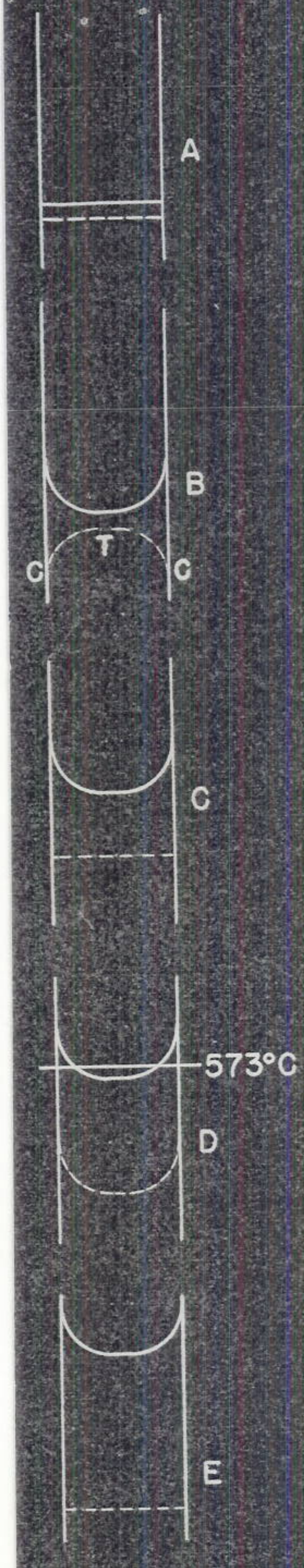


Diagram showing temperature and stress gradients in a cylinder of sand at room temperature. Solid line represents temperature and dotted line represents stress.

When the sand is heated the temperature rises first at the surface, and expands causing compressive stresses in the surface layers and tensile stresses in the interior.

Since sand is a granular material and the grains are coated with a layer of clay, some rearrangement of the grains takes place which relieves the stress. The temperature is still rising so the temperature gradient is unchanged in shape.

The sand at the surface reaches the inversion point and begins to contract slightly while the interior continues to expand at a high rate. This produces high tensile stresses at the surface.

At this temperature the sand has developed some hot strength so the stress is relieved by cracking at the surface instead of by rearrangement of the grains.

FIGURE 2 Diagram showing temperature and stress gradients in a cylinder of sand.

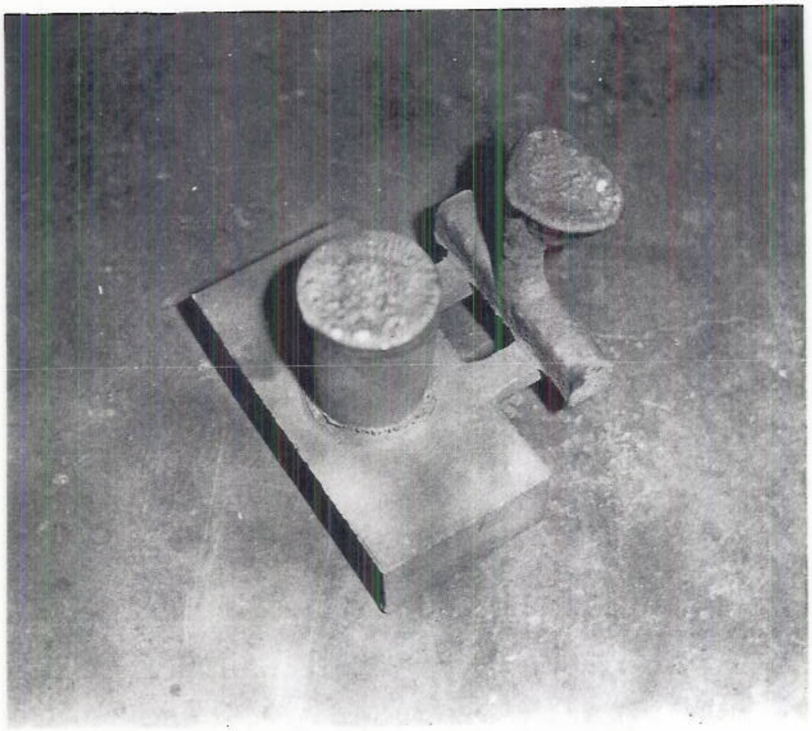


FIG. 3 TEST CASTING, TOP VIEW.

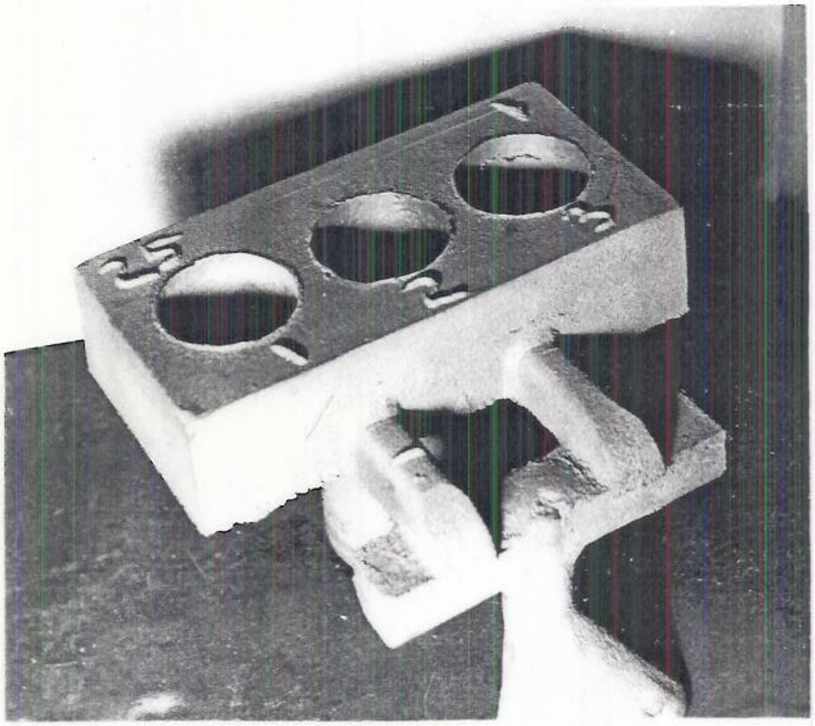
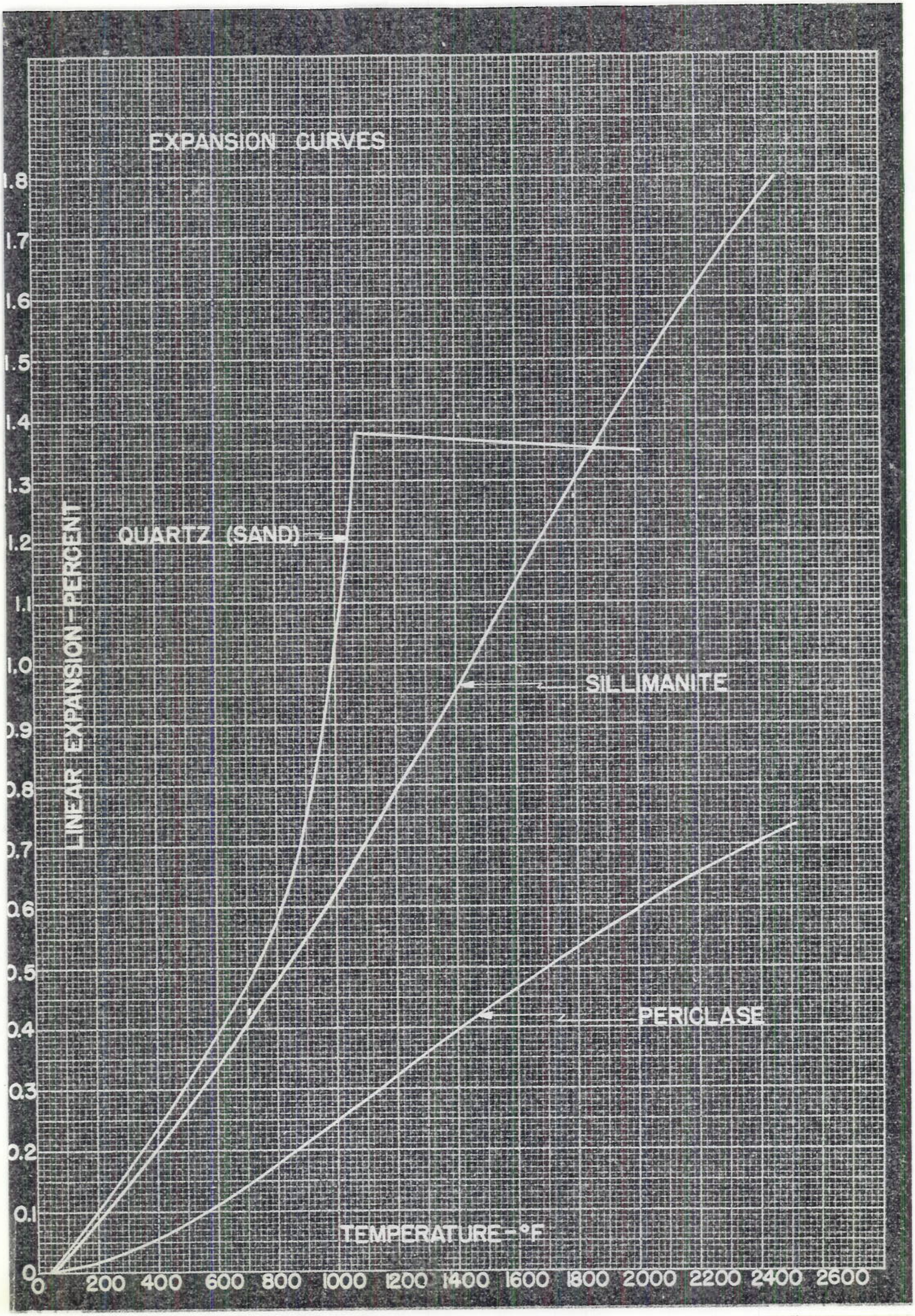


FIG. 4 TEST CASTING, BOTTOM VIEW.


EXPANSION CURVES
LINEAR EXPANSION - PERCENT
TEMPERATURE - °F
QUARTZ (SAND)
SILLIMANITE
PERICLASE
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600

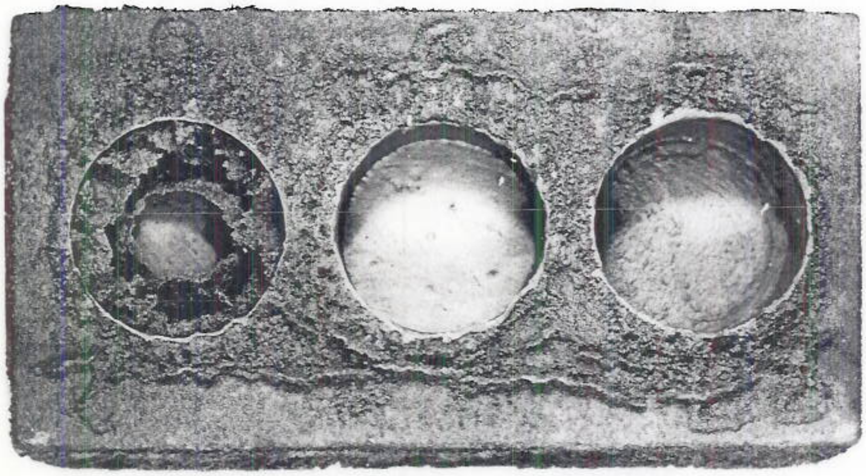


FIG. 5 TEST CASTING SHOWING RESULTS PRODUCED BY TEST SPECIMENS OF SAND, SILLIMANITE AND PERICLASE.

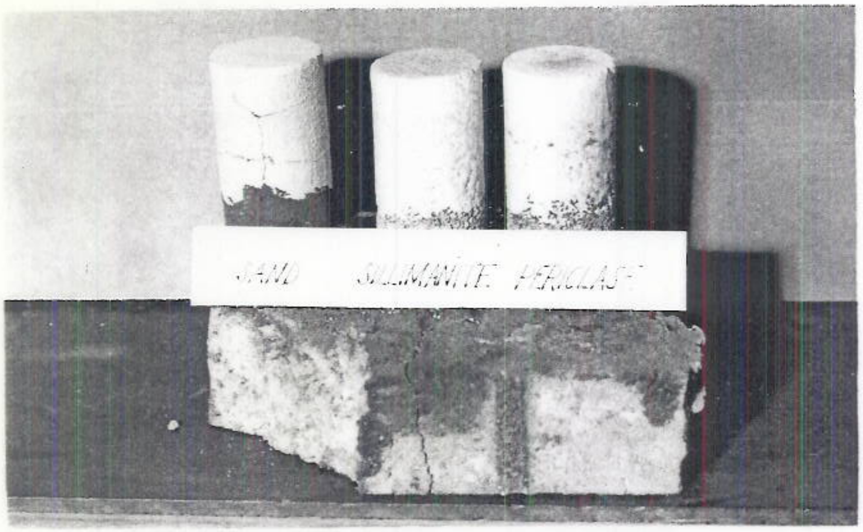


FIG. 6 TEST SPECIMENS AFTER BEING SUBJECTED TO A SHOCK HEATING TEST AT 1093°C (2000°F).

FIG. 7 TOP OF RISER SHOWING LOW-MELTING CONSTITUENT WHICH HAS EXUDED.

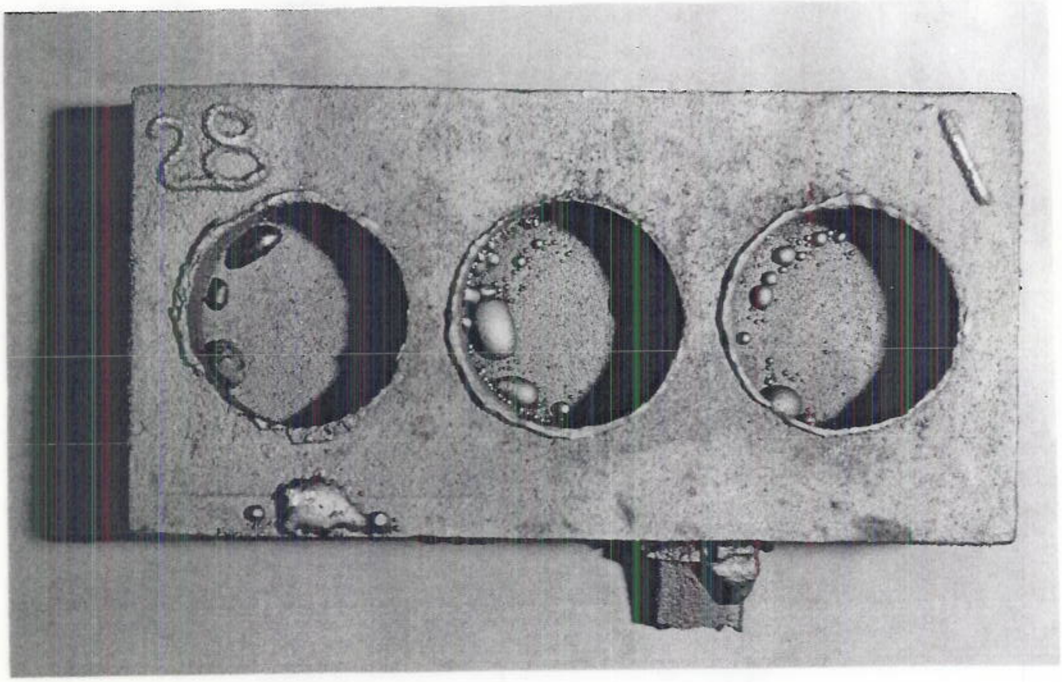


FIG. 10 CASTING SHAKEN OUT FOUR MINUTES AFTER IT WAS POURED.

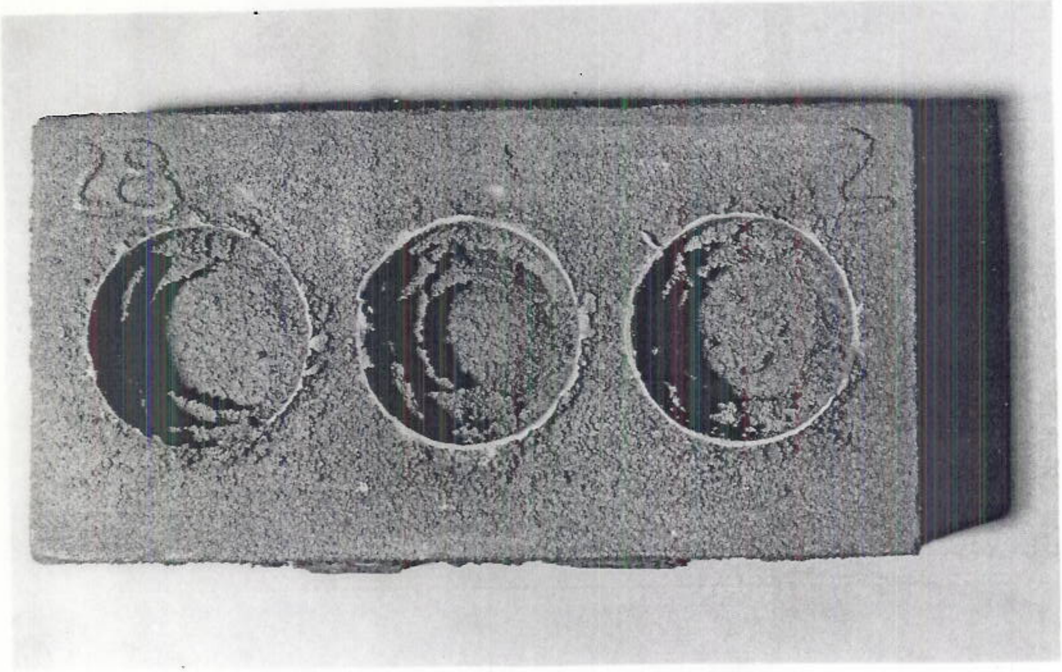


FIG. 11 CASTING FROM SAME HEAT, COOLED OVERNIGHT IN THE MOLD.

PLATE 8

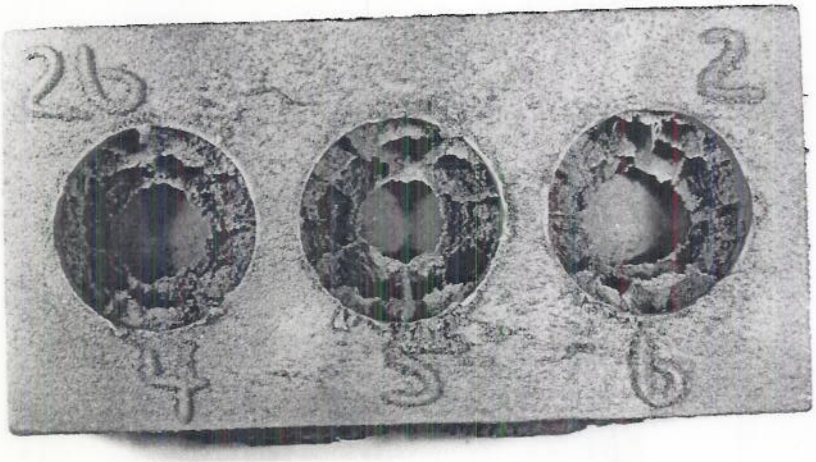


FIG. 12 TEST CASTING SHOWING THE EFFECT OF DIFFERENT AMOUNTS OF RAMMING.

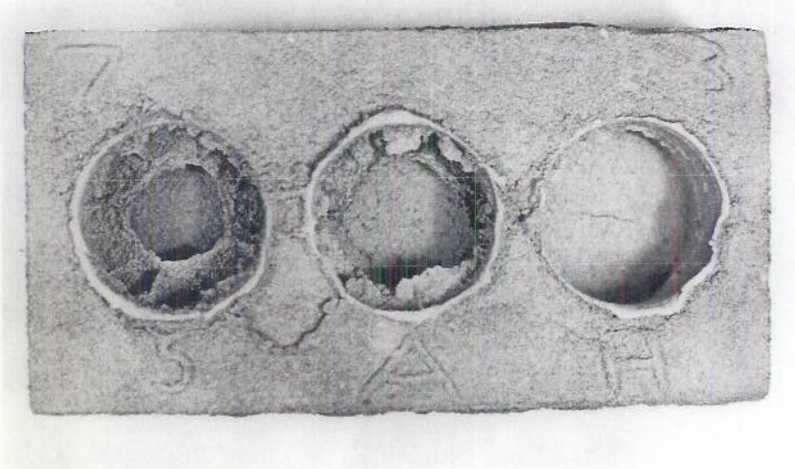


FIG. 13 TEST CASTING SHOWING THE EFFECT OF SAND GRAIN SIZE.

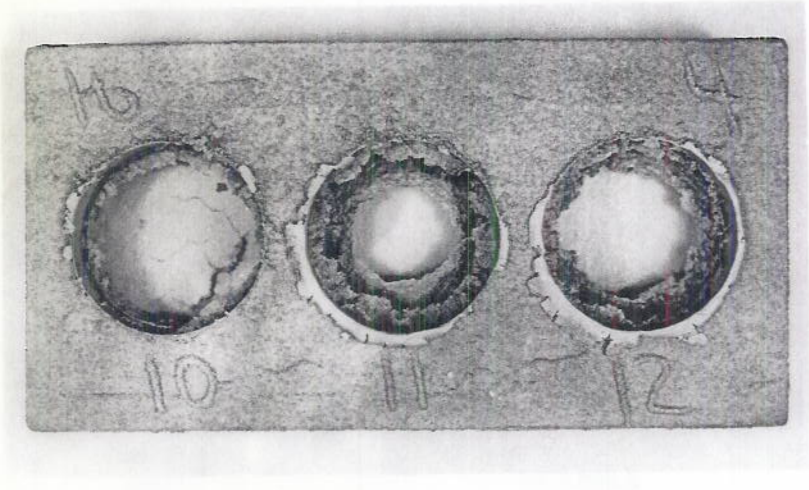
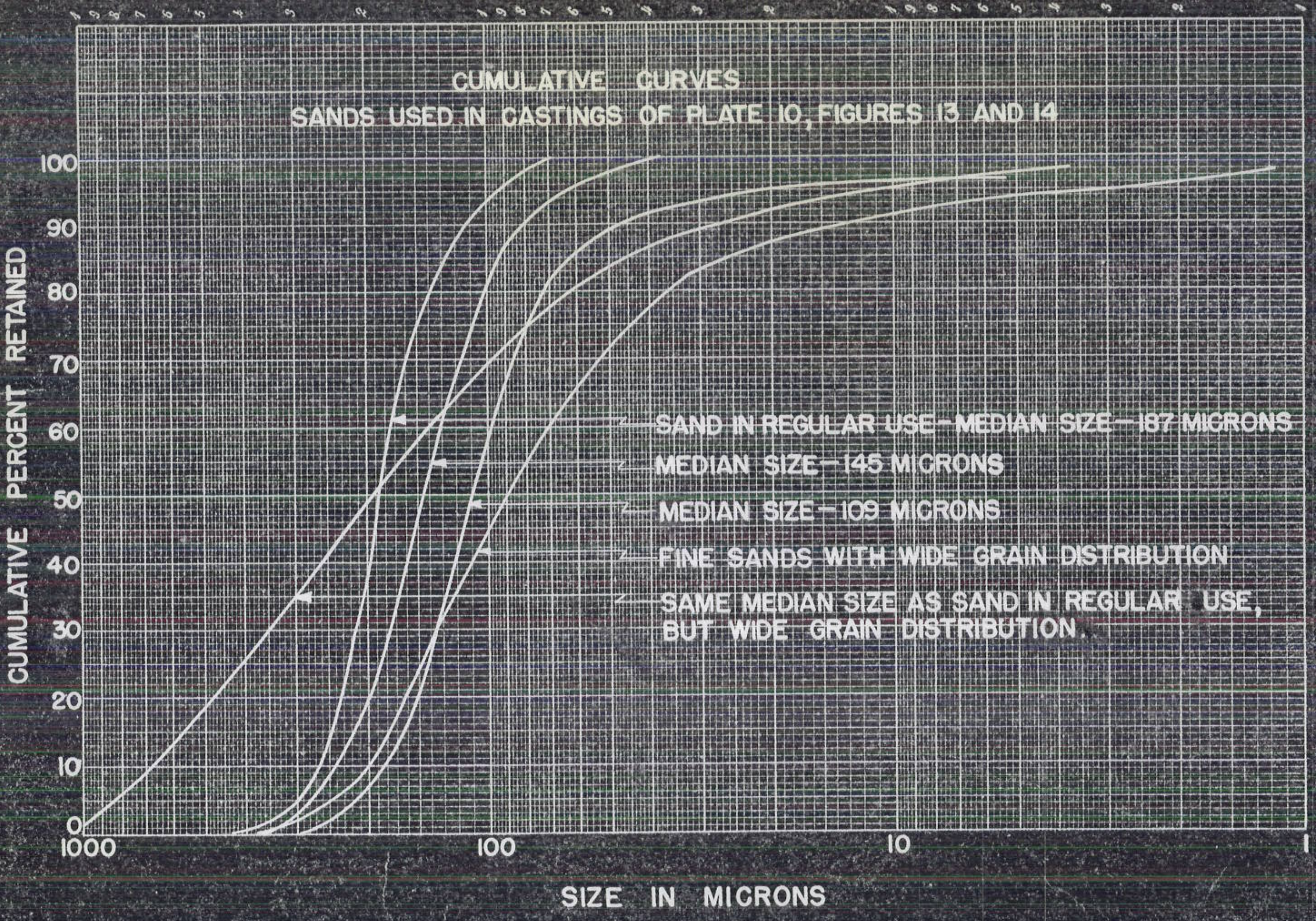


FIG. 14 TEST CASTING SHOWING THE EFFECT OF SAND GRAIN DISTRIBUTION.

PLATE 10

PLATE


CUMULATIVE CURVES
SANDS USED IN CASTINGS OF PLATE 10, FIGURES 13 AND 14
CUMULATIVE PERCENT RETAINED
100
90
80
70
60
50
40
30
20
10
0
1000
100
10
1
SIZE IN MICRONS
SAND IN REGULAR USE—MEDIAN SIZE—187 MICRONS
MEDIAN SIZE—145 MICRONS
MEDIAN SIZE—109 MICRONS
FINE SANDS WITH WIDE GRAIN DISTRIBUTION
SAME MEDIAN SIZE AS SAND IN REGULAR USE, BUT WIDE GRAIN DISTRIBUTION.

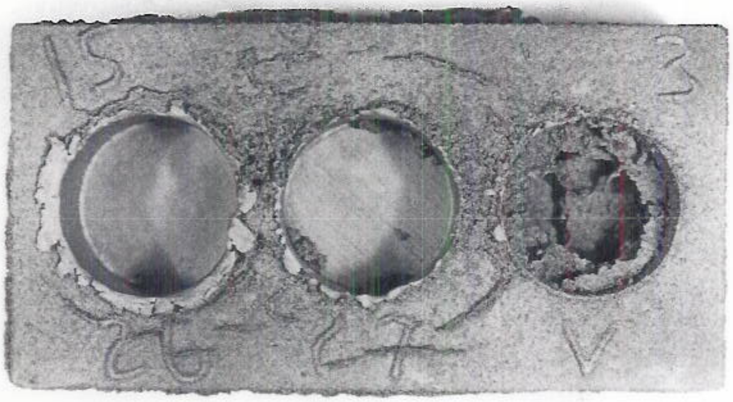


FIG. 15 THE EFFECT OF SANDS WITH WOOD FLOUR AND BORAX ADDITIONS COMPARED WITH REGULAR MOLDING SAND.

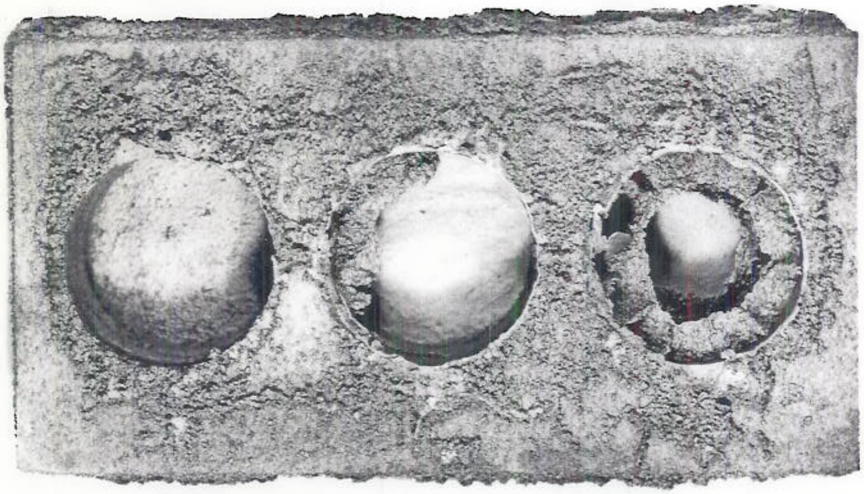


FIG. 16 A COMPARISON OF WASHES OF A SOLUTION OF SODIUM CARBONATE, SILICA FLOUR OVER SODIUM CARBONATE, AND REGULAR SILICA FLOUR.

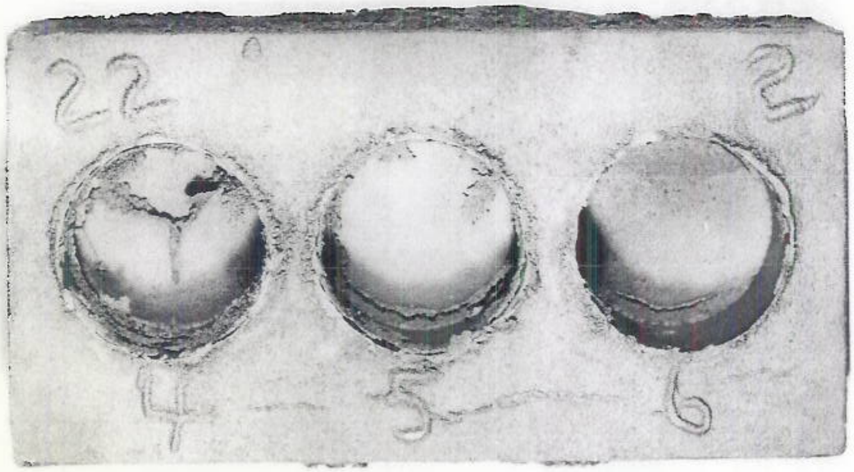


FIG. 17 CASTING SHOWING THE EFFECT OF USING MOLDING SANDS CONTAINING 1 PERCENT, 3 PERCENT AND 10 PERCENT BENTONITE WITH NO CEREAL BINDERS.

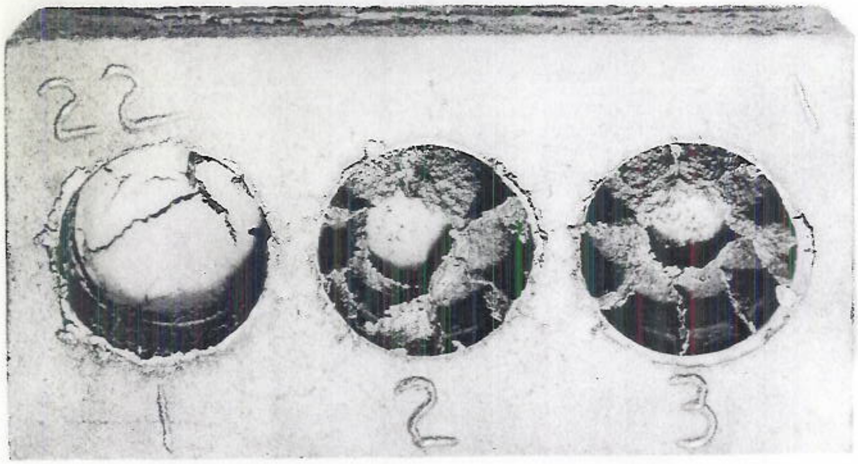


FIG. 18 CASTING SHOWING THE EFFECT OF CORE SANDS WITH INCREASING AMOUNTS OF CORE OIL AND CORN FLOUR.

PLATE 13

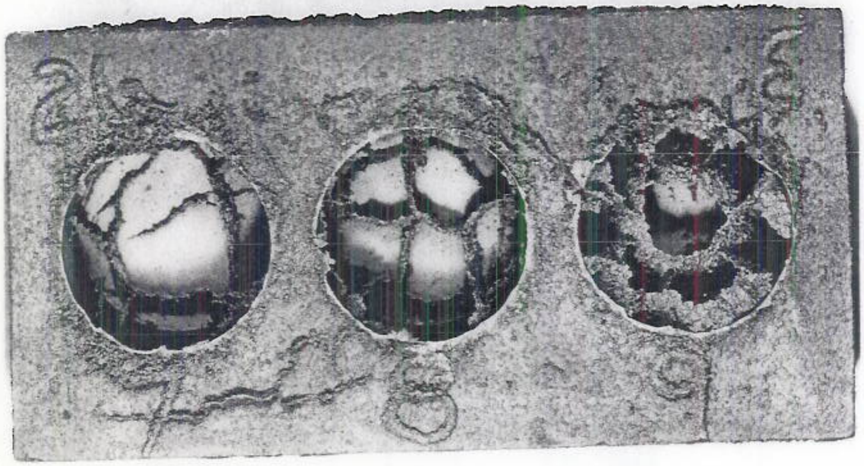


FIG. 19 CORES CONTAINING A RESIN BINDER COMPARED WITH REGULAR CORE SAND.

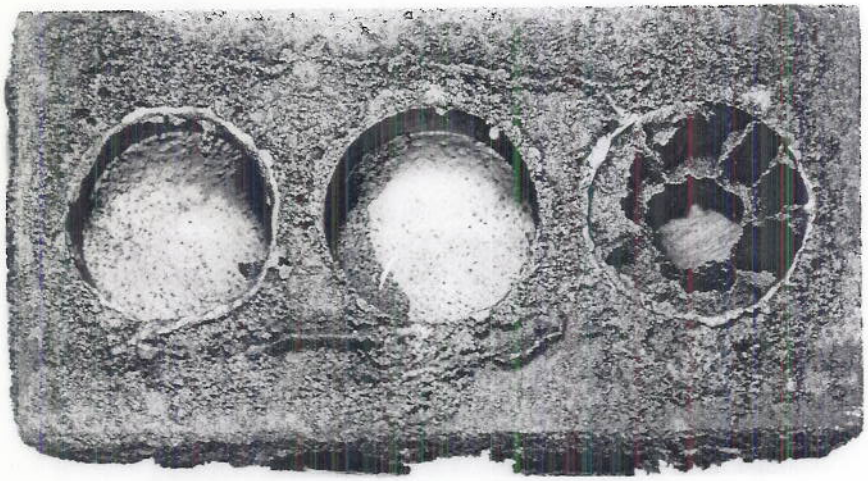


FIG. 20 A COMPARISON OF CORES OF THE SAME COMPOSITION WHICH WERE MIXED BY DIFFERENT METHODS.