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Methods of Casting
Steel Torpedo Parts

Naval Research Laboratory
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ABSTRACT

Eight each of several torpedo parts and one each of two torpedo propellors were cast of a high fluidity, high strength copper steel. These parts, because of their thin irregular sections, present difficulties not encountered in the majority of steel castings. Photographs are included showing the methods used in gating and feeding. Blind risers and chills were frequently used to promote soundness in the heavy sections of these castings. It was found that these parts could all be cast of steel although in some cases redesigning the casting would facilitate the work. Service tests are to be made on these castings in experimental torpedos to compare them with the bronze castings and steel forgings used at present.

AUTHORIZATION

1. This problem was authorized by the Director in accordance with letter of request S-75-1 (18789) (G1-MLM) from the Inspector of Ordnance in Charge to Director, Naval Research Laboratory, dated 2 October 1942.

STATEMENT OF PROBLEM

2. The object of this work was to make a number of steel castings to be used in experimental torpedos. Torpedo parts are at present cast of bronze or machined from forgings, but because of the shortage of copper, tin and other non-ferrous metals it would be desirable to substitute steel for bronze in torpedo parts wherever possible. This would not only alleviate these shortages but would enable the parts to be made more economically and with higher strength. In replacing forgings with steel castings, the heavy burden now placed on forge shops would be lightened. The project was initiated after a conference between personnel at the Naval Torpedo Station at Newport, Rhode Island, and representatives of the Naval Research Laboratory. The parts selected for making as steel castings to replace forgings were the forward and after propellors, trubine frame, tail cone, and spindle casing. Others selected which are now cast of "G" bronze are the pendulum, immersion gear casing and mechanism base plate. The propellors are Mark 10-3 and the remainder of the parts are for the Mark 13 model 2 torpedo. One of each of the propellors and eight of each of the other parts were desired so that they could be subjected to service tests in experimental torpedos.

3. These torpedo castings all have thin sections, many only an eighth of an inch thick, and because of this as well as their intricacy of design it is improbable that many foundries would attempt to develop them commercially. An important phase of this work, therefore, was to find a way to cast them which would be commercially practical.

KNOWN FACTS BEARING ON PROBLEM

4. In making the torpedo castings, information obtained from previous Naval Research Laboratory reports was used to great advantage. In making castings of thin sections, it is necessary to have a very fluid steel. In NRL Report No. M-1657, it was found that increasing pouring temperature and adding copper and silicon markedly improved the fluidity of cast steel. NRL Report No. M-1935 discussed copper cast steels containing about 1.00% manganese and 1.00% silicon and showed that this steel, in addition to being very fluid, is an age-hardening alloy. Tensile strengths of 100,000 PSI can be obtained with a carbon content below 0.25 percent. NRL Report No. M-1783 described the use of blind risers for making castings, and all of the castings with the exception of the propellors were made this way. The making of these castings was largely a matter of putting to practical use information previously reported.

METHODS USED IN TESTING

5. The molds were made with a facing sand of washed silica grains, with which was mixed 1 percent Mogul, 4 percent Bentonite and 3-1/2 percent Water. They were rammed as hard as possible and no effort was made to allow them to dry. The castings were poured whenever the furnace facilities were available which was from 2 hours to 4 days after the molds were made. The cores were made, except when otherwise noted, of baked core sand mixed with 2% linseed oil.

6. The metal was melted in a 300 pound induction furnace from either SAE 1015 steel or scrap with a low sulphur and phosphorus content. The composition of the castings is about 0.20% carbon, 1.00% manganese, 1.00% silicon and 1.5 to 1.75% copper and 0.15% aluminum was added to the steel in the ladle while it was being tapped. The castings were all poured at a temperature above 3000°F., because of their thin sections. The castings were normalized after two hours at 1700°F. and after rough machining are to be age hardened at 930°F. for two hours. This increases the yield and tensile strength by 20,000 pounds and does not appreciably affect elongation or reduction of area. Each casting was checked by X-rays and if shrinkage was disclosed, as was often the case in the first castings made, larger risers or chills were used. Castings were also sectioned and deep acid etched to test for soundness. Some of these castings were made centrifugally.

DATA OBTAINED

7. Each type of casting is discussed separately with illustrations showing the molding technique used. Also a photograph of the finished castings is included.

Tail Cone

8. The tail cone, shown in Plate 1, casting number 1, tapers in outside diameter from 11 inches to about 6-1/2 inches with four ribs about an inch square equi-spaced along the side. The center is cored out. It was found to be impossible to make the casting using a linseed oil core even with the weakest possible mixture, as there were always longitudinal tears along the hot spots beneath the ribs. The hot tear problem was solved by using a green sand core which was weak enough to break down under the contraction of the metal around it. It was necessary to use an aluminum pattern which left its own core since the walls were so thin that a wood pattern would be easily warped or broken.

9. The wall of the tail cone is such that it has varying thickness. At the bottom and top, and at a point midway between the bottom and the top, the thickness increases. This casting was first made with a blind riser at the bottom of each of the four ribs and an open riser at the top but there were small shrinkage cavities at the thick middle section

below each of the ribs. This shrinkage is probably not serious but to be safe four additional risers were placed on the ribs at these points to feed the shrinkage. The mold for the tail cone is shown in Plate 2 and the casting, with its array of risers is shown in Plate 3, Fig. 1.

10. An alternative method for making the tail cone sound would be to pad the wall of the cone either toward the top, in which case the center section could be fed by the open riser, or toward the bottom which would permit it to be fed by the blind risers. This would involve additional machining but the cost probably would not be more than the added molding, casting and cleaning of the additional risers for the method which was used.

11. This casting can be made centrifugally in a vertical casting machine but it is problematical whether much would be gained by this method. To make a centrifugally cast tail cone the mold was spun at a speed of 225 RPM for the first 1-1/2 minutes after pouring and then dropped back to a speed of 170 RPM. It was found that if the mold was spun continuously at 225 RPM there was not enough metal left on the bottom to make the casting and if it was spun continuously at 170 RPM, a speed low enough to deposit an adequate thickness of metal on the bottom, the top wall of the mold was not thick enough. The combination of the two speeds seems to make a satisfactory casting. A photograph of the centrifugally cast tail cone is shown in Plate 3, Fig. 2.

12. The tail cone forging could be redesigned as a casting by padding as suggested above without impairing its usefulness and could then be made very economically in the foundry.

Turbine Frame

13. Although the finished turbine frame casting weighs only about 12 pounds, it was found necessary to use six risers and several chills to make it sound due to the uneven thickness of section. Plate 4, Fig. 1, is a photograph of the mold for the turbine frame and shows the position of the risers and chills. The chills are shown as the dark spots on the mold, four in the drag and one in the cope. The chills at the base of the two arms are placed there to prevent the slight hot tears which occurred at these points when no chills were used. The other three were used to remove the small amount of shrinkage which would otherwise occur at these points. This casting as shaken from the mold is shown in Plate 4, Fig. 2. In the first attempt to make the casting, chills were placed on the lugs at the ends of the three arms, but x-rays showed that a minute amount of shrinkage was present so the chills were replaced with small risers. The turbine frame with gates and risers removed is casting 5 of Plate 1. It is necessary to cast this mold between 3050° and 3100°F. in order to fill the very thin sections.

14. The attempt to make this casfing centrifugally by pouring the metal through a gate over the hole in the casting was unsuccessful because it was not possible to feed through the thin sections in the arms. In addition the arms of the casting were torn by the centrifugal force. Redesigning this part also as a casting instead of a forging would facilitate foundry work, lessen the cost and would not impair its efficiency.

Spindle Casing

15. The spindle casing is casting 6 of Plate 1. It has a 2 inch diameter hole through its center and numerous lugs and bosses on its external surface. Due to its irregular exterior it is difficult and impracticable to make it as a static casting with a cored hole. Chills are required on each of the small projections, and on the larger projections blind risers are needed which destroy the contour of the casting.

16. The spindle casing can, however, be very easily made in several other ways all of which show an advantage over forging. This part is admirably suited for centrifugal casting methods. It is particularly adaptable to a horizontal centrifugal casting as several of them can be made at a time and a hole through the casting can be obtained while at the same time all of the irregular projections on the exterior surface will be sound. Since the horizontal casting machine at the Naval Research Laboratory was not installed in time, this casting was made as a vertical centrifugal casting. The mold was made of core sand in two halves as shown in Plate 5, Fig. 1. The two halves were pasted together and the mold tightly fitted into the centrifugal casting machine. The metal was poured through the open uppermost part of the mold which was rotated at a speed of 400 RPM. The castings thus obtained were souhd but due to the hole through the center being of a paraboloidal shape more machining was required on the vertical casting than would be required on the horizontal casting. At high enough speeds vertical centrifugal casting can rival the horizontal type in the amount of machining required. It should be remembered, however, that several horizontal castings could be made at one time in one mold whereas only one vertical centrifugal casting can be made at one time.

17. Another method which has proved satisfactory and which requires neither a centrifugal casting machine nor risers is, using the same type of mold as shown in Plate 5, Fig. 1, pour the metal through the open end and after a sufficient thickness of skin has been formed on the walls, pour the still molten metal back out through the gate. A series of castings were poured and bled at times varying from 1 to 3-1/2 minutes after pouring. These castings were sawed through the center and a photograph of the group is shown in Plate 6. The casting which was upended 2-1/2 minutes after pouring seems to have about the right thickness of metal. The diameter of this hole is 2 inches at its widest point and since the finished diameter of the hole is about 2-1/2 inches, there is an adequate allowance for machining. Plate 5, Fig. 2, is a photograph of the spindle casing casting as shaken from the mold.

18. Even if these molds were not bled and all of the metal was permitted to solidify in the mold, it would still rival the forging in economy of production. A considerable amount of metal would have to be removed in boring the spindle casing but not as much as required at present in the forging.

Propellors

19. The propellors were first made as centrifugal castings, cast to size, with no allowance for machining. However, the quality of surface required on the blades could not be obtained on a casting made in ordinary sand and in the regular casting way. A very small pinhole or sand spot on a blade will cause its rejection as it is a nucleus for corrosion and causes turbulence in operation. The blades were then made thicker so that about a sixteenth of an inch of the surface could be machined off. However, when these propellors were spun centrifugally, there were hot tears at the junctions of the blades and hub. These tears were due, largely to the centrifugal force which tends to pull the blades off the hub.

20. Since centrifugal casting methods did not work satisfactorily in making the propellors, a few of them were cast statically by pouring the metal down a riser over the hub. The blades were easily run with hot metal but there were still small tears at the junctions of the hub and blades on the drag side of the propellors. Since the hub was not cored out but was left solid, there was a large temperature differential between it and the thin blades, a situation which is conducive to hot tearing. It was believed that if this temperature differential could be reduced the tears would disappear. Accordingly, a core was placed in the hub of the propellor as shown In Plate 7, Fig. 1, which greatly reduced the volume of metal in the hub. This core allowed a metal thickness around the bottom of the hub of about 1/4 inch and tapered upward so that feeding could still take place. The blades and hub solidified at more nearly the same rate and there were no tears. However, x-ray inspection disclosed small gas holes in the blades of these propellors. The holes were present in propellors made in dry sand molds so were not caused by moisture, and incomplete deoxidation was not the cause since the steel contained 1% silicon, 1% manganese and aluminum additions were made during tapping. It was concluded that the cavities were caused by the turbulent metal entering the mold entrapping air and because the blades are so thin the metal freezes before the air can escape.

21. Two remedies for preventing these turbulence cavities were tried; one by bottom gating the propellors, which resulted in a smooth flow of metal into the blades with no turbulence and hence no air entrapment; the second, by pouring the metal down the riser as before but using overflow basins at the ends of each blade to allow metal to flow through the blade to wash out the air. Both of these methods proved successful. To doubly insure a sound casting it is recommended that both of these devices be used in making the propellors. A bottom

gated casting as removed from the mold is shown in Plate 7, Fig. 2. The gate extends through the center of the core flaring out at the top similar to an inverted horn gate. The cleaned forward and after propellors are castings 4 and 7 of Plate 1.

Mechanism Base Plate

22. Castings 8 of Plate 1 are mechanism base plates placed so that the details of both the top and bottom can be seen. This casting is no more difficult to make than numerous other steel castings in daily production. Like the other torpedo castings the metal should be hot because there are a few thin members. The three cores required for this casting are shown in Plate 8, Fig. 1. The core on the left has a chill imbedded in it to make the boss in the casting solid. Plate 9 is a photograph of the mold for the base plate with the cores in place ready for closing, one core being tied to the cope of the mold. The casting as shaken from the mold is seen in Plate 8, Fig. 2, and the position of the risers is clearly shown. The mold was cast in a tilted position with the gate at the lowest point to allow the mold to be filled with an even flow of metal and with a minimum of turbulence.

Immersion Gear Casing

23. Two immersion gear casings are seen in Plate 1, castings number 3. To insure complete soundness in the casting, numerous chills are incorporated in the cores to chill the projections on the casting which cannot be reached by the risers. The cores for the casting are shown in Plate 10, Fig. 1; the dark areas are chills. The photograph of the mold for the immersion gear casing is seen in Plate 10, Fig. 2, with the cores in place. The casting is gated into a blind head which feeds the two heavy lugs at the ends of the arms and a small open riser is placed on the base of the casting. The base below the riser is padded to improve feeding. Plate 11 is a photograph of this casting with the gates and risers intact. In order to fill the thin sections and the irregular projections on the castings and to avoid cold shuts, the castings should be poured hot. These castings were poured at about 3150°F. and no difficulty was experience with "burnt on" sand.

Pendulum

24. The torpedo pendulum, two views of which are shown in 2 of Plate 1, was the most difficult casting to make due to its intricate sections. The cores required for this mold are shown in Plate 12, Fig. 1. The core in the left corner of the picture is very difficult to make and a sand of high green strength is necessary due to the small irregular projections on it. The cores used for these castings was made of a No. 60 silica sand containing 1.25% linseed oil, 0.70% Mogul, 0.30% Bentonite and 3% water. Chills were placed in the cores as shown by the dark areas in the two middle cores of Plate 12, Fig. 1. The core in the right center has 4 lugs, two at the top and two midway between

the top and bottom which were at first chilled at the ends. These chills did not prove entirely satisfactory and were replaced by internal chills, which were nails with the heads removed. Plate 12, Fig. 2, shows the mold for the pendulum, and Plate 13, Fig. 1, is this mold with cores in place ready to close. Two methods of gating these castings were used; one, a single downgate with gates leading into the two blind risers and the other, two downgates, one leading into each riser, with a pouring basin as shown in the cope of the mold in Plate 12, Fig. 2. The latter method is preferred since the metal does not lose as much heat in reaching the mold as it does with a single downgate. Plate 13, Fig. 2, is a photograph of the pendulum casting as removed from the mold.

CONCLUSIONS & RECOMMENDATIONS

25. All of the torpedo parts discussed in this report can be made as steel castings. The test castings should satisfactorily replace the forgings and bronze castings used at present although final judgment must be reserved until they are machined and subjected to service tests.

26. The mechanism base plate and the spindle casing can be made as steel castings with no unusual difficulty, the latter being suitable for centrifugal casting. The tail cone can be made without too much trouble if the inner walls are padded to make feeding easier, and it could also be made as a centrifugal casting. However, the tail cone and also the turbine frame, as designed, are suited for forgings operations and it would probably be more economical to make them as forgings. The propellors, immersion gear casing, turbine frames and pendulum, all have sections thinner than are normally cast with steel but they can successfully be cast if the metal is around 3100° F. and a fluid type of steel is used.

27. It if it is decided to purchase any or all of these castings commercially, it would be desirable to redesign them slightly to make them easier and cheaper to make, and consequently more appealing to the foundryman. The parts could also be improved by redesigning as castings. The changes would be slight but extremely important to the foundry.

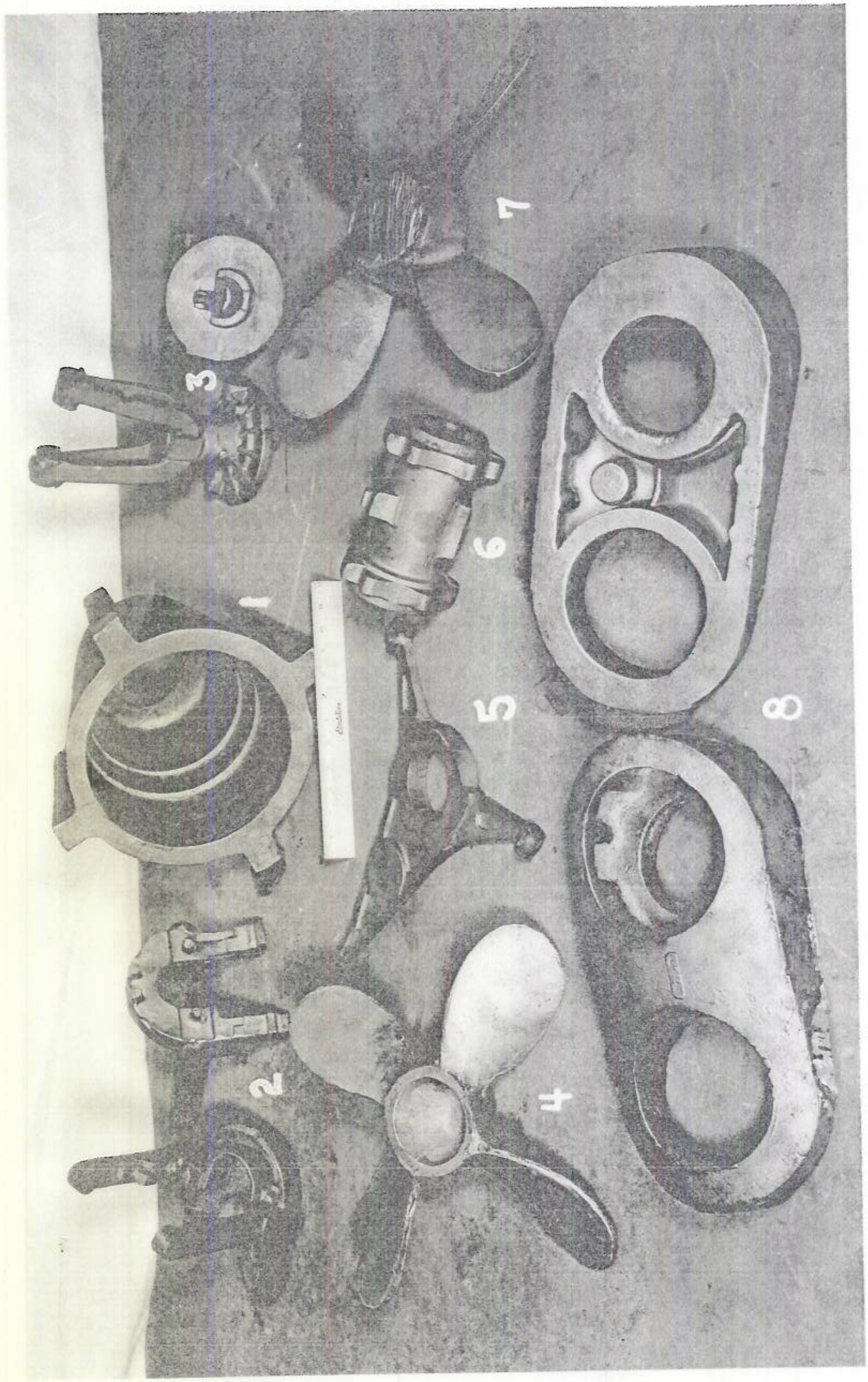

PLATE I

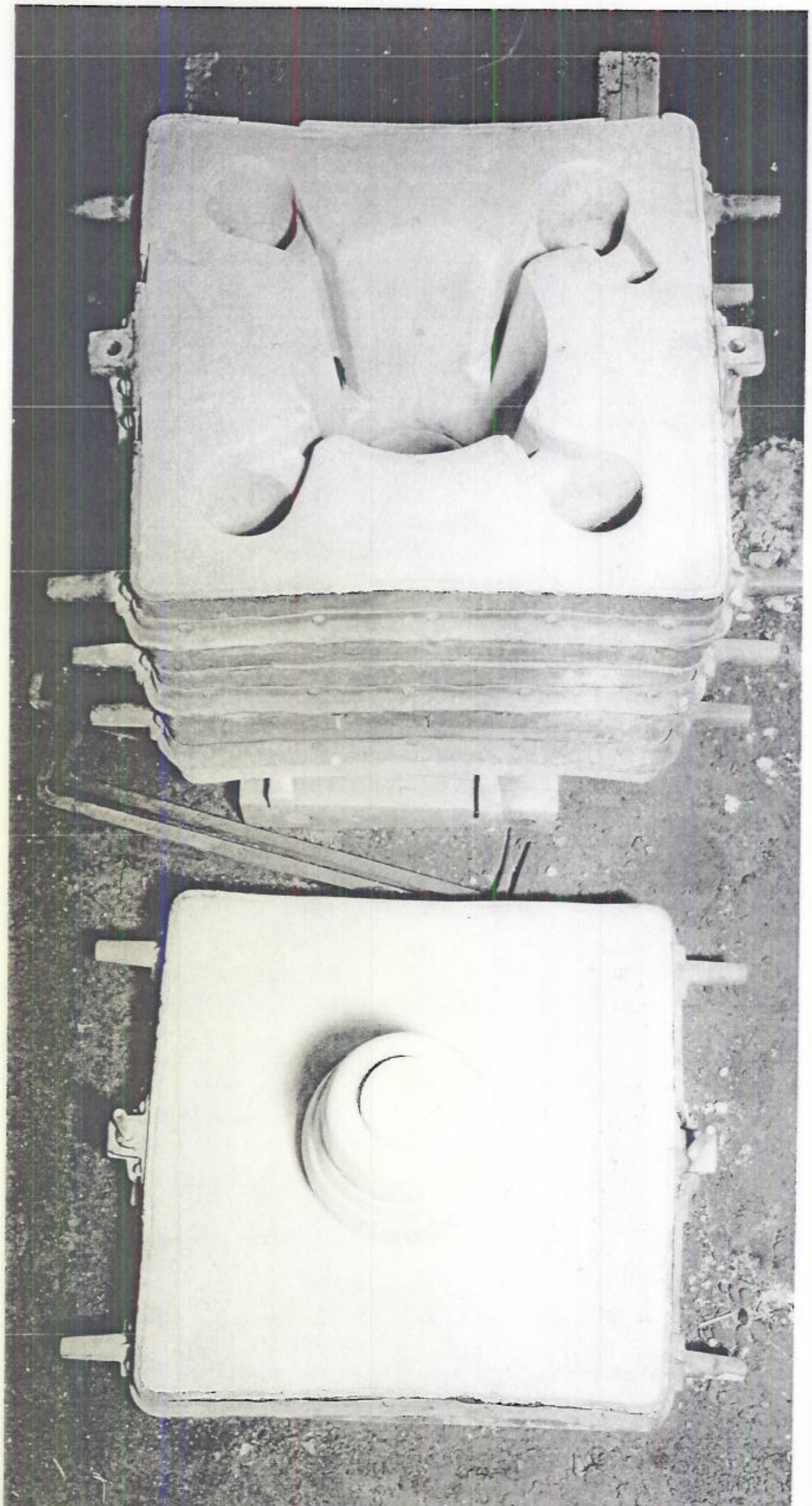

PLATE 2

FIG. 1

FIG. 2

PLATE 3

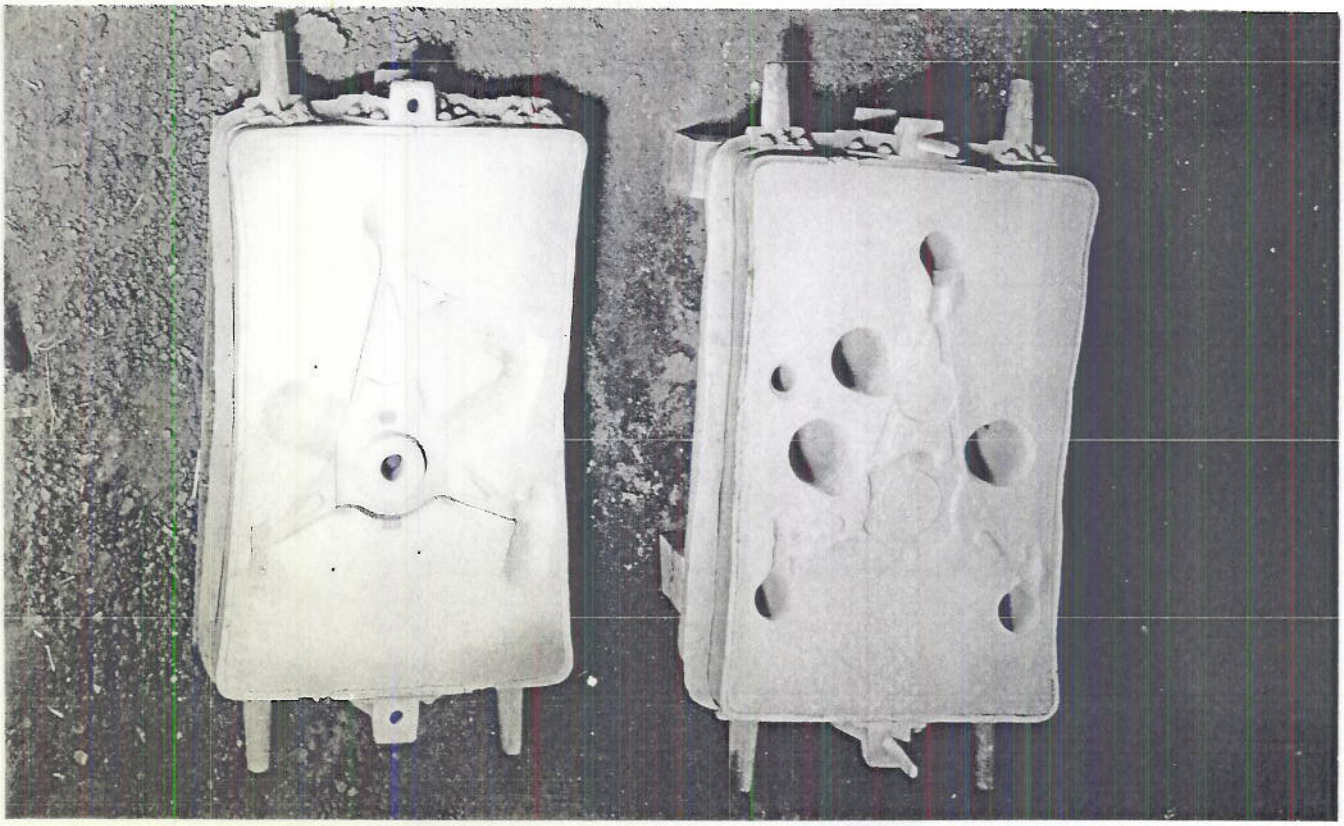

FIG. 1

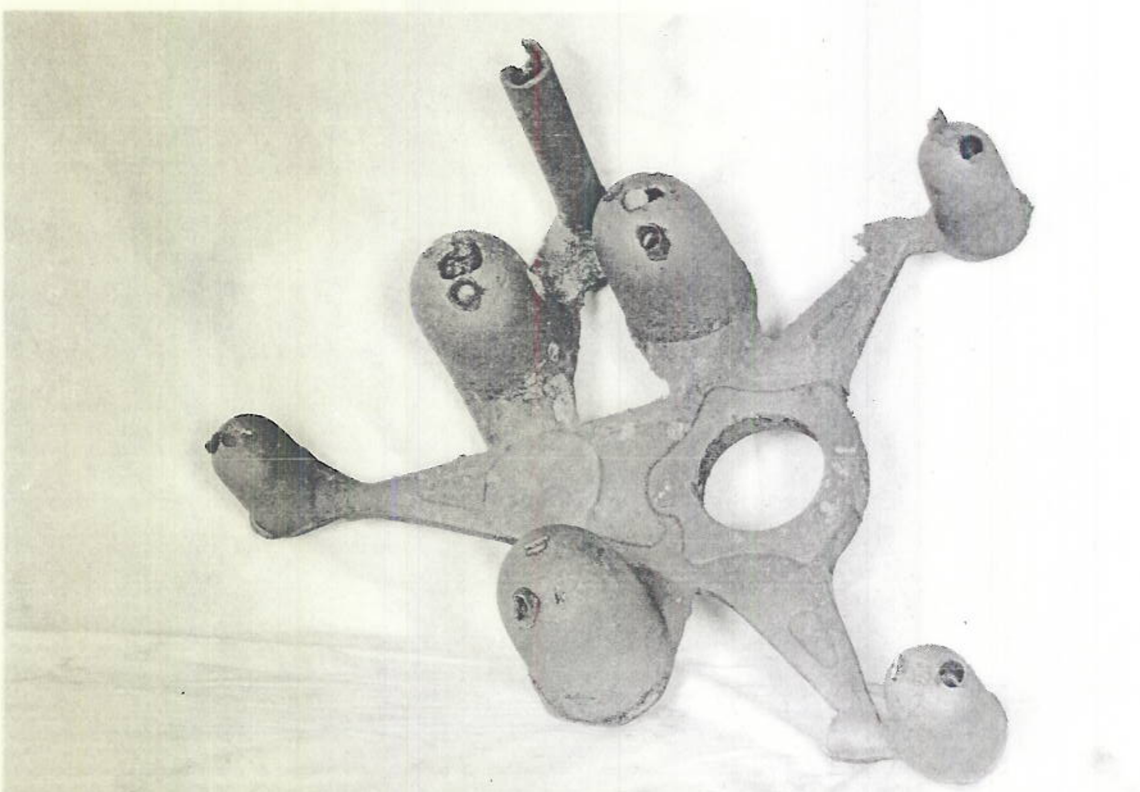

FIG. 2

PLATE 4

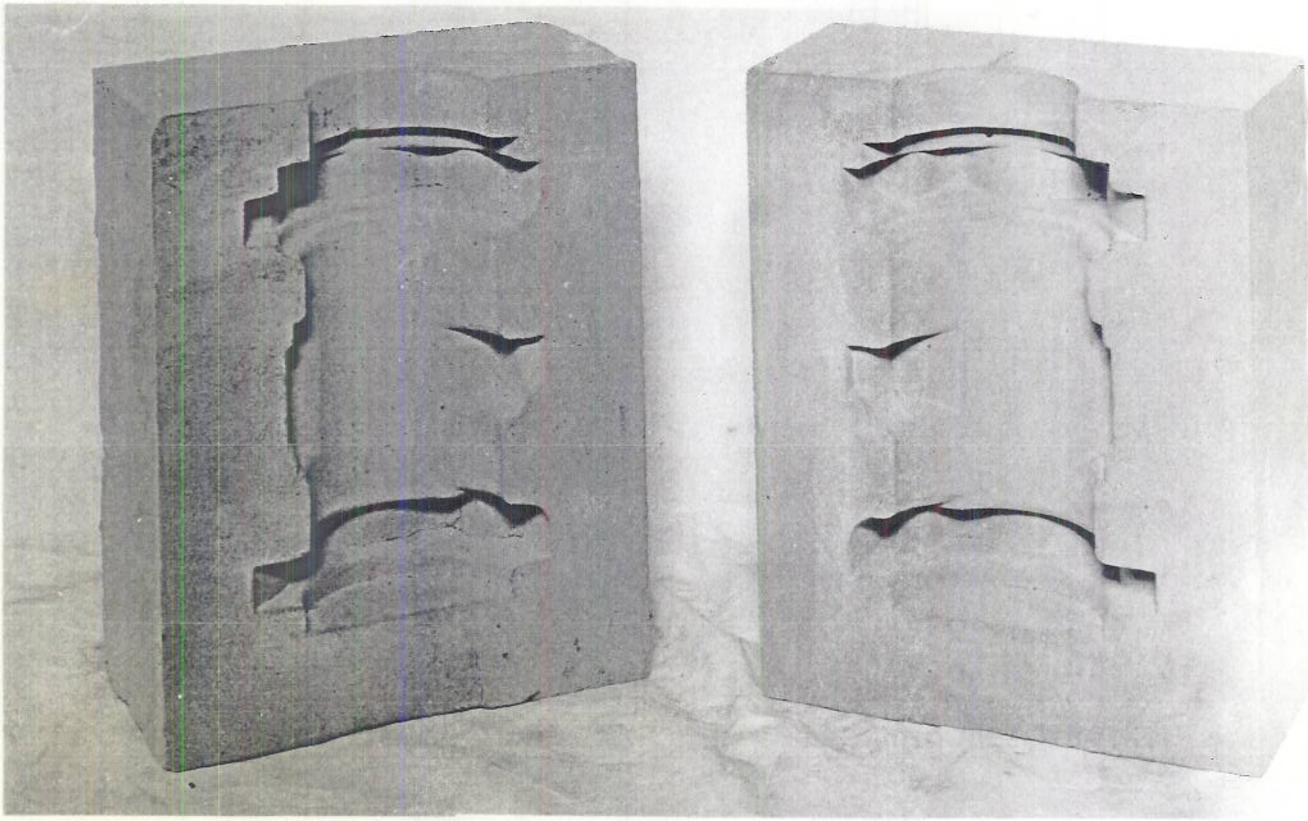

FIG. 1

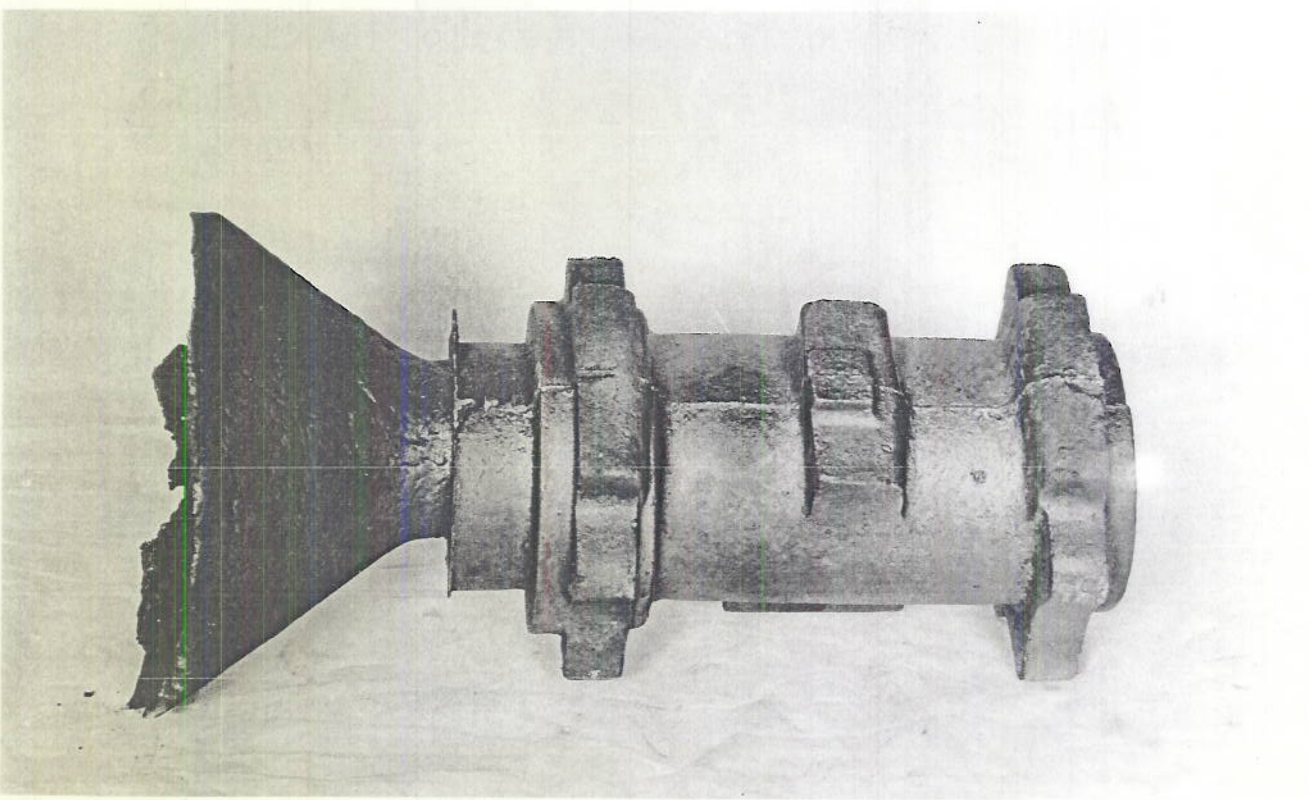

FIG. 2

PLATE 5

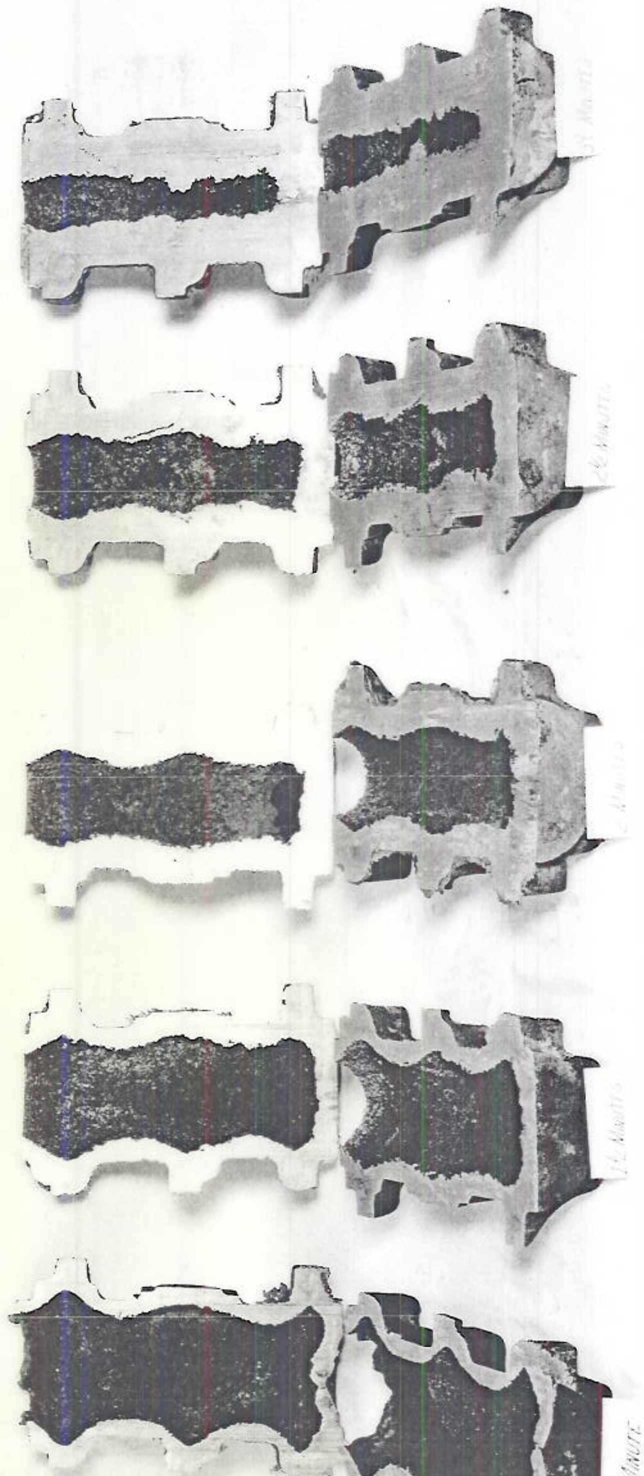

PLATE 6

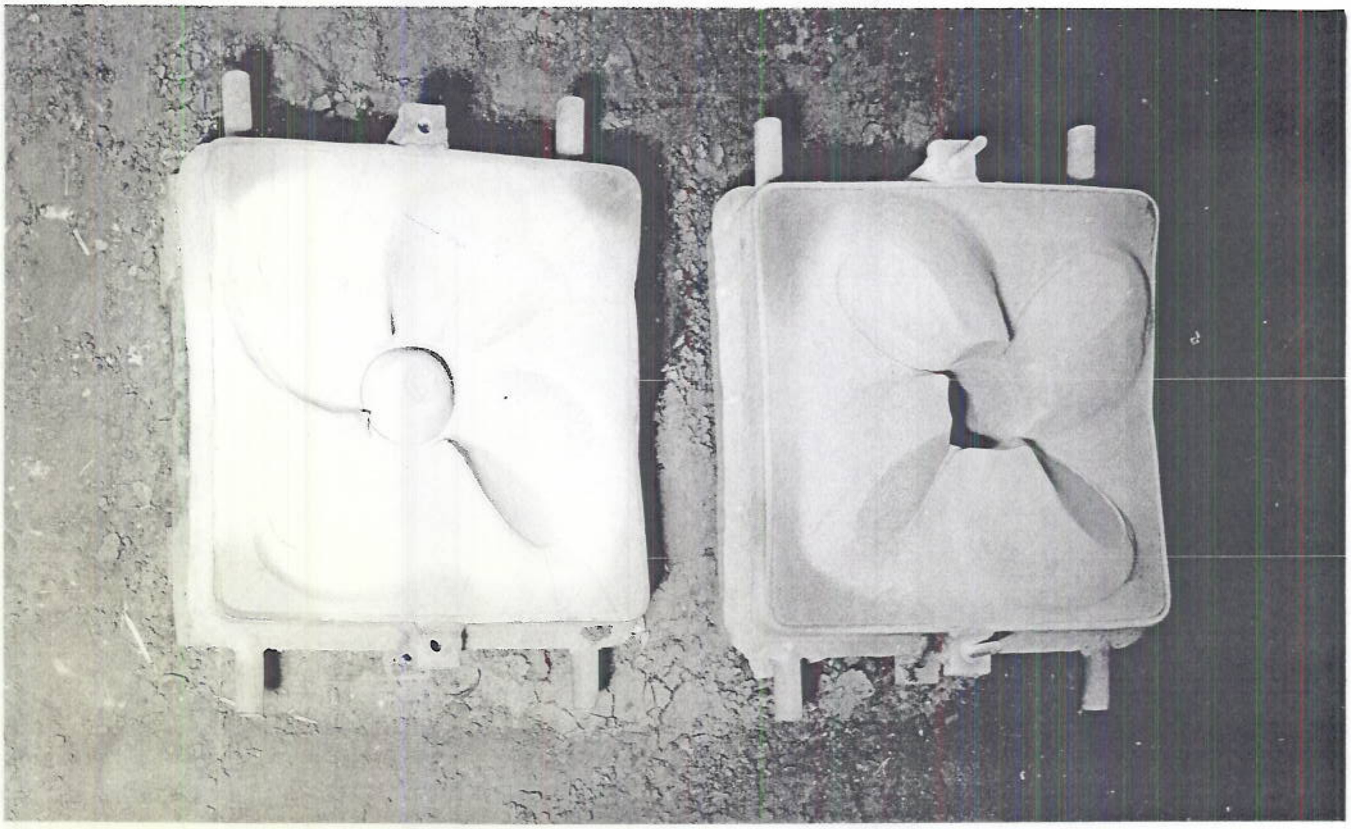

FIG. 1

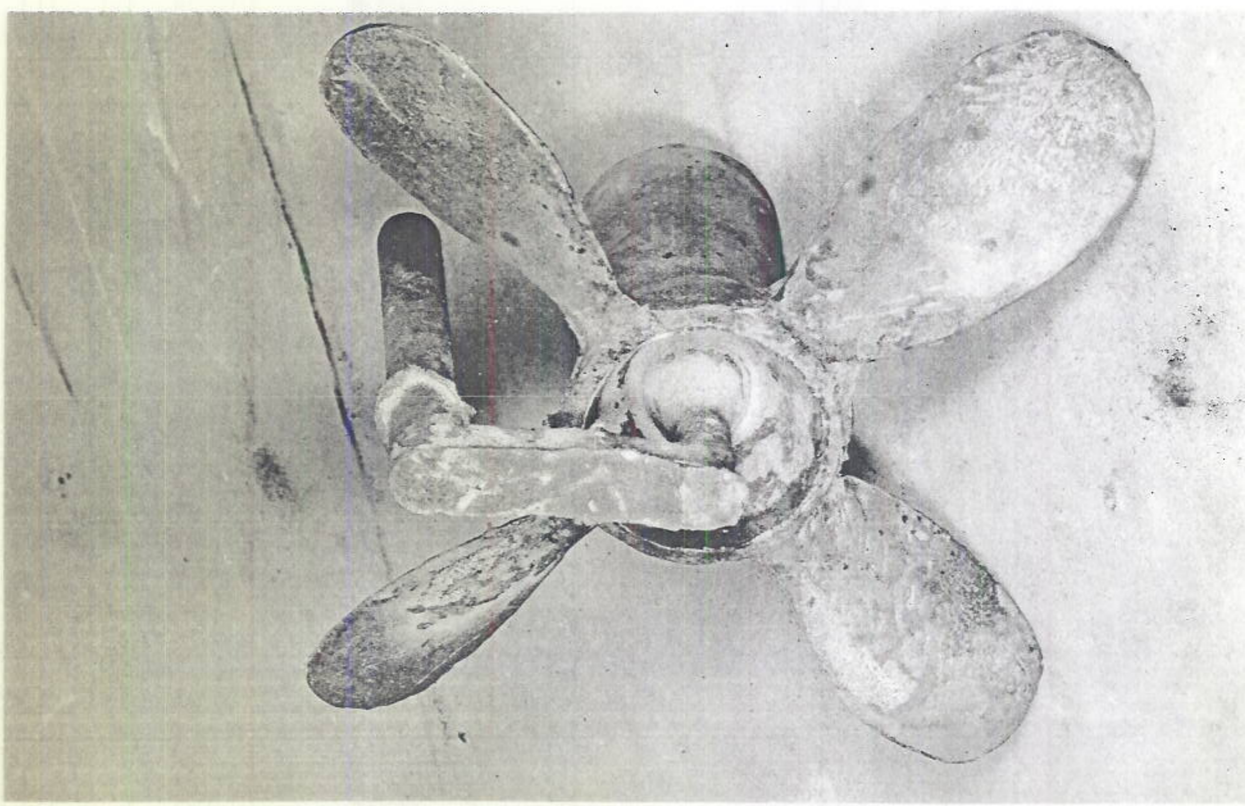

FIG. 2

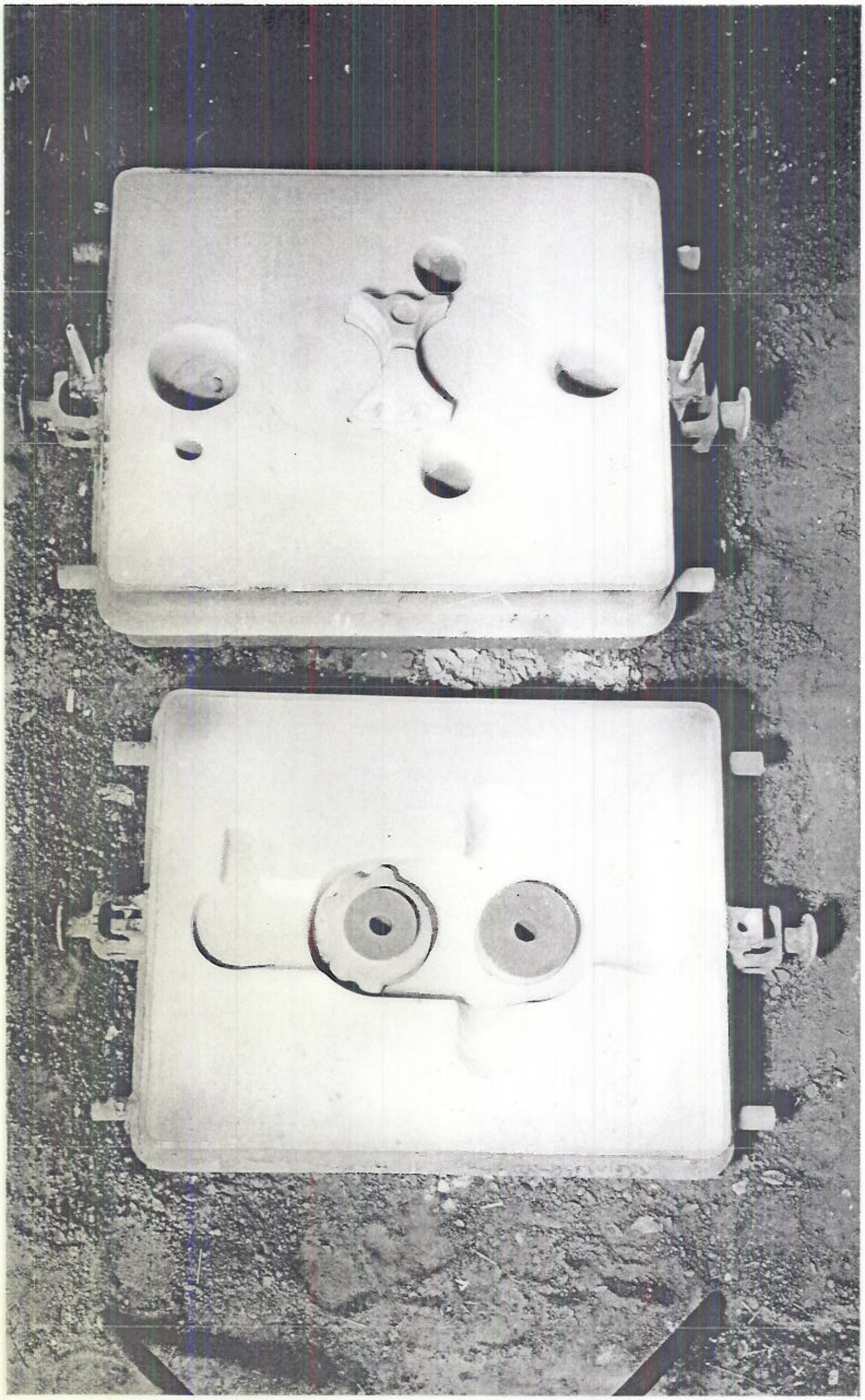

PLATE 9

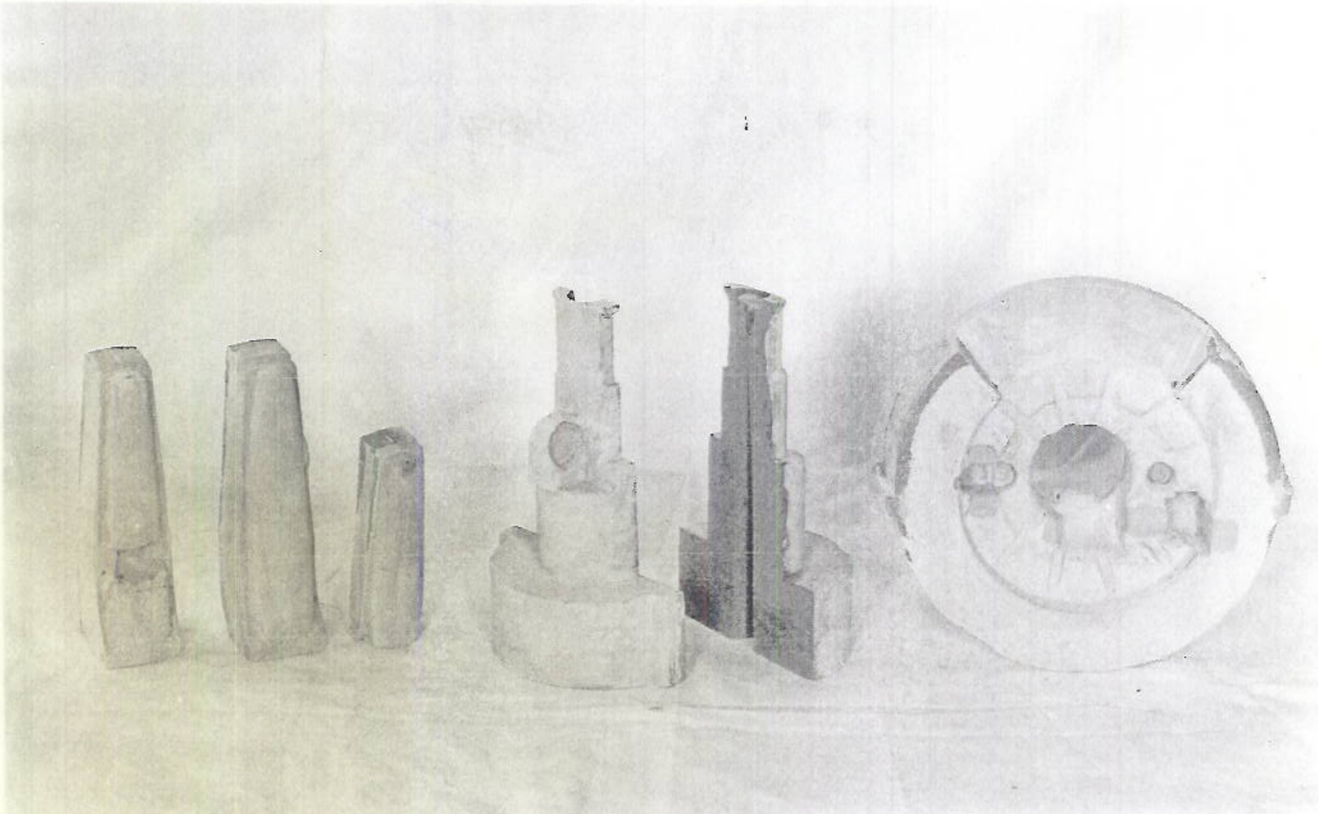

FIG. 1

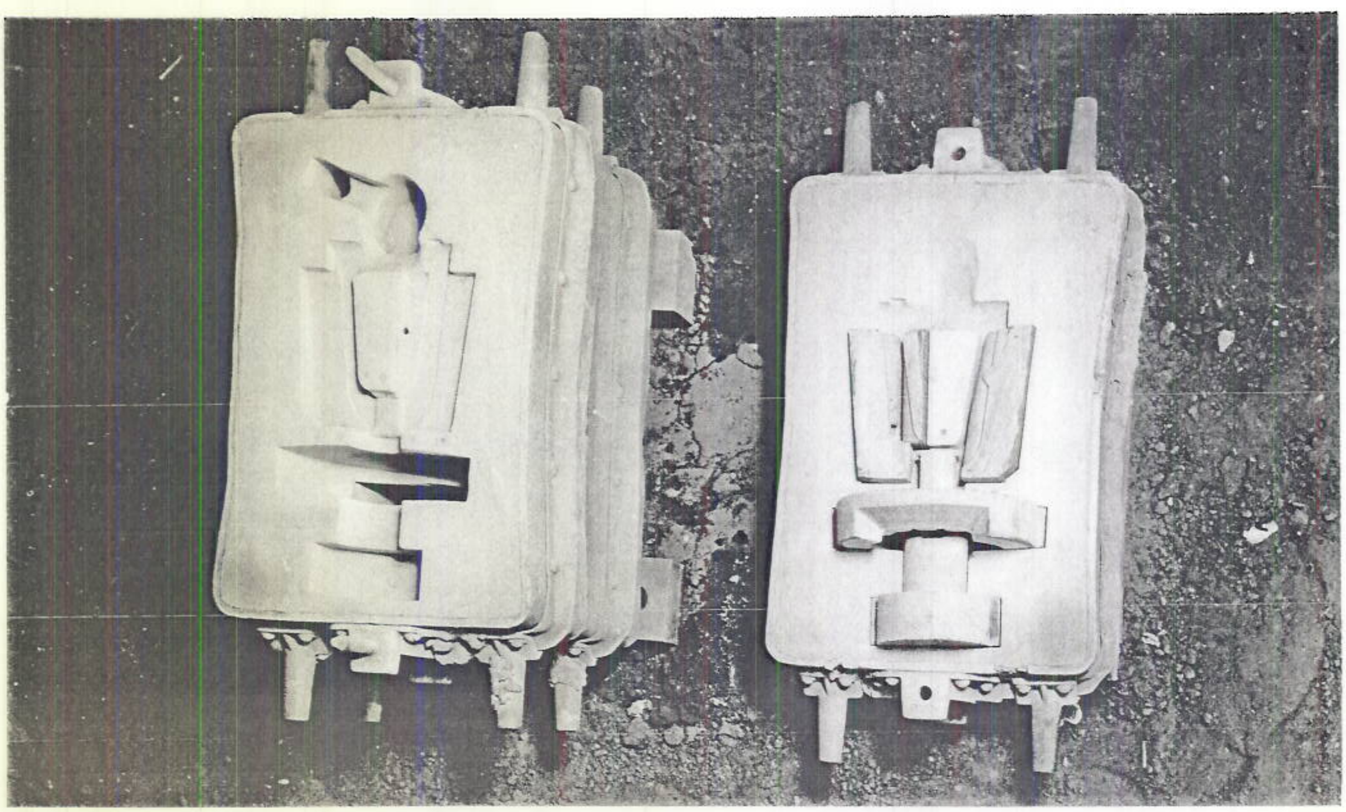

FIG. 2

PLATE 10

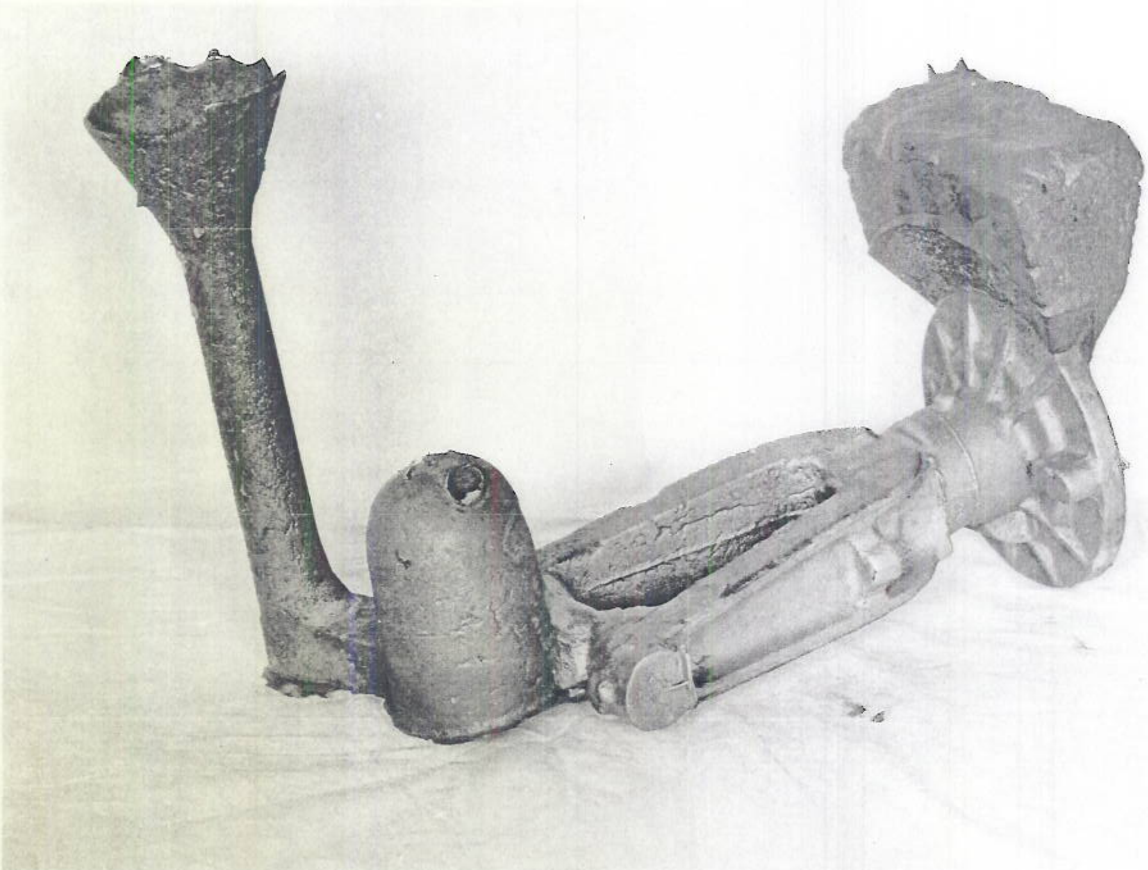

PLATE II

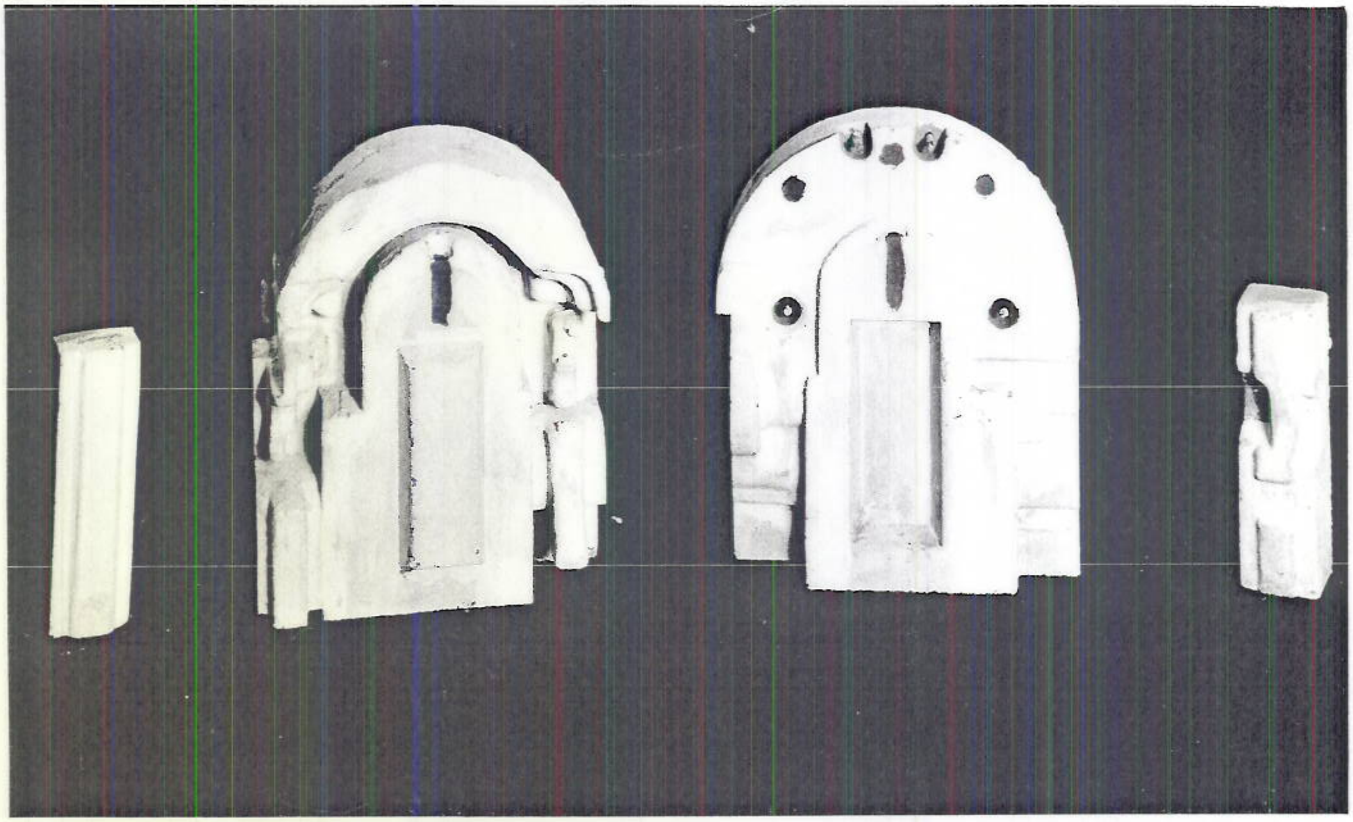

FIG. 1

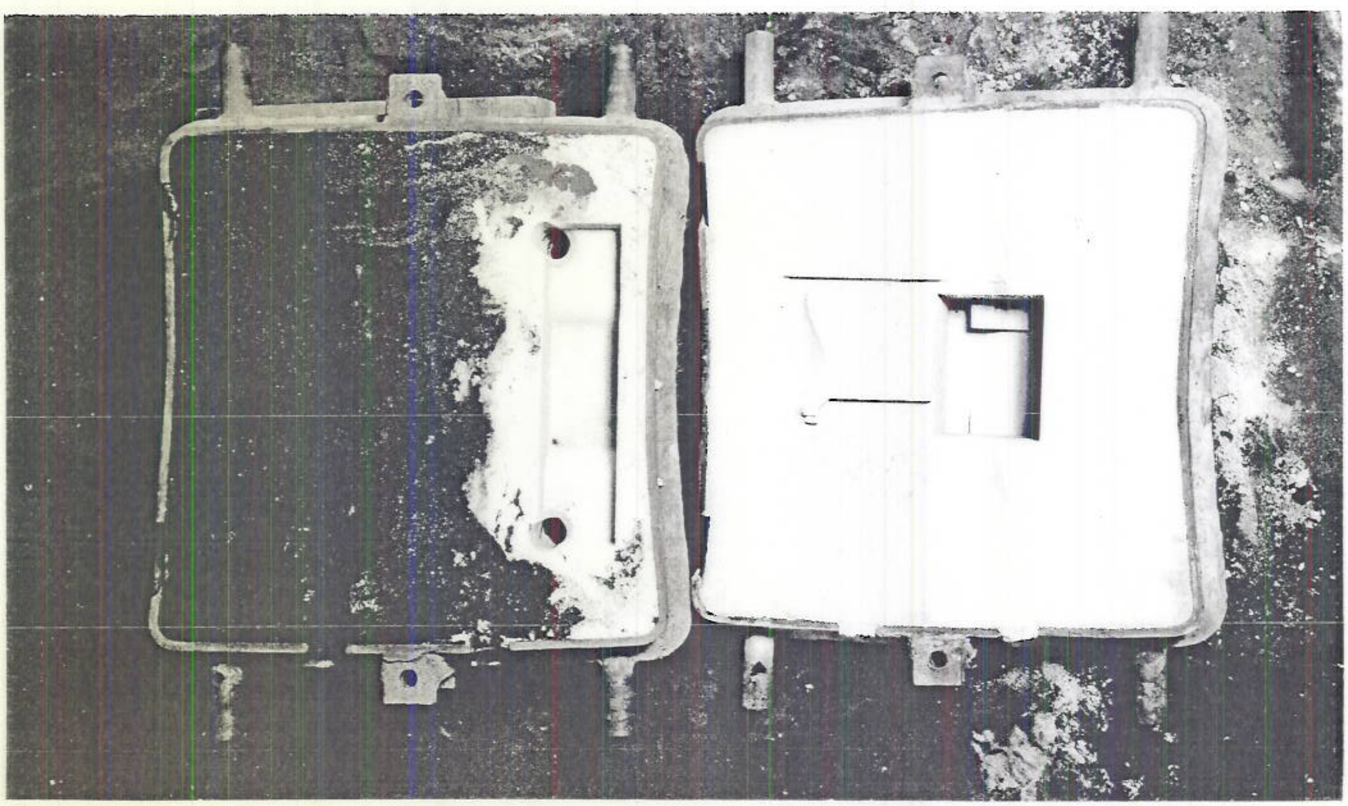

FIG. 2

PLATE 12

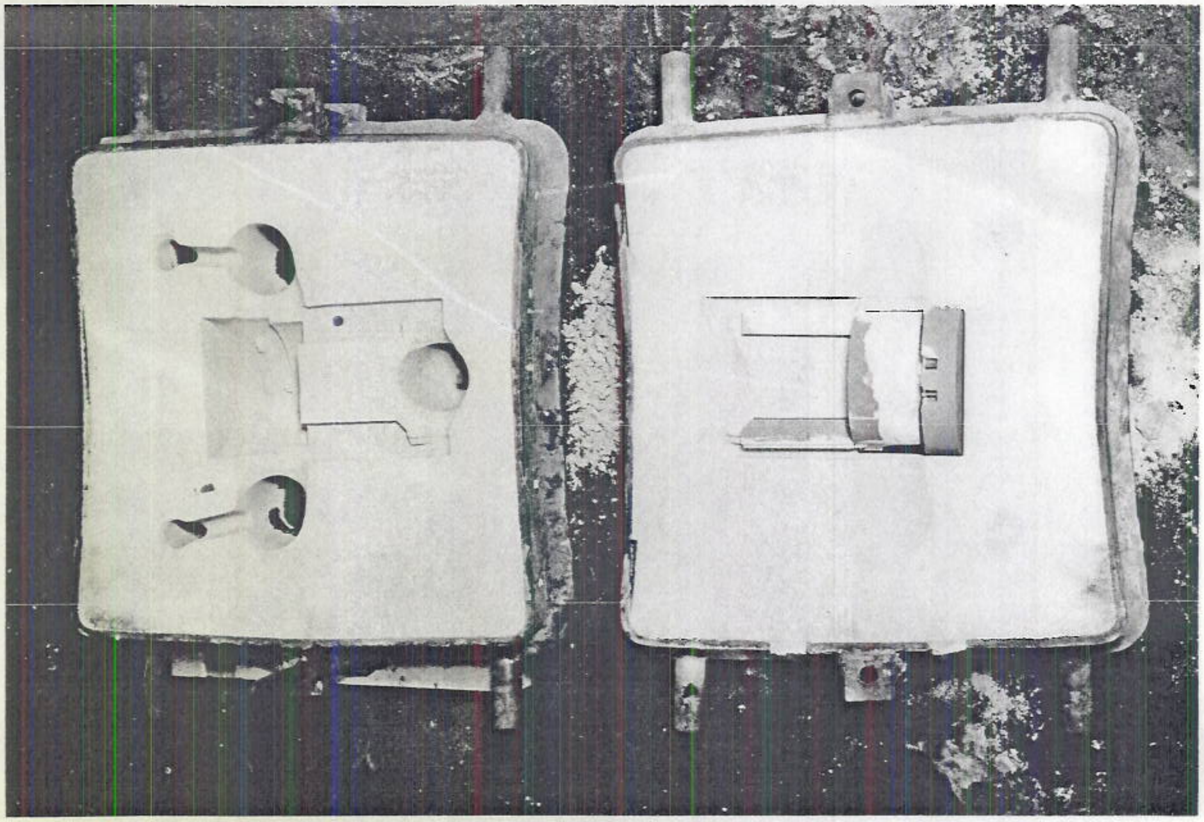

FIG. 1

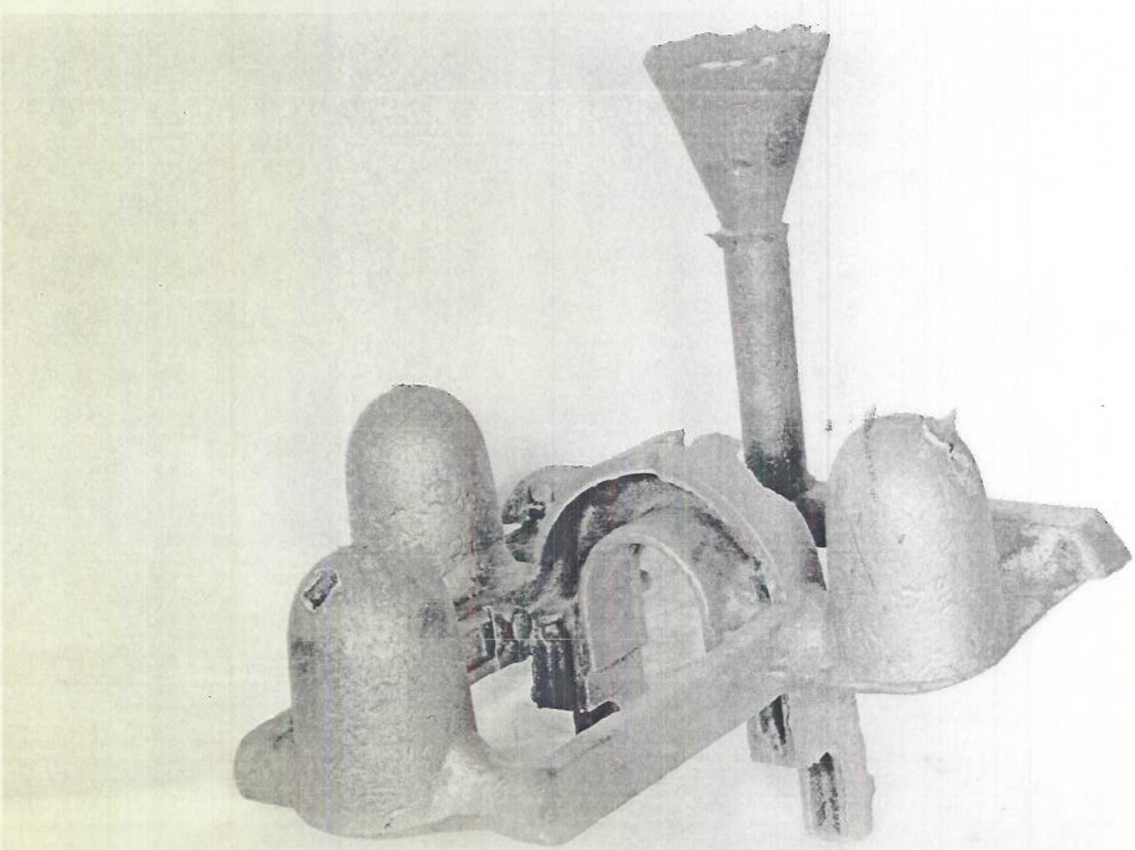

FIG. 2