Director, Mines Branch

CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 58-92

THE DEVELOPMENT OF IMPROVED ZINC-BASE DIE CASTING ALLOYS (Project Zn-6). Phase II(a): Preparation of Model 1000 ABC Die Casting Machine for Production of Die Cast Test Pieces.

by

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PHYSICAL METALLURGY DIVISION

COPY NO. 21

MAY 20, 1958

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ABSTRACT

A two-cavity test bar die has been designed and manufactured for use on a Model 1000 ABC die casting machine.

The mechanical properties of the test bars produced have satisfactory reproducibility. Ultimate tensile strength and impact strength compare favourably with published values for Zamak 3 die casting alloy. The ductility is lower than published values, possibly because of the high die temperature necessary for successful operation.

Considerable experience has been gained in the operation of this type of die casting machine.

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1. INTRODUCTION

Initiated in March 1956, a research project designated "Zn-6", aimed at the development of an improved zinc base die casting alloy, has recently been completed at the Laboratories of the Physical Metallurgy Division, Mines Branch, Ottawa, under the auspices of the Canadian Zinc Research and Development Committee.

The work of the project has been carried out in two phases. Phase I dealt with studies to determine methods of introducing a series of elements into standard zinc base die castings, and has been reported separately as a Mines Branch research report (1). Phase II, dealing with the casting of the alloys on a Model 1000 ABC die casting machine, the mechanical testing of the test bars produced, and the evaluation of the additives based on the mechanical testing results, is now complete and is being prepared for issue as a second research report.

For the purposes of Phase II it was essential to be able to produce test bars from Zamak 3 alloy with reproducible mechanical properties. In general, size and location of porosity in the casting is the critical factor which affects the reproducibility of the mechanical properties. Porosity is controlled by die design and by the operating characteristics of the die casting machine.

During Phase II, however, numerous unexpected difficulties were encountered in the operation of the ABC die casting machine and in designing a suitable test bar. The purpose of the present Investigation Report is to place on record both the difficulties encountered and their solutions.

2. DIE CASTING MACHINE

Machine Specifications

The die casting machine used during this project (Model No. 1000, ABC Die Casting Machine Company, Chicago) was supplied on loan by the Consolidated Mining and Smelting Company of Canada, Limited. It is shown in Figures 1 and 2 at the end of this report.

The specifications issued by the manufacturer are as follows:

Die block size - 8 in. x 10 in.
Number of tie bars - 2
Tie bar diameter - 1 in.

Die thickness, standard, two halves - 4 in.
maximum, two halves - 6 in.

Die locking pressure - 16 tons
Die opening, standard die blocks - 4 in.
Plunger diameter at 1500 psi - 1 3/8 in.

Weight of metal per shot - 1 lb
Free cycle speed, cycles per hour - 1,000
Pot capacity, zinc-base alloy - 300 lb

Operating air pressure - 80-90 psi
Electric power - 110-125 volts, a.c.

Adjustable electric time dwell on toggle and shot - 0 - 15 sec.

Weight of machine - 1,700 lb

Height, 60 in.; width, 30 in.; length, 90 in.

The plunger and gooseneck, as supplied, are nitrided. The gooseneck is an integral part of the pot casting, as shown in Figure 3. The nitrided sleeve is press fitted into the vertical cylindrical section. Heat is supplied to the pot by a propane gas burner located in a chamber immediately below the pot. The burner location can be seen in Figure 2. The machine is equipped with an automatic temperature controller which controls this burner. A second burner is installed for supplying heat to the nozzle.

Operational Difficulties

Many of the numerous difficulties encountered were due largely to the choice of the Model 1000 die casting machine for a project of this type. Basically, the machine is a good one, and it has characteristics which make it suitable for use on research work. However, this particular model is somewhat small for producing test bars of the size required. The main difficulties are as listed below: (The order of the listing is not intended to signify the relative extent or seriousness of the difficulties encountered.)

(a) The heating capacity of the installed burner was found to be inadequate for melting down the alloy charge to the pot, and at times during casting runs. Auxiliary burners were used when required. The air and gas supply hoses for these auxiliary burners can be seen in the background of Figures 1 and 2.

(b) As originally installed, removal and replacement of the plunger was a difficult operation, requiring the stripping down of the complete shot cylinder assembly. During the early stages of the casting phase, the plunger was removed only at the completion of a specific additive series of melts. It was not removed after melts within a series, but the pot was completely drained in each case. During the die break-in period, the metal level was drained to a point below the inlet ports of the gooseneck, and allowed to freeze in the pot between casting runs.

The practice of leaving the plunger installed between melts caused dross build-up in the gooseneck. This caused sticking of the plunger to occur fairly frequently, and in some cases plunger ring breakage occurred. In the later stages of the project, the casting supporting the shot cylinder was cut to permit easy and rapid removal and replacement of the plunger. As a result of this modification, difficulties due to plunger sticking and ring breakage were practically eliminated.

(c) The difference in level between the injection nozzle hole and the inlet ports of the gooseneck is small. Operation with the bath level above the nozzle hole resulted in the flow of metal by gravity into the die, or at least into the relatively cold nozzle, where freezing and blockage occurred. Operation with the level slightly above the top of the gooseneck ports resulted in the entry of air and/or dross into the gooseneck, and this caused gross porosity in the castings. The allowable leeway in bath levels was found to be extremely small, and until the significance of level control was realized, unexplainable porosity was obtained in the test pieces.

(d) Considerable difficulty was encountered with leakage of metal from the injection nozzle. The design of the die is such that heat must be supplied to the nozzle at all times during casting runs. The rate of heat application required was found to vary considerably during runs, depending on such factors as casting rate, die temperature, metal temperature, and level in the pot. The variations in the intensity of the nozzle burner flame were sufficient to cause appreciable heating and cooling of the cover-half hold-down bolts. This resulted in expansion and contraction of the bolts, of sufficient magnitude to break and reseal the contact seal between the nozzle and the seat machined into the back surface of the die block. The metal that leaked past this seal generally dropped into the nozzle burner and in time blocked it, making the machine inoperable. The leakage metal also presented a safety hazard, in that very often it was forced away from the machine in the form of a jet.

The nozzle leakage was eventually controlled, although not completely eliminated, by insulating the hold-down bolts with asbestos cloth. In addition to this measure, the practice of tightening down the bolt nuts when the nozzle burner was at its peak of intensity was followed.

At intervals during the project, it was necessary to clean out the nozzle seat on the cover-half die block. This was done by lapping a spare nozzle into the seat with a carborundum paste.

(e) The die blocks supplied with the machine are of a relatively soft material. The Brinell hardness is approximately 115, as compared with a recommended hardness of 230-250 for die steel. Difficulties were encountered which were thought to be associated with the softness of the die blocks. The cover-half block had a distinct tendency to deform when it reached operating temperature. The pressure applied on the edges by the hold-down bolts, and the back pressure exerted by the nozzle at the centre, caused the block to bend. As a result, incomplete die closure was obtained at the outer edges. This resulted in the spraying of molten metal from the outer extremities of the dies on practically every shot. On numerous occasions, metal flashed over to the lower tie bar, and filled the clearance space between the tie bar and the hole through the ejector-half die block. This generally made the machine inoperable. In some cases it was possible to trim the flash metal flush with the die face, and to operate, in effect, with a bearing of die casting alloy. However, when this was done it was necessary to keep the tie bar well lubricated in order to maintain a fast enough movement of the platen to effect casting ejection.

This difficulty of die warpage was overcome by the installation of a heavy stiffener on the lower edge of the cover-half die block.

(f) The most serious difficulties encountered were associated with the fact that the machine is equipped with only two tie bars. The projected area of the casting as eventually finalized, is approximately 9 sq in., which includes a flash allowance. At the injection pressure of 1500 psi, a locking pressure of approximately 13.5 tons should be sufficient to ensure die closure. Thus, the rated locking pressure of 16 tons should be adequate for this particular die. However, with the two tie-bar design of the machine the corners of the cover-half die block diagonally opposite to the tie bars are not fastened rigidly, and there is a tendency for the die block to pivot about the injection nozzle, resulting in incomplete closure at either of these corners.

During the early stages of die break-in, excessive flashing occurred in the area of the tensile bar gate runner. Figure 4 shows two typical castings with this defect. This type of flashing was practically eliminated by installing set screws in the previously mentioned stiffener bar, which butt up against the machine base casting. By proper adjustment of the set screws, movement of the lower corner of the die block was prevented, and satisfactory castings resulted. This did not eliminate excessive flashing in the area of the impact bar overflow well. This flashing, which occurred fairly frequently, was not of a serious nature and no efforts were made to overcome it.

Although flashing was controlled with reasonable success, it still accounted for a considerable amount of operational troubles. It was necessary to clean the die surface after each shot. If small pieces of flash metal were left on the faces, particularly in the corner areas opposite the tie bars, flashing was again excessive.

During most runs, it was necessary to make constant adjustments to the tie bar nuts controlling die closure. The tie bars were subjected to uneven heat from the nozzle burner and from the flue gases of the pot burner. This uneven heating caused the bars, particularly the upper one, to expand or contract sufficiently to necessitate adjustments. During casting runs, when expansion occurred incomplete die closure resulted and caused excessive flashing. When a suitable adjustment was made the contraction that usually followed frequently prevented the toggle from extending completely, and the shot mechanism was not actuated. Occasionally, the delays caused by the interruptions in the casting cycle were of sufficient duration to upset the heat distribution in the die and to cause additional operational difficulties.

Mechanical Defects and Miscellaneous Difficulties

(a) Shortly after the machine was placed in operation, the automatic temperature controller on the pot burner was found to be defective. Investigation revealed that the controller must be mounted in a vertical position on a shock-free mount. Rather than have it installed away from the machine on a solid foundation, operation was carried on with manual control of the burner, using an indicating pyrometer.

(b) Soon after the first few casting runs were made, leakage of alloy from the pot, at a point immediately below the vertical gooseneck cylinder, was noticed. The pot was removed from its setting and examination revealed the presence of a crack approximately 5/8 in. long. Since the leakage was not excessive, the pot was placed back into operation until a replacement was obtained. The leakage appeared to occur only during the melting down of the charge, indicating that the crack opened up on cooling, and sealed itself on heating. Extended use did not appear to aggravate the leakage or cause the crack to grow appreciably in size. The replacement pot was examined on receipt and was found to have no surface flaws. However, after a very short period of use this second pot developed a similar type of leak in the same location.

Considerable difficulties were encountered during the installation of the replacement pot. It was found that certain critical dimensions of the two pots differed considerably. In order to make the pot fit into the setting, it was necessary to grind the casting, and to elongate the bolt holes so that it could be fastened to the machine base casting. In addition, it was necessary to grind down the base casting below the nozzle, to allow clearance for the installation of the cover-half die block. The installed nozzle was also noticeably shorter than that on the original pot. In order to continue the use of the previously mentioned stiffener bar on the bottom of the cover-half block, this nozzle had to be replaced with a new one of the original length.

After the necessary adaptation work was completed, and the machine placed in operation again, considerable difficulties were encountered with nozzle leakage. Examination revealed that the nozzle on the new pot was located approximately 1/16 in. lower than that on the original, relative to a datum point on the machine base casting. This difference in level was sufficient to allow a rocking of the cover-half die block on the nozzle during cycling of the machine, thus breaking the seal and allowing metal leakage. Rather than shim the new pot up to the desired level, the original pot was reinstalled and used for all subsequent casting runs.

(c) After making a number of casts, the cast iron bottom bell casting of the shot cylinder failed in operation. This casting contains a packing gland and the air outlet. Repairs were carried out by the Welding Section of the Physical Metallurgy Division and the part was placed back into service. The replacement, which has been carried as a spare, is a steel casting.

(d) Spare parts received for the machine differ considerably from original equipment. Replacement plungers contain one ring groove, instead of two as on the original. The explanation offered was that ring breakage in the two-groove type was excessive, and that experience had shown the second groove to be unnecessary. Spare nozzles supplied were considerably shorter than the original, and not suitable for use with the stiffened cover die block. New spares were machined by the Maintenance Section.

3. TWO-CAVITY TEST BAR DIE

Die Design and Manufacture

The test bar die was designed by Mines Branch personnel and manufactured in the machine shop of the Maintenance Section. In order to speed up the machining, test bar cavity inserts from a test bar die previously used on the Cleveland die casting machine were adapted for use in this die. Inserts for gates and overflows were made in the machine shop as required.

Figure 5 shows the ejector side of a typical casting produced from the test bar die as originally designed. Evident in this picture are the sizes of the overflow wells and of the gates leading into the test bar cavities. As will be discussed later, it was necessary to modify the design considerably in order to obtain reasonably sound castings. Figure 6 is a drawing of the modified test bar die. Typical castings from the modified die are shown in Figures 7 and 8, and these show the cover and ejector-half surfaces respectively.

Die Modifications

It was recognized that considerable modification work would have to be carried out before either the machine operation or the quality of the test pieces was satisfactory. A log of the modifications made during the die break-in period is appended as Schedule 1 (see page 28). In this schedule, the modifications are listed in the chronological order in which they were carried out. Figures 9 and 10 are presented in conjunction with Schedule 1: the first shows the manner in which the overflow wells were increased in size and the second shows the types of tensile gating mentioned.

The modifications made may be grouped into three classifications, dealing respectively with operational improvements, temperature control, and porosity elimination. It is not intended to discuss each modification as such, but the following comments cover the main points encountered:

(a) Operational Improvements -

The main modification was the installation of the stiffener bar on the base of the cover-half to prevent die block warpage and thus control flashing.

(b) Temperature Control -

No provision was made for water cooling of the die blocks in the original design. It was soon found necessary to cool the sprue pin on the ejector half in order to effect stripping of the castings from the sprue hole. In the early stages of the die break-in, this sprue pin cooling was sufficient to maintain the ejector-half die block at temperatures of 200°C-220°C (390°F-430°F), when once equilibrium operating conditions were reached. However, it was not sufficient to cool the cover-half block, and temperatures approaching 300°C (570°F) were reached towards the end of casting runs. These higher-than-normal temperatures were responsible for metal soldering to the die cavities, and consequent poor ejection. As a result it was necessary to apply die lubricant much more frequently than desirable. Unsuccessful attempts were made to lower the cover-half temperature by protecting it from the nozzle burner and the hot flue gases of the melting pot burner with asbestos sheeting and with a sheet metal frame filled with vermiculite.

When it became apparent that insulation was inadequate for temperature control, it was decided to install water cooling in the cover-half die block. It was felt that the use of horizontal water lines would be the safest method of supplying cooling water, because cavity inserts were used in the die construction and because of the poor quality of the die block material. Accordingly, three 3/16 in. diameter holes were drilled through the die block with appropriate spacing. These were connected in series, with the water inlet at the top hole. It was found that holes of this size permitted an excessive flow of water, causing excessive cooling. Since the water flow could not be throttled back sufficiently, it was impossible to prevent sprue freezing and breakage, and the machine was inoperable. To overcome excessive water flow, copper tubing was installed inside the drilled holes. In conjunction with this type of cooling, copper tubing was also coiled inside the vermiculite-filled frame on the back surface of the die block. By adjusting the flow of water through these two lines, adequate temperature control was possible. However, operational difficulties encountered made it necessary to abandon the vermiculite frame. As previously mentioned, nozzle leakage occurred relatively frequently and leakage metal built up around the copper water line in the frame. During periods when the water was shut off, temperatures became high enough to melt this metal, and attack of the copper tubing resulted in pin hole leakage.

As will be discussed later, in an effort to control porosity in the test pieces an increase was made in the size of the overflow well cavities in the ejector-half die block. The extra volume of metal resulted in higher temperatures in the upper half of this block, and additional cooling was required to supplement that supplied by the sprue pin coolant. This cooling was obtained by machining a semicircular groove in the top surface of the die block large enough to allow a 3/16 in. diameter copper tube to be laid lengthwise across it. A steel plate, similarly grooved, was then bolted to the die on top of the water line, to hold it in position. This addition was effective in enabling temperature control in the upper section of the die block.

When once it was possible to successfully control the die temperatures, no further difficulties were encountered with soldering and/or poor casting-ejection. Die lubricant was used at regular predetermined intervals during the casting runs, throughout the program.

(c) Elimination of Porosity -

Castings produced from the test-bar die as originally designed contained gross porosity. It was thought that this porosity might be due to lack of proper temperature control. However, once proper temperature control was attained, as discussed above, it became evident that modifications to the gating and overflow systems would be required to eliminate porosity. Modifications were carried out, based on suggestions received from Mr. G. D. Fry in correspondence (2) and on the work of G. L. Werley (3).

The modifications were carried out in steps largely by trial and error. After each modification, a casting run was made and the test bars were examined radiographically and subjected to mechanical testing. The subsequent modification was based on the results of the examination and of the testing. This procedure was repeated until the mechanical properties were considered to be sufficiently high, and reproducible enough to meet the needs of the general program.

The modification work entailed enlarging of the gate cross-sectional areas, changing the shape of the tensile cavity gate, enlarging the overflow wells, and increasing the size and number of the vents.

The initial work was concentrated mainly on increasing the sizes of the overflow wells, although some changes were made in the gate sizes at the same time. Figure 9 illustrates the steps by which the overflow wells were enlarged. As can be seen, the improvement of the impact bar was the first consideration. The maximum size and projected area allowable was approached at step 3, with subsequent changes being made in an effort to effect easier ejection of the casting and to impart strength to the runner joining the impact bar and the overflow well. The maximum size of the tensile overflow well was reached at step 5, the increase between steps 3 and 4 being the major one.

Once the size of the overflow wells approached the limits allowable by the relatively small die blocks, small changes in the gating produced significant differences in the type of porosity in the test bars, as indicated by mechanical testing and radiographic examination. It was also found that when changes were made to the tensile bar gate, flow into the impact cavity was altered. As a result, in several instances changes to one gate had to be followed by changes to the other. With the impact bar, where the flowing metal is in contact with the cover half, a progressive increase in gate size was effective in producing progressively sounder impact bars. In the case of the tensile bar, where the metal discharging from the gate does not immediately come into contact with the cavity walls, size increases alone were not effective.

Changes were made to the type of gating on the tensile cavity side, and these were eventually effective in at least confining the porosity to the grip section and away from the gauge length section. The changes made were as illustrated in Figure 10. The first change was from type "a" to type "b". In type "b", half of the gate is cut into each die block. This change was made in order to discharge the metal into the cavity in such a manner that the stream would be less likely to strike the cavity wall in the gauge length section. However, it was not until the type "c" gate was installed that indications of improvement became apparent. The improvement seemed to be due to the fact that the turbulent flow was confined to the grip section at the gate end, and entrapped air was prevented from entering the gauge length section. The type "d" gate was installed after flow lines were noticed lightly etched on the gate insert faces at the location of the added vertical grooves. However, this change had harmful effects and the type "c" gate was reinstalled. The die design was finalized with this type of gate.

4. ESTABLISHMENT OF OPTIMUM OPERATING CONDITIONS

During the period in which the modification work was carried out, a total of 33 casts were made using Zamak 3 die casting alloy. While making these casts, it was possible to establish the optimum operating conditions for this particular test bar die, with regard to ease of operation and soundness of the test pieces.

The installation of water cooling, as discussed previously, made it possible to control the die temperatures. However, it was found necessary to operate with the die blocks at temperatures higher than those used in normal die casting practice. Operation with die temperatures comparable to those used in commercial practice resulted in casting and testing difficulties. While it was recognized that these difficulties could be overcome by further modifying the die design as suggested by Mr. G. D. Fry, it was felt that the modification would be unnecessarily time-consuming, since with operation at the higher temperatures it was possible to obtain reasonably sound test pieces with acceptable reproducibility of mechanical test results. It was considered that the additional die modification work was not warranted in view of the shortage of time and the fact that relative values of mechanical properties would be sufficient at least during the exploratory phase of the program.

While making the 33 casts mentioned above, considerable experimentation was carried out to determine the proper casting cycle. A cycle of 6 sec die closure and 3 sec plunger dwell proved to be most satisfactory. A longer closure caused excessive heating of the die blocks, and necessitated a slow casting rate in order to maintain proper temperature control. A shorter closure produced castings of inferior strength due to insufficient cooling of the sprue section, and this resulted in breakage of the sprue in the sprue hole. With a longer plunger dwell, it was necessary to apply excessive heat to the injection nozzle to prevent freezing of metal in the nozzle which then had to be cleared before casting could recommence. A shorter dwell resulted in a physical weakness of the sprue section of the casting, and sprue breakage. Neglecting the accompanying operational difficulties, longer closure and plunger dwell times did not appear to have noticeable effects on the mechanical properties of the test pieces. Indications were that the 3 sec plunger dwell allowed sufficient time for metal in the sprue and runners to freeze completely under pressure, and a larger period was unnecessary.

The operating data for the casts carried out are shown in Table 1.

The number of shots made during each cast varied considerably. Generally, die modifications were made after each run, and the length of run depended on the time available after the die blocks were returned from the machine shop. Where unusually short runs are indicated, they were terminated because of mechanical or operational difficulties, or because the casting cycles were changed. When the cycle was changed a new cast number was allotted.

Castings were saved for examination and testing from all casts, regardless of the length of run. Since equilibrium operating conditions were arrived at in all cases before castings were saved, it was felt that the testing results of the test pieces from all casts would be significant.

When the cast duration was timed, a casting rate was calculated. In most cases where the rate is not shown, interruptions due to operational difficulties were numerous and the calculation of casting rates was not feasible.

For casts 31 and 31a, the cooling water flow into the cover-half die block was reversed from the normal. In this case the water entered at the lower level. With this condition, and using the installed nozzle burner only, a plunger dwell of longer than 0.75 sec made the machine inoperable. A dwell of 2 sec was possible when an auxiliary burner was used on the nozzle. For all other casts the casting cycle was varied as shown, in an effort to determine the optimum cycle.

The die temperatures shown for casts 12 to 28 inclusive are estimated values only. Unfortunately, the contact pyrometer used for measuring die surface temperatures became defective during cast 12 and the defect was not detected until cast 29. At that time the instrument was checked and was found to be reading 40-50°C low. Based on this, and on operational experience before and after casts 12 and 28 respectively, the die temperatures have been adjusted as shown.

The temperatures shown are the averages of readings taken at the mid point of the die block faces. Temperatures in the upper section of the cover half were usually approximately 10°C lower than those indicated, while those in the lower section were approximately 40°C higher. On the ejector half the temperature was fairly uniform, with variation from point to point being less than 10°C.

The effects of the efforts to control the die temperatures are evident. For casts 1 to 8 inclusive, the cover-half die block was not protected from the nozzle burner or the flue gases from the melting-pot burner. For casts 9 and 10, asbestos cloth and the vermiculite-filled frame were used to protect the back surface. The water cooling of the cover-half die block was installed for cast 11, and was used until the project was completed. For casts 30 and 33 the flow of cooling water was increased and resulted in the lower temperatures shown. With runs 31 and 31a, the flow of cooling water was reversed, with entry at the sprue level. The castings produced from these four casts had a surface quality inferior to that of those produced with the higher die temperatures. Cold shuts and flow lines were much in evidence, particularly at the vent ends of the test pieces. In addition to this, the tensile bars tended to crack, on ejection, at the point where the grip section tapers down to the gauge length thickness. Because of this, and the susceptibility at the lower temperatures to some of the previously mentioned operational difficulties, die temperatures of approximately 200°C (390°F) and 250°C (480°F), for the ejector and cover-half blocks respectively, were chosen as the standard conditions for the project.

The casting rate also had an effect on the operating temperatures. It was generally found that approximately 80 shots/hr was an optimum rate. Casting at this speed also allowed adequate time for cleaning the die faces of flash metal.

5. RADIOGRAPHY

The test pieces saved, for mechanical testing, from all casts made during the die modification period were examined radiographically before being tested. The examination showed that earlier modifications, which were made primarily to obtain proper temperature control, had little effect in eliminating the gross porosity that was present in the test pieces produced from the die as originally designed. Pores were present in a random distribution, and their size varied from that barely visible to the naked eye to that approaching 1/8 in. in diameter.

Improvements were not noted radiographically until enlargement of the overflow wells was attempted. Figure 11 shows the radiograph of test pieces from cast 12. Prior to making this cast, the impact overflow well was increased in size from 7 to 18g. On the impact bars, porosity is confined to a centre line distribution, with some variation in the width of this line. On the tensile bars, porosity is evident in both grip sections and in the gauge length section. It should be noted that, because of underexposure, the radiograph does not give a true indication of the severity of porosity in the thicker grip sections. The extent of porosity in the gauge length section is clearly evident. Most bars show gross porosity in the central portion, and some gross porosity at the gate end where the cross-sectional area changes.

Figure 12 shows the radiograph of the test pieces from cast 24. This cast was carried out after most of the die modification program as outlined in Schedule I had been completed. Considerable improvement in the soundness of the test bars is evident. In the impact bars, the band of centre line porosity has been considerably narrowed. There is some scatter at the gate end, but the area of porosity was in most cases close enough to the gate to have a negligible effect on the testing results. In a few cases, the porosity extended to the point of contact of the impact tup, and when this occurred, lower impact values were obtained. In the case of the tensile bars, porosity has been almost totally confined to the gate-end grip section. In some bars, fine porosity is evident in the gauge length section, and in one case it can be seen at the gate-end shoulder. On testing these bars, fracture did not necessarily occur at the point of porosity as indicated by the radiograph.

Since testing results were rejected only if porosity was present at the fracture surfaces, once the radiographic quality of the test bars approached that shown in Figure 12 it was no longer possible to reject results on the basis of radiography alone. The die design was eventually finalized with the overflow wells, gates and vents in use when cast 24 was made.

Radiography and mechanical testing indicated that, at this stage, satisfactory castings could be produced and the casting of the titanium series of alloys was therefore commenced. However, considerable difficulty was encountered. The first five casts were carried out with the die temperatures in the lower range, previously discussed. In subsequent casts it was necessary to adopt the higher temperatures as being standard. Also, during the first ten casts of this series the effects of improper bath level were first noticed. The radiograph of cast TI, shown in Figure 13, is typical for test bars made during these runs. In a large number of the test bars examined, the porosity extended from gate to vent end. In many cases, holes were present at the vent ends, and could be seen on visual inspection. In Figure 13, the gross porosity in the grip sections is clearly visible. The test pieces have been so arranged that the gate ends of the tensile bars are at the top of the radiograph and the gate ends of the impact bars are at the bottom.

It was discovered that the gross porosity was due to improper bath level control. During the first cast of the zirconium series (ZA), an attempt was made to control the level of the metal in the pot at a point where air and dross could not be sucked into the gooseneck. The radiographs of Figures 14 and 15 show the importance of level control, and its effects on the quality of the test pieces. In these radiographs, the test pieces have been arranged in the order of production. In Figure 14 (tensile bars), the sequence starts at the upper right and ends at the lower left corner. In Figure 15 (impact bars), the sequence is from the upper left to the lower right corner. In all cases, the gate ends are at the top of the radiographs.

During this run, the level was controlled until shot 160 was made, after which no further alloy additions were made and the metal level was allowed to drop. In the tensile bars, porosity started to become evident at the vent end at shot 176, and the quality of the castings rapidly deteriorated to that of shot 189 (last in the sequence). With the impact bars, the effects of decreasing the bath level became evident at shot 172. The critical nature of bath level control is illustrated by the fact that only twelve shots were made before vent end porosity became evident. To make these shots, approximately 6 lb of alloy was required, this small amount of metal having been removed from a bath containing approximately 300 lb. The drop in bath level between shots 160 and 172 could not be detected visually. All subsequent casts of the program were carried out with adequate level control, and porosity from this source was successfully eliminated.

6. MECHANICAL TESTING

The results of the mechanical testing of specimens from the casts made during the die modification period are appended as Table 2. Averages of the results from the various tests are shown. Alongside each result are shown the number of readings comprising the average and the number rejected because of the presence of flaws. Elongation results were rejected when flaws were evident on the fracture faces and when breakage occurred outside of the gauge length punch marks.

The impact strength results for the first ten casts were generally erratic and quite low. The tensile strengths for these casts were of the order of 40,000 psi, approximately the same as for castings from the final design.

The impact strengths of specimens from casts 11 to 24 improved gradually to the acceptable values. At the same time tensile results for these casts dropped, and then improved. This was due to the fact that major changes were first made to the impact-bar side of the die, and these changes affected the flow of metal to the tensile side. Subsequent changes improved tensile properties.

Results from casts 25 to 29 varied from cast to cast as minor changes to the die design were made. Casts 30, 31, 31a and 33 were carried out at the lower die temperatures. This condition caused lower test results, due partly to testing difficulties encountered, as discussed previously. The results also indicated that for low temperature operation, additional design modifications might be necessary. For cast 32, although the die design was as for cast 24, the impact strengths obtained were noticeably lower. During cast 32, the lower, shot-cylinder bell-casting failed after the plunger seized in the down-stroke position. It is believed that conditions which caused the failure were responsible for the lower test results. When the piston was removed after the enforced shut-down, it was noted that the piston rings were broken. Although not evident during the run, the ring breakage may possibly have occurred on starting up, resulting in a lower-than-normal effective pressure on the metal in the gooseneck. The plunger seizure could have been caused by jamming of a piece of the ring between the cylinder wall and the plunger.

7. METALLOGRAPHY

In an effort to determine the reasons for the low elongation values obtained on the castings produced, numerous specimens were subjected to metallographic examination. Typical photomicrographs, obtained at a magnification of X100, are presented in Figures 16 to 20. In all cases, the specimens were etched for 0.5 sec in a solution of 50g CrO_3, 4g Na_2SO_4 and 2000 ml water. Figure 16 shows the vent end of a tensile bar cast on a Cleveland die casting machine, and is included for reference. Elongations of approximately 20% were obtained on test bars of similar structure produced on this machine. Figures 17 and 18 show the gate and vent end sections of tensile bars cast on the ABC die casting machine. In both cases the edges shown were in contact with the die cavity surface machined into the cover-half die block. These specimens show a relatively coarse grain structure and virtually no outer fine-grained skin. The higher-than-normal operating temperatures are responsible for this type of grain growth. Elongations of approximately 4% were obtained on similar test bars, and it is felt that the unusual grain structure has caused the low ductility, or at least contributed to it.

Figures 19 and 20 show the vent end of a typical impact bar produced on the ABC die casting machine. Both photomicrographs were prepared from the same mounted specimen. Figure 19 shows the edge of the bar in contact with the relatively hot surface of the cover-half die block, and Figure 20 the edge of the opposite face which is machined into the ejector-half block. In Figure 19, the columnar edge growth is similar to that of Figures 17 and 18, but the mass of edge crystals forms a reasonable outer skin. In Figure 20, the grain pattern is similar to that of Figure 16. The outer skin is well defined, but the individual grain size is larger than on the test bar produced on the large die casting machine. The structure of the impact bars produced on the large machine is similar to that of the tensile bars.

8. SUMMARY AND CONCLUSIONS

The work discussed in the present report was carried out in an effort to adapt a model 1000 ABC die casting machine for the production of die cast test pieces to be used in the evaluation of the effects of a series of addition elements on the mechanical properties of standard zinc-base die casting alloys.

A two-cavity test bar die was designed to produce test pieces of suitable quality. The order of reproducibility of mechanical testing results was sufficiently high to make possible the statistical evaluation of the effects of a series of additive elements.

Test bars were produced having an impact strength of approximately 43 ft-lb. This compares favourably with the published value for the impact strength of Zamak 3 alloy. Ultimate tensile strengths were lower at approximately 40,000 psi, as were the elongation values of approximately 4.0%. The published values of Zamak 3 alloy are 41,000 psi and 10% respectively. The higher-than-normal die temperatures required in the operation of the ABC die casting machine equipped with the test bar die as designed were probably responsible for the low ductility of the castings produced.

During the period of work discussed, experience was gained in the operation of the die casting machine and numerous operational difficulties were overcome.

9. REFERENCES

1. H. Guttman, The Development of Improved Zinc-Base Die Casting Alloys. Phase I: Alloy Preparation. Research Report R-13, Mines Branch, Dept. of Mines and Tech. Surveys, Ottawa, Canada, (May 26, 1958).

2. G. D. Fry, Ontario Steel Products Company Limited, Chatham, Ontario. Private Communication (Feb. 1957).

3. G. L. Werley, A Study of Die Design Changes for the Improvement of Soundness and Uniformity of Test Bars. Proc. ASTM 37, Part 1, 223-232 (1951).

4. S. R. Dunbar, The Metallography of Zinc and Zinc Alloys. Metals Handbook, Amer. Soc. Metals, 1085-1086 (1948).

(Tables 1 and 2, Schedule 1,)
(and Figures 1-20 follow,)
(on pages 26-37)

HG:(PES)sws

TABLE 1

Die Casting Machine Operating Data

Cast No.	Date	No. of Shots Made	Casting Rate, shots/hr	Casting Cycle, seconds		Average Die Temp.			
						Ejector Half		Cover Half	
				Closure	Dwell	°C	°F	°C	°F
	1956								
1	Dec.27	16		8	4				
2	Dec.28	20		8	4				
3	Dec.28	20		8	3				
	1957								
4	Jan. 7	40		8	3	210	410	285	545
5	Jan. 7	40		8	4	210	410	285	545
6	Jan. 7	20		8	2	210	410	285	545
7	Jan.10	60		10	3	200	392	280	536
8	Jan.11	100		10	3	210	410	285	545
9	Jan.22	100	100	9	2.5	210	410	265	509
10	Jan.24	100	90	9	4	212	413	255	491
11	Feb.15	40		6	2	195	383	240	464
12	Feb.18	20		6	2	200*	392	250*	482
13	Feb.19	80	70	7	3.5	200	392	245	473
14	Feb.19	40	75	9	4	200	392	245	473
15	Feb.20	40		6	4	200	392	250	482
15a	Feb.20	10		6	3	200	392	250	482
16	Feb.25	50	106	6	3	205	401	255	491
17	Mar. 1	10		6	2	200	392	245	473
18	Mar. 8	80	83	6	2	200	392	245	473
19	Mar. 8	40	86	6	3	200	392	245	473
20	Mar.12	30		6	3	200	392	250	482
21	Mar.13	100	100	6	3	210	410	255	491
22	Mar.15	100	100	6	3	210	410	255	491
23	Mar.21	120	90	6	3	205	401	250	482
24	Mar.26	120	103	6	3	210	410	255	491
25	Mar.28	100	80	6	3	200	392	245	473
26	Apr. 1	80	96	6	3	205	401	255	491
27	Apr. 8	120	103	6	3	210	410	260	500
28	Apr.16	120	96	6	3	205*	401	260*	500
29	Apr.26	120	100	6	3	205	401	265	509
30	Apr.29	80	96	6	3	190	374	220	428
31	Apr.30	60	100	6	0.75	195	383	215	419
31a	Apr.30	40	100	6	2	195	383	215	419
32	May 3	60	80	6	3	200	392	255	491
33	May 9	80	96	6	3	190	374	215	419

* Temperatures for casts 12 to 28 inclusive are estimated.

TABLE 2

Average Mechanical Testing Results

Cast No.	Ultimate Tensile Strength, psi	Elongation, % in 2 in.	Impact Strength, ft-lb	
			Gate	Vent
1	38,400 (12, 4)	3.7 (12, 4)	18.3 (14, 8)	10.9 (13, 9)
2	39,900 (14, 6)	4.3 (15, 5)	20.3 (15, 5)	14.1 (12, 8)
3	40,000 (16, 4)	4.6 (15, 5)	21.8 (19, 3)	9.6 (12,10)
4	40,800 (37, 3)	4.8 (30,10)	26.0 (35, 5)	14.5 (31, 9)
5	39,500 (39, 1)	3.4 (34, 6)	23.2 (28,12)	14.2 (21,19)
6	40,400 (18, 2)	3.2 (14, 6)	22.8 (13, 7)	9.6 (12, 8)
7	39,600 (22, 3)	4.6 (19, 6)	27.8 (20, 5)	15.2 (19, 6)
8	39,300 (18, 7)	4.6 (14,11)	22.8 (14,11)	9.6 (10,15)
9	41,100 (24, 1)	5.3 (24, 1)	29.3 (22, 3)	21.0 (33, 2)
10	38,800 (23, 2)	4.3 (20, 5)	26.7 (23, 2)	15.6 (21, 4)
11	39,300 (34, 2)	3.6 (34, 2)	32.1 (33, 3)	29.1 (33, 3)
12	37,400 (22, 0)	3.0 (22, 0)	30.9 (16, 6)	32.7 (16, 6)
13	35,600 (25, 0)	2.4 (25, 0)	37.2 (19, 6)	37.0 (23, 3)
14	37,275 (20, 0)	2.9 (20, 0)	30.4 (17, 3)	37.3 (18, 2)
15	36,740 (20, 0)	2.3 (20, 0)	33.2 (13, 7)	34.6 (17, 3)
15a	36,530 (10, 0)	2.4 (10, 0)	34.8 (9, 1)	31.4 (6, 4)
16	38,340 (20, 0)	3.4 (17, 3)	38.3 (9, 11)	38.6 (15, 5)
17	37,250 (10, 0)	3.0 (10, 0)	43.7 (10, 0)	37.4 (10, 0)
18	37,330 (20, 0)	2.4 (20, 0)	37.9 (13, 7)	32.2 (9, 11)
19	36,350 (20, 0)	2.2 (20, 0)	37.4 (11, 9)	40.5 (18, 2)
20	38,600 (30, 0)	3.1 (30, 0)	43.3 (29, 1)	39.4 (25, 5)
21	38,000 (20, 0)	3.8 (20, 0)	44.6 (17, 3)	39.6 (12, 8)
22	40,200 (20, 0)	4.2 (19, 1)	38.1 (19, 1)	35.3 (17, 3)
23	37,600 (24, 0)	4.6 (24, 0)	40.0 (16, 8)	40.7 (22, 2)
24	39,900 (24, 0)	6.6 (24, 0)	44.5 (22, 2)	42.9 (20, 4)
25	37,000 (24, 0)	3.2 (24, 0)	37.4 (19, 5)	37.8 (23, 1)
26	38,100 (24, 0)	5.0 (24, 0)	42.8 (21, 3)	39.5 (20, 4)
27	40,600 (24, 0)	8.0 (23, 1)	40.4 (21, 3)	38.8 (21, 3)
28	39,800 (23, 1)	5.5 (23, 1)	36.1 (14,10)	36.9 (19, 5)
29	38,800 (24, 0)	4.2 (24, 0)	37.7 (18, 6)	36.6 (20, 4)
30	37,200 (18, 6)	2.8 (15, 9)	32.0 (19, 5)	35.0 (24, 0)
31	36,400 (14, 3)	3.8 (9, 8)	32.4 (20, 4)	36.0 (20, 4)
31a	38,100 (15, 1)	3.6 (15, 1)	34.2 (15, 1)	34.9 (13, 3)
32	39,000 (24, 0)	4.6 (24, 0)	38.3 (24, 0)	33.2 (20, 4)
33	38,800 (24, 0)	4.0 (23, 1)	37.4 (22, 2)	40.7 (23, 1)

<u>N.B.</u>: Numbers in brackets signify number of readings comprising average and number rejected, respectively.

Schedule 1 - Log of Die Modifications, ABC Die Casting Machine

Original Design Data:
Tensile gate size - 0.025 in. x 1/8 in.
Impact gate size - 0.025 in. x 1/8 in.
Tensile overflow well size - 7g
Impact overflow well size - 7g

(a) Dec. 27, 1956
- Sprue pin water cooled.

(b) Jan. 7, 1957
- Die locating dowel pins relocated. Lower hole welded over to prevent flashing of metal into hole.
- Both entry gates enlarged to 0.050 in x 1/8 in.

(c) Jan. 8, 1957
- Stiffener bolted to bottom of cover-half die block.
- Set screws installed in stiffener to butt up against machine base casting.

(d) Jan. 22, 1957
- Asbestos sheeting installed behind cover-half die block.

(e) Jan. 24, 1957
- Frame filled with vermiculite installed on back of cover-half block to replace asbestos sheeting.

(f) Jan. 29, 1957
- Three 3/16 in. diameter water cooling holes drilled horizontally through cover-half block.

(g) Jan. 30, 1957
- 1/8 in. copper tubing placed in water cooling holes to reduce water flow.
- 3/16 in. copper tubing installed in vermiculite-filled frame.

(h) Feb. 12, 1957
- Tensile and impact entry gates enlarged to 0.060 in. x 3/16 in.
- Gates into overflow wells increased from 1/16 in. x 3/16 in. to 0.060 in. x 3/16 in.
- Impact overflow well increased from 7 to 18g.
- Original vents widened to 3/4 in.
- 2 new impact vents cut at 0.004 in. x 3/4 in.
- 1 new tensile vent cut at 0.004 in. x 3/4 in.

(i) Feb. 16, 1957
- 1/8 in. copper tubing in water cooling holes replaced with 3/16 in. tubing.

(j) Feb. 20, 1957
- Tensile gate enlarged to 0.060 in. x 1/4 in.
- Top tensile vent deepened to 0.006 in.

(k) Feb. 25, 1957
- Gating into tensile bar changed from type "a" to "b" of Figure 10. Dimensions changed to 0.025 in. x 0.210 in.

(l) Feb. 28, 1957
- Impact overflow well increased from 18 to 31g.
- Tensile overflow well increased from 7 to 16.5g.

(m) Mar. 12, 1957 - Tensile overflow well increased from 16.5 to 31g.

(n) Mar. 14, 1957 - Tensile gate flanged from runner width to full width of bar x 0.050 in. deep, as shown in "c" of Figure 10.
- Water cooling installed on top of injector-half die block.

(o) Mar. 18, 1957 - Taper increased on overflow wells. Weight increased from 31 to 35g.
- Tensile gate deepened to 0.070 in.
- Impact gate enlarged to 0.060 in. x 1/4 in.
- Top impact vent deepened to 0.006 in.

(p) Mar. 22, 1957 - Impact gate size reduced to 0.060 in. x 3/16 in.

(q) Mar. 27, 1957 - Tensile gate shape altered to that of type "d" of Figure 10.

(r) Mar. 29, 1957 - Impact gate deepened to 0.070 in. x 3/16 in.

(s) Apr. 2, 1957 - Tensile gate changed back to type "c" of Figure 10. Deepened to 0.075 in. New overflow wells installed with extra wall thickness on cavity side. Sizes now 34g for each.

(t) Apr. 5, 1957 - Vermiculite-filled frame removed from cover-half die block.

(u) Apr. 15, 1957 - Tensile gate deepened to 0.080 in.

(v) Apr. 30, 1957 - Water flow reversed. Introduced through lower line.

(w) May 3, 1957 - Water flow reversed to original.
- Tensile gate 0.070 in. deep reinstalled.
- Impact gate 0.060 in. x 3/16 in. reinstalled.

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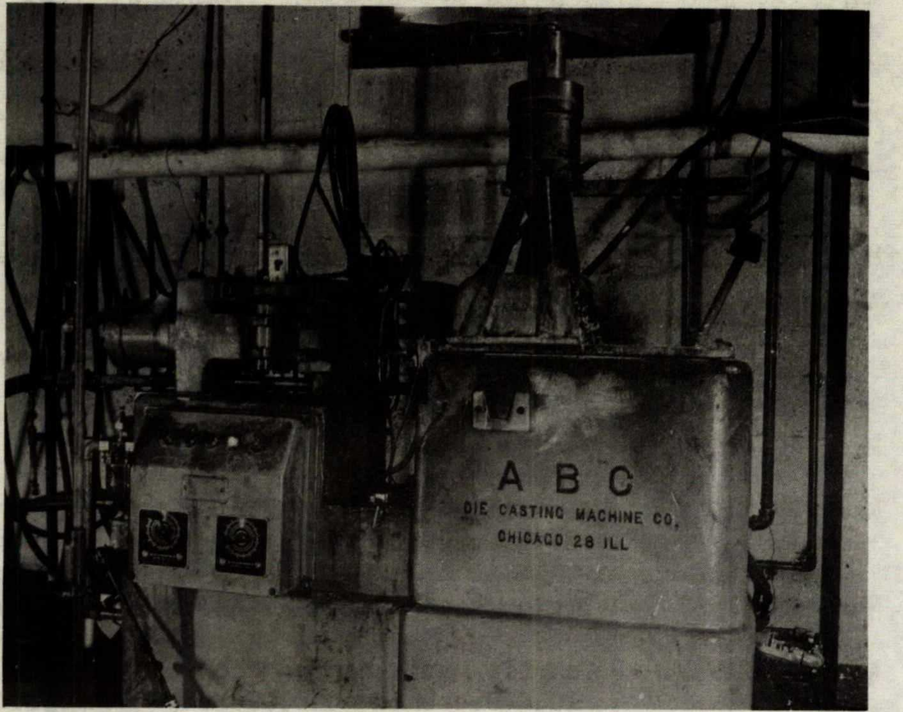


Fig. 1. - ABC die casting machine.

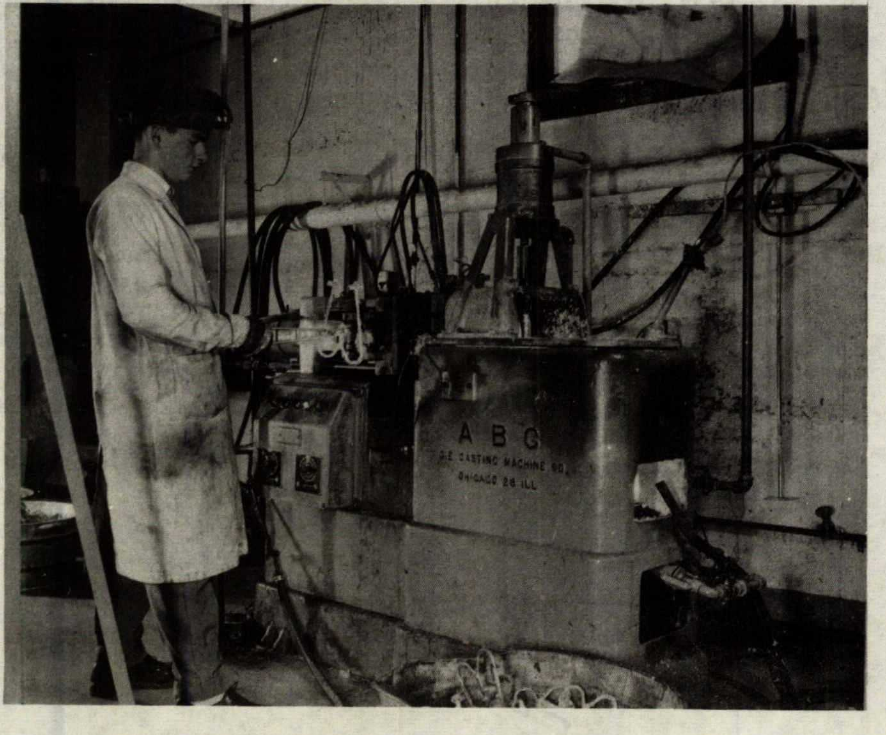


Fig. 2. - ABC die casting machine (showing melting pot burner location).

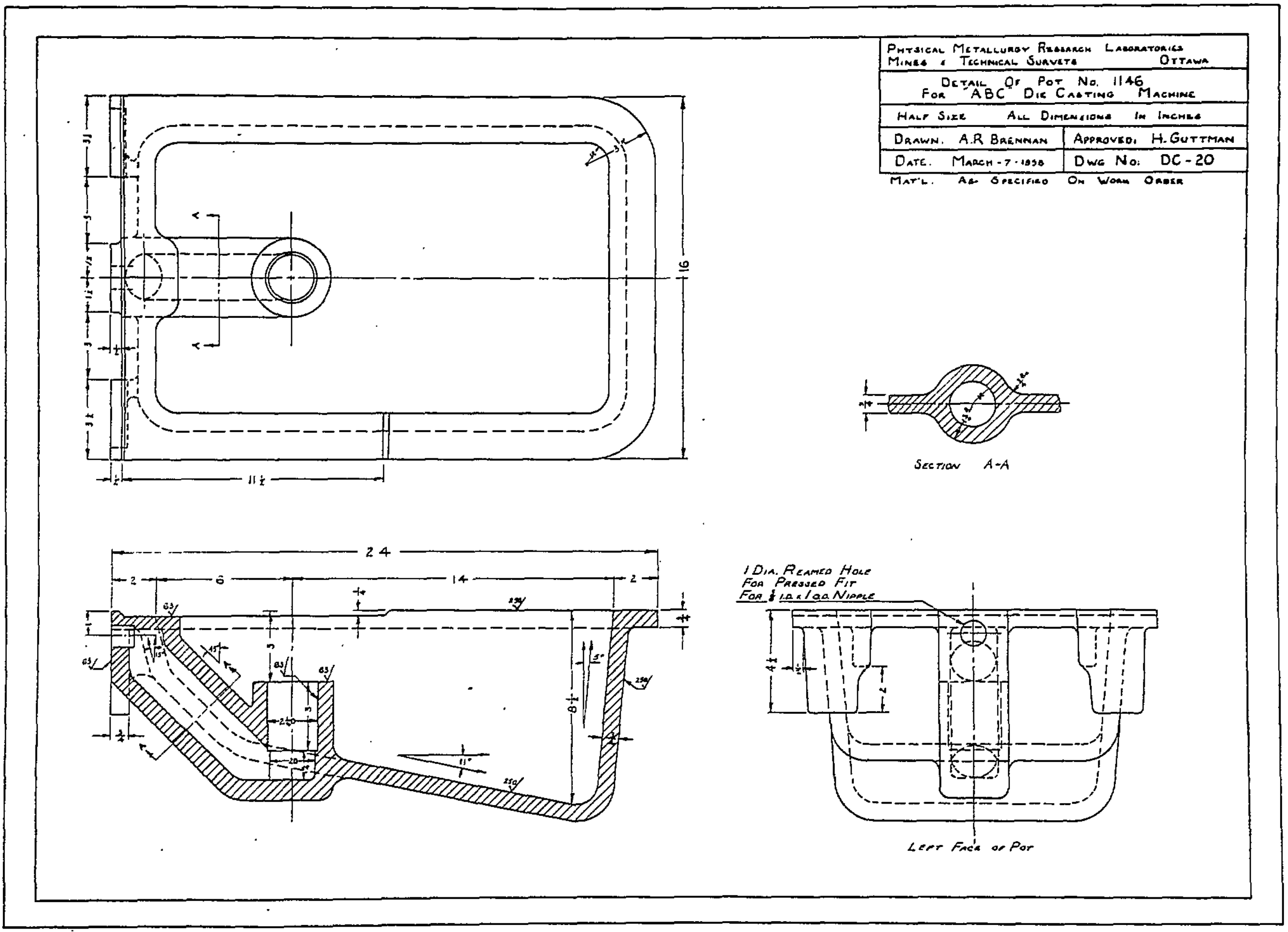
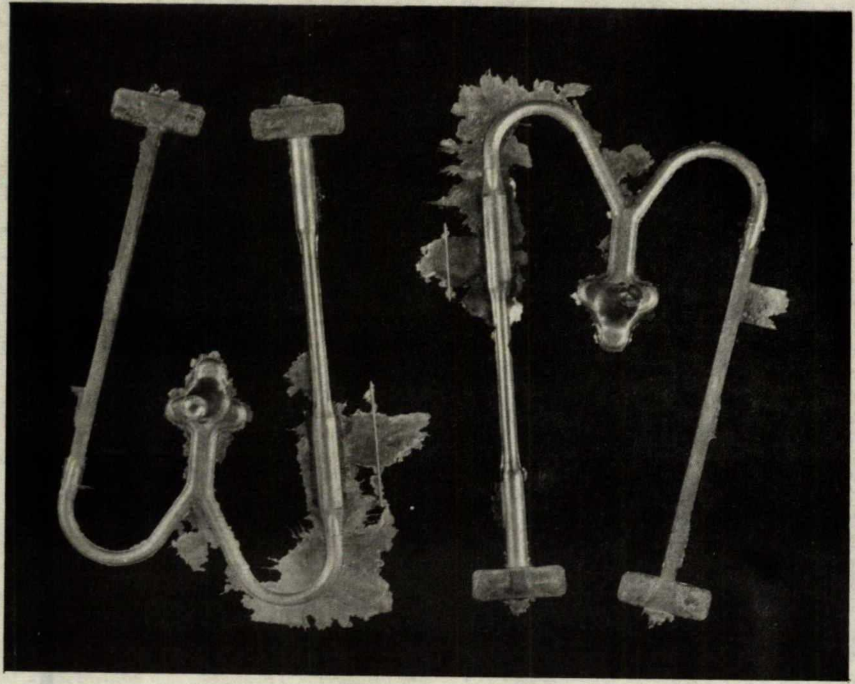
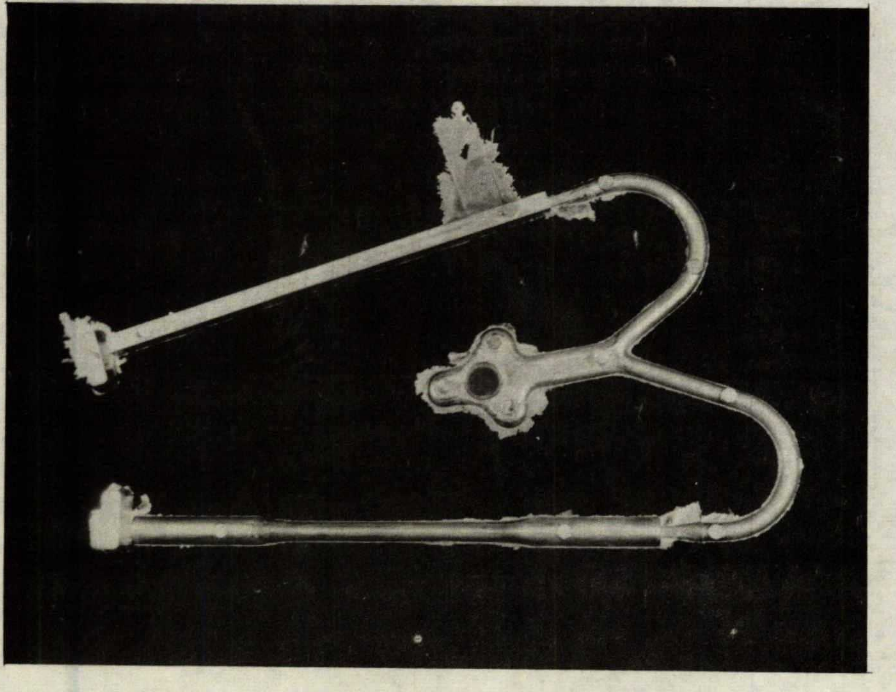


Fig. 3. - Drawing of pot for ABC die casting machine.



X1/3 approx.

Fig. 4. - Test bar castings, showing excessive flash.



X1/3 approx.

Fig. 5. - Test bar casting as originally designed (ejector surface).

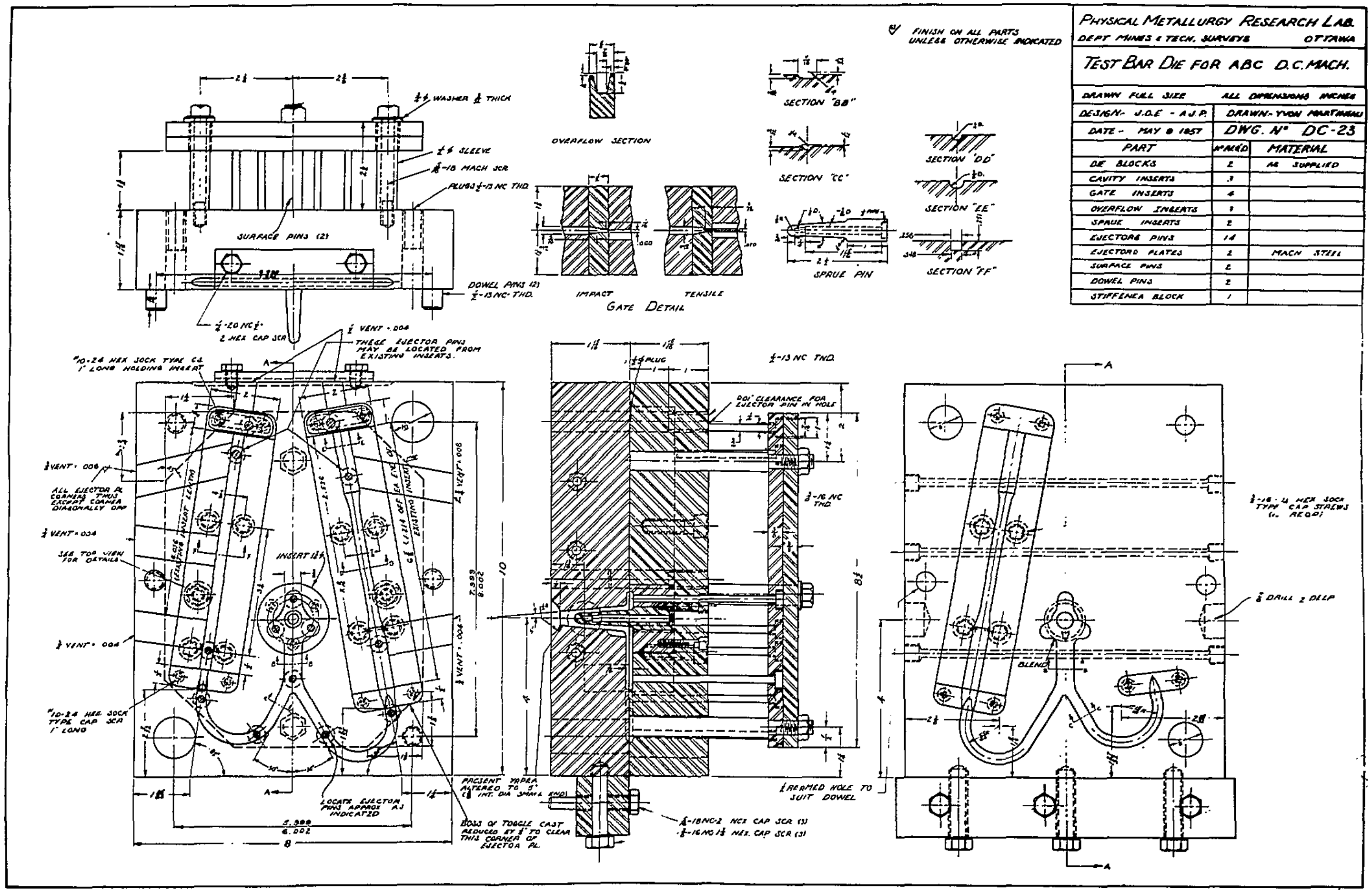
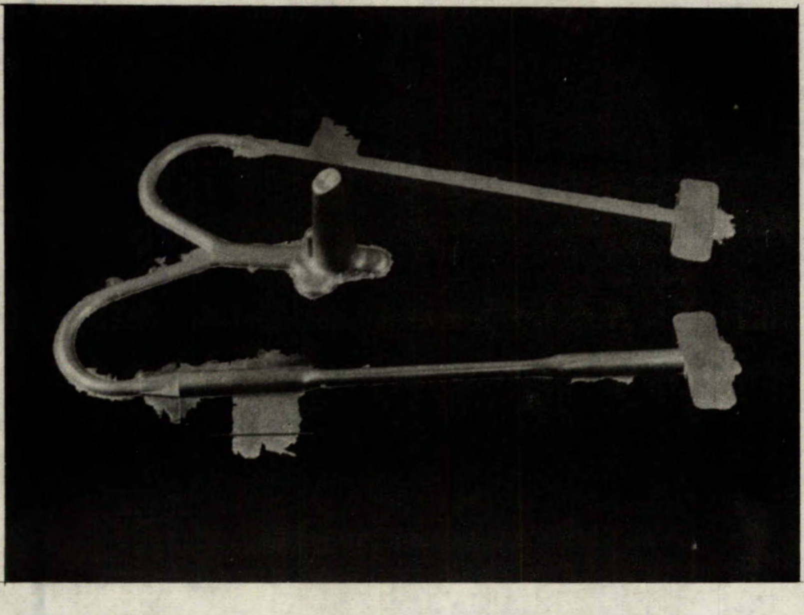
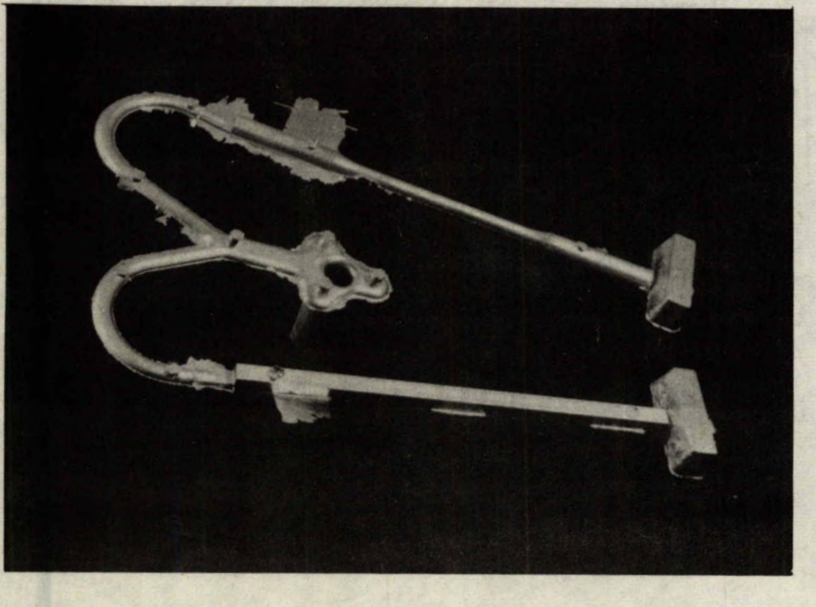


Fig. 6. - Drawing of test bar die for ABC die casting machine (finalized design).



X1/3 approx.

Fig. 7. - Test bar casting showing cover-half surface (finalized design).



X1/3 approx.

Fig. 8. - Test bar casting showing ejector half surface (finalized design).

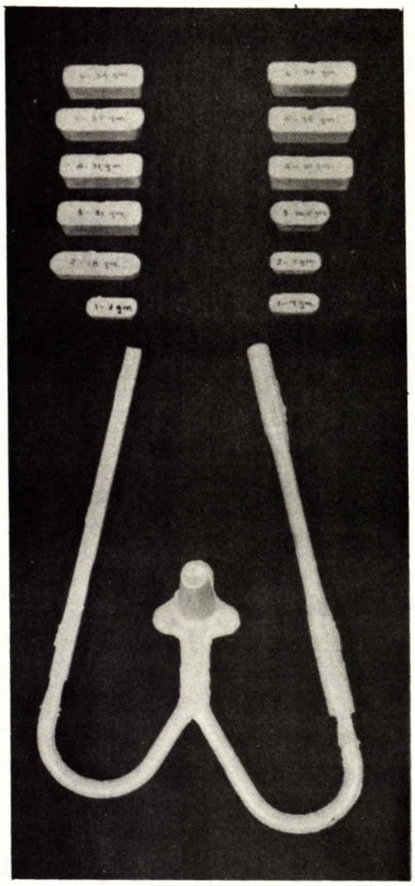


Fig. 9 - Overflow well enlargement.

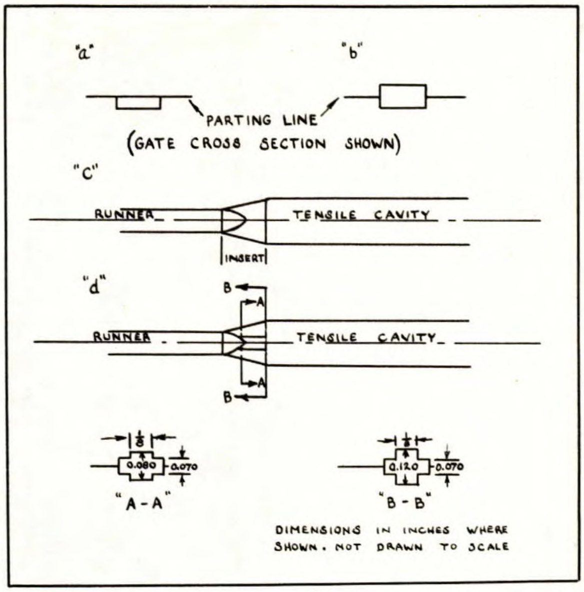


Fig. 10. - Types of tensile gates.

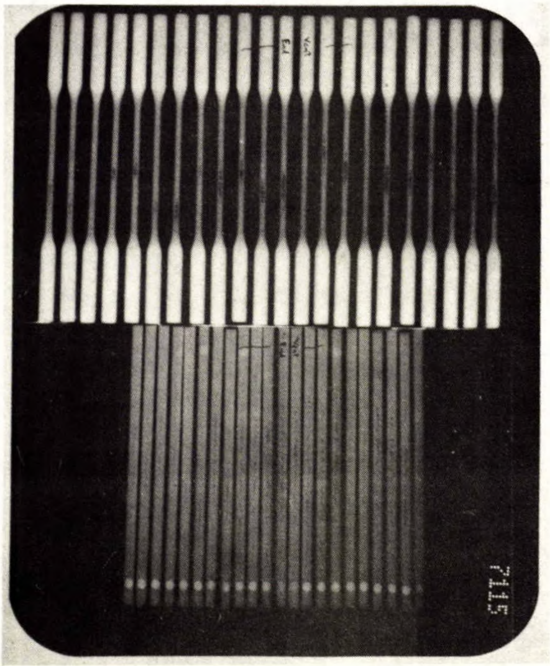


Fig. 11. - Radiograph of bars of cast 12.

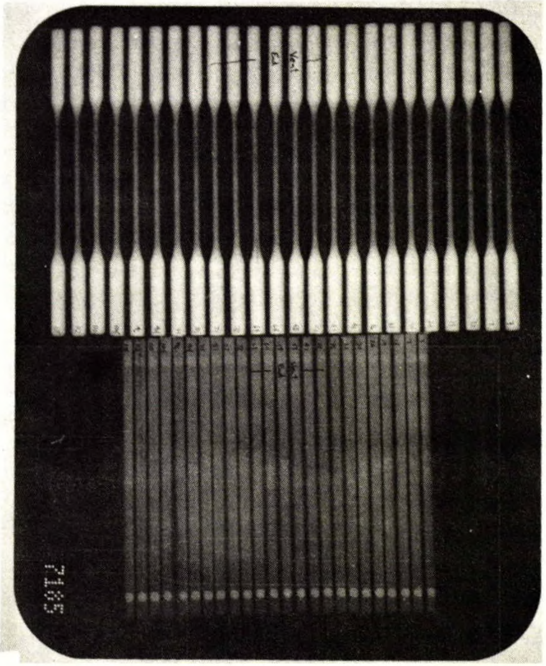


Fig. 12. - Radiograph of bars of cast 24.

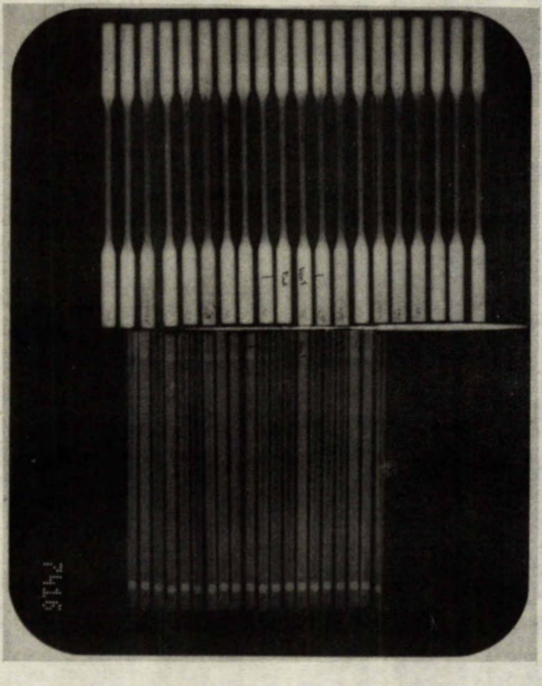


Fig. 13. - Radiograph of bars of cast TI.

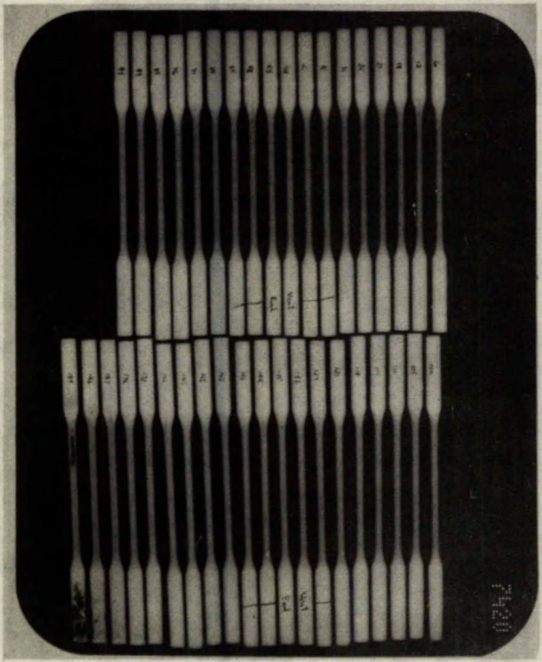


Fig. 14. - Radiograph of tensile bars of cast ZA.

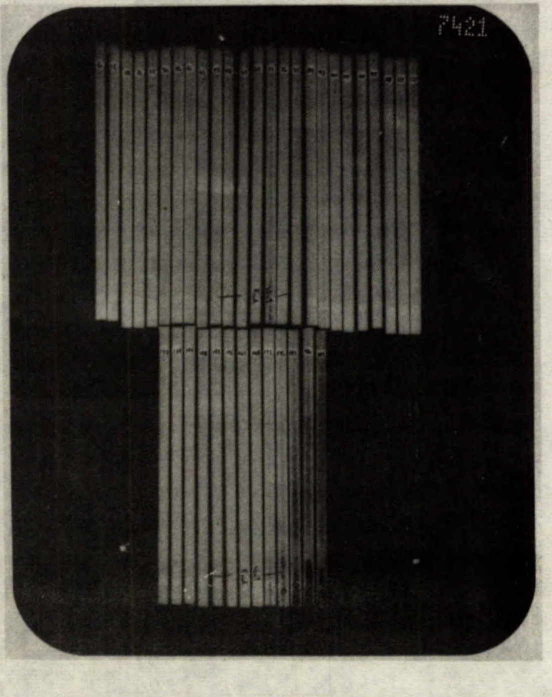


Fig. 15. - Radiograph of impact bars of cast ZA.

Fig. 16. - Tensile bar cast on Cleveland die casting machine (vent end).

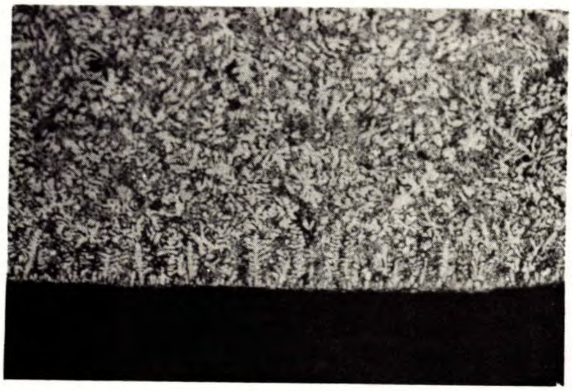


Fig. 17. - Tensile bar cast on ABC die casting machine (gate end).

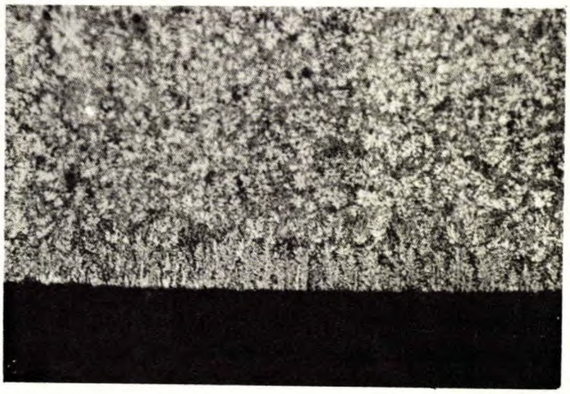


Fig. 18. - Tensile bar cast on ABC die casting machine (vent end).

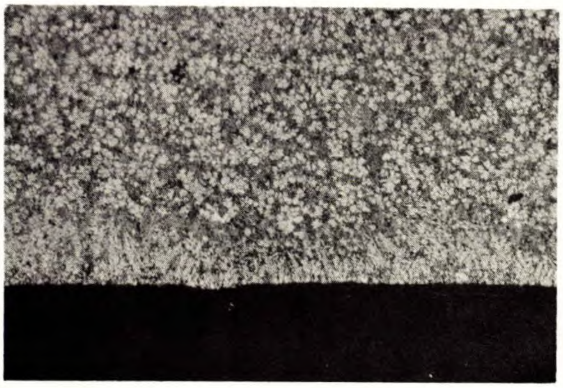


Fig. 19. - Impact bar cast on ABC die casting machine (vent end, hot face).

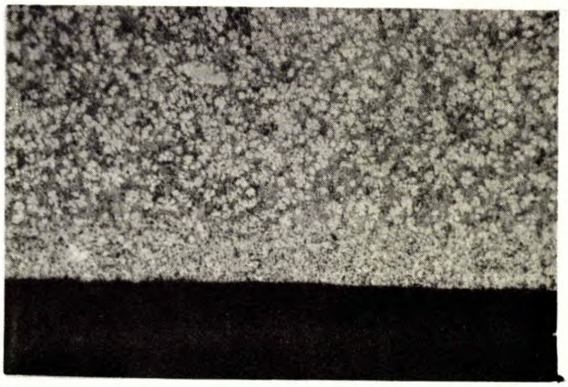


Fig. 20. - Impact bar cast on ABC die casting machine (vent end, cool face).

(NOTE: ALL ABOVE SPECIMENS ETCHED; MAGNIFICATION, X100).

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