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GATING SYSTEMS FOR METAL CASTING

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ABSTRACT

This investigation was undertaken to observe the effects of gate design upon the flow and turbulence of liquid steel as a casting is poured. Gating systems and pouring techniques such as top pouring, whirl gates, riser gates, finger gates, horn gates, step gates and bottom side gates were studied. The results of these studies showed that many gating systems did not function as commonly supposed. The behavior of each system is described in the text.

To observe the discharge of molten steel into mold cavities, use was made of motion pictures at 64 frames per second. High-speed photography at 1000 frames per second was used in a study of the flow of molten steel through sprues. The most interesting scenes of flow and turbulence produced by the various gating systems have been assembled into a 16-mm sound film.

PROBLEM STATUS

This is a interim report on this problem; work is continuing.

AUTHORIZATION

NRL Problem No. M02-12R.

GATING SYSTEMS FOR METAL CASTING

INTRODUCTION

Since foundry techniques for gating molten metals into molds are generally developed by trial and error, the need for the study of the behavior of molten metal within gating systems is widely recognized. Most of the information on fluid flow available in the literature is concerned with steady flow conditions and is therefore inapplicable to the filling of a mold.

Studies of flow in models of gating systems have been reported by S. L. Fry[1] and by R. B. Fisher.[2] Fry recorded the behavior of lead and aluminum, both low-melting nonferrous metals, by Cine-radiography. He placed plate molds between an X-ray source and a fluorescent screen and photographed the image with a 35-mm Cine camera. Fisher poured Wood's metal at 250°C into molds faced with transparent lucite and photographed the flowing metal through the lucite with a 16-mm Cine camera. His work dealt with the flow characteristics produced by various designs of gates and different rates of pouring.

EXPERIMENTAL PROCEDURE

In the NRL studies, molten steel at 3000°F was poured by means of various gating systems into open mold cavities. From directly over the mold 16 mm Kodachrome motion pictures at 64 frames per second recorded the flow and appearance of the metal. As molten steel is highly luminous at the pouring temperature, it was possible to photograph the flow behavior directly, without artificial lighting, using an aperture of f16. Studies were made in this manner of top pouring, whirl gates, riser gates, finger gates, horn gates, step gates and bottom side gates. Several variations of each of these gating systems were used.

The sprues and ingates in all gating systems were one inch in diameter, except where a deviation from this dimension is noted below. In

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[1] Fry, S. L., Foundry T. J. 76, pp. 213-216, July 12, 1945.

[2] Fisher, R. B., Ingersoll-Rand Company, Phillipsburg, N. J., Correspondence.

the studies of top pouring, and of step and bottom side gates, a casting 5" x 5" square by 18" high was used with a riser 7" by 7" by 7". Whirl gates, riser gates, finger gates, horn gates, and other step gates were used on a 6" by 6" by 12" casting without a riser. This mold was placed in a horizontal position except in the case of step gating when it was vertical.

Throughout this investigation either open or plugged sprue cups were used. Comparative runs between plugged cups and open sprue cups were made in order to examine the effects of variations in reservoir levels. Some differences in the fluid behavior in the gating systems were noticed. Therefore, high-speed photography, 1000 frames per second, were used to examine the type of stream flowing from each type of cup. The mold arrangement used for these studies is shown in Figure 1.. Metal was poured into the sprue cup, placed above an open sprue without a runner, and the molten steel was photographed as it emerged.

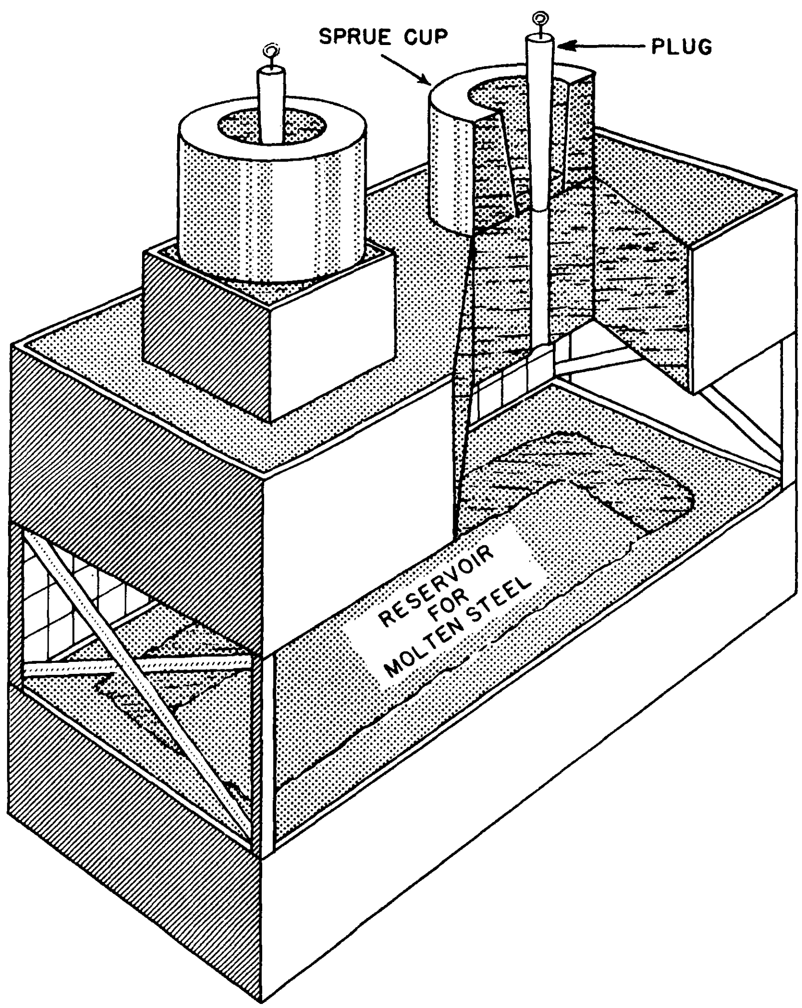

Fig. 1 - Unattached Sprues Used for High-Speed Photographic Studies of Metal Streams

Slow-motion pictures of the flow of fluids within glass models of various gating systems were also taken. Water was poured into the models and a solution of potassium permanganate was added to the pouring stream at the desired time to outline the extent of turbulence in the fluid in the mold, as shown in Figure 2B. These models included top pouring, horn gates, step gates and bottom side gates.

OBSERVATIONS

Occurrence of Turbulence

Turbulence in the castings was revealed by the swirling and rolling of the molten metal in the mold. Swirling turbulence is identified by a clockwise or counter-clockwise movement, or even both, on the surface of the metal in the mold. The axis of rotation is vertical. Rolling turbulence is characterized by a uniform flow on the surface of the metal from one side of the mold to the opposite side. Its axis of rotation is parallel to the runner.

Effects of the Use of Open and Plugged Sprue Cups

Observations made when pouring steel indicated that the time required to fill a mold by means of a plugged sprue cup was only two-thirds as much as that required when using an open cup. Therefore, high-speed photography, at 1000 frames per second, was used to record the behavior of molten steel as it emerged from a sprue.

The stream from an open cup when photographed at 1000 frames per second appeared very turbulent for some time after pouring started, but as the sprue cup was choked the flow became steadier and streamlined. On the other hand, the flow from a plugged sprue cup appeared to be streamlined during the entire pouring time. The stream as it emerged from the sprue indicated that it wetted the orifice of the sprue, and this caused the stream below the sprue to have variations in cross-sectional area. The use of a plugged sprue cup definitely reduced turbulence in the metal flow when compared with open cup behavior.

Top Pouring

Although direct pouring of molten metal into the top of a mold, as shown in Figure 2A, is not commonly used in the foundry industry, steel ingots are cast by this method. Severe spattering occurred immediately and continued throughout the pouring cycle. Considerable turbulence was noted. A water-in-glass model, Figure 2B, showed that even when the model was nearly full, approximately two-thirds of the liquid was agitated by the entering stream. This phenomenon has also been observed by Northcott[3] and other investigators.

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[3] Northcott, L., J. Iron and Steel Inst., 143, pp. 49-89, 1941.

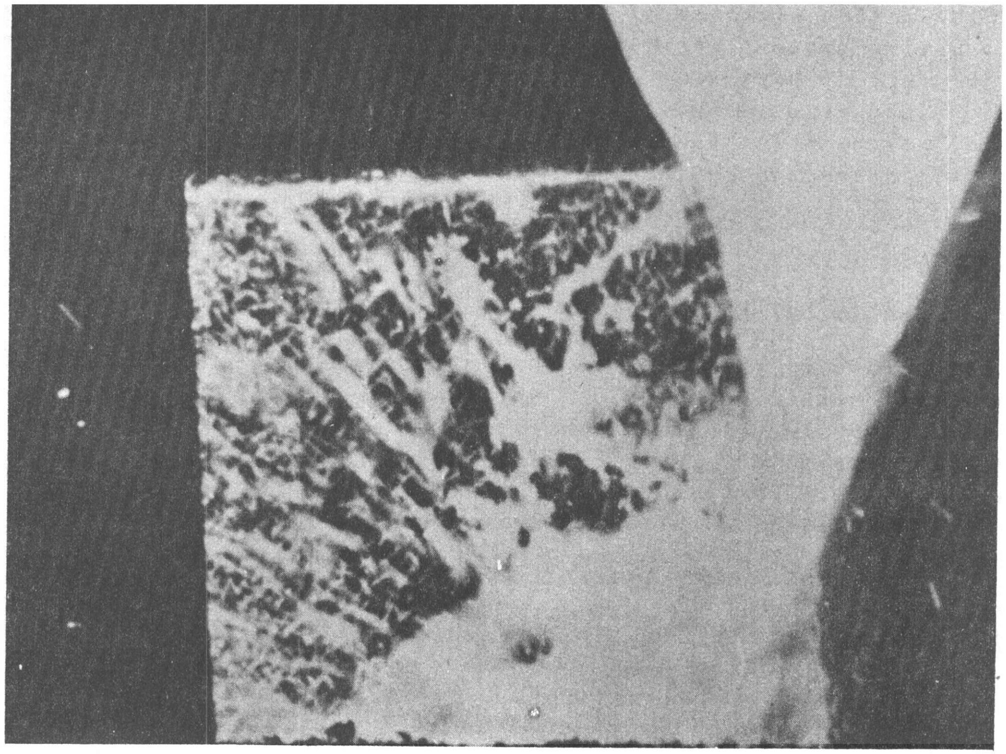


Fig. 2A - Top Pouring - Steel

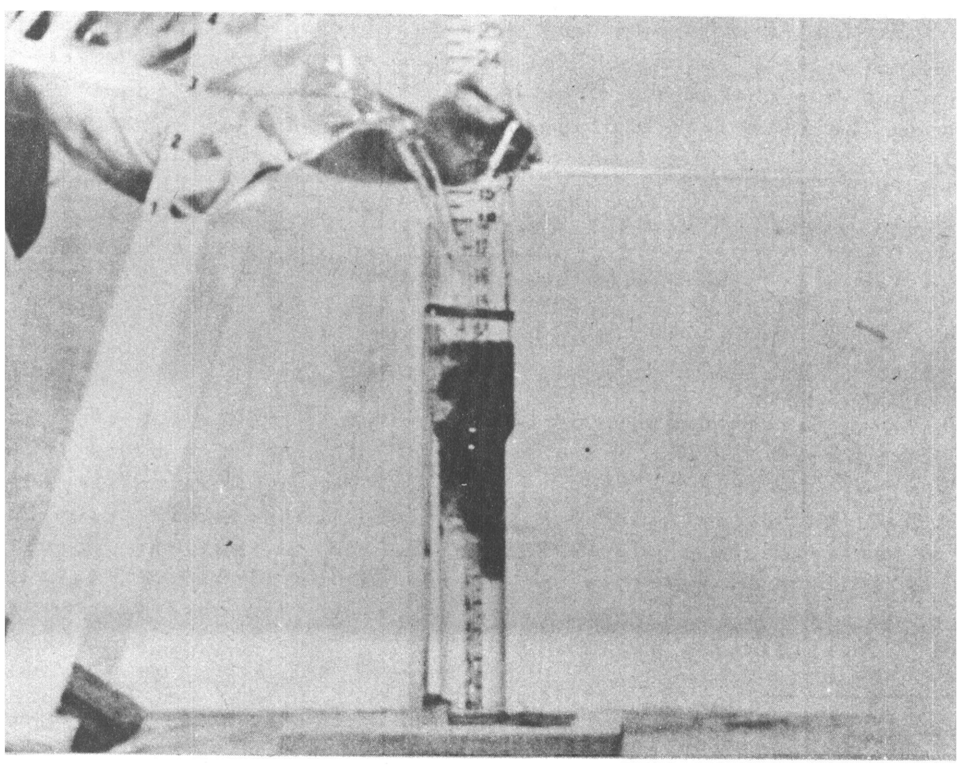


Fig. 2B - Top Pouring - Water and Dye

Whirl Gating

A whirl gate receives its name from the rotation it imparts to the liquid metal passing through it. Separation of slag from metal by centrifugal force is an objective. In the two variations of whirl gates studied, the runner and ingate always had the same cross-sectional area and were in the same plane, but the angle of the runner was varied with respect to that of the ingate.

In the first variation, shown in Figures 3A and 3B, the ingate was at an angle of 90° to the runner. The metal ran through the gate into the casting before the bottom of the gate was completely covered, and some slag entered the mold. Later, when the whirl became fully developed, slag appeared to be more completely separated. In the second variation of this gate, shown in Figures 3C and 3D, the ingate was at an angle of 180° to the runner. Again metal entered the mold before the bottom of the gate was completely covered and in this stage some slag escaped into the mold. Swirls indicating turbulence were apparent in the molten steel in the mold with both gate designs.

Riser Gating

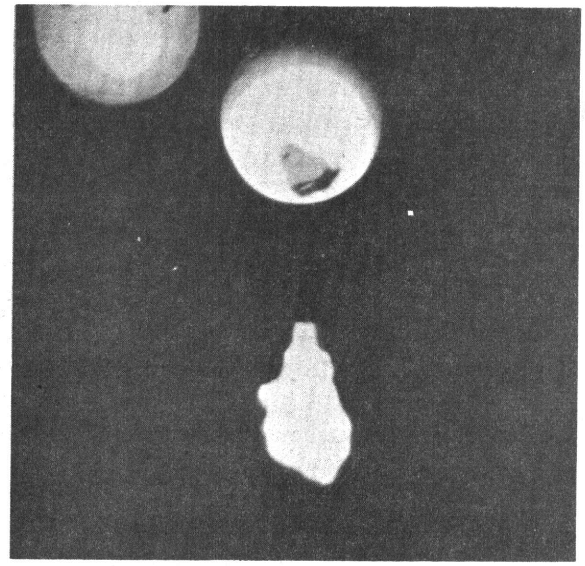
A riser gate differs from a whirl gate only in having a larger ingate, which allows it to function as a riser when pouring stops. Figures 4A and 4B show a horizontal mold with a riser gate. This gate delivered metal at lower velocity than the whirl gates, but turbulence was still present in the casting. An interesting phenomenon noticed in this system consisted of frequent changes in light intensity on the metal's surface during and after pouring. The cause of these "flashes" is not known at present, but they were also observed in other gating systems.

Finger Gating

Finger, or pencil gates, are employed to distribute metal into the mold in a horizontal plane over a large area. The number of fingers, their positions relative to the sprue, and angle of entering the mold were factors studied. Arrangements of four finger gates of equal size in which the total finger area was twice that of the sprue were studied first. Most of the molten metal, as shown in Figure 5A and 5B, entered the casting through the fingers farthest from the sprue. Two opposing swirls on the surface of the steel show that this continued throughout the pouring.

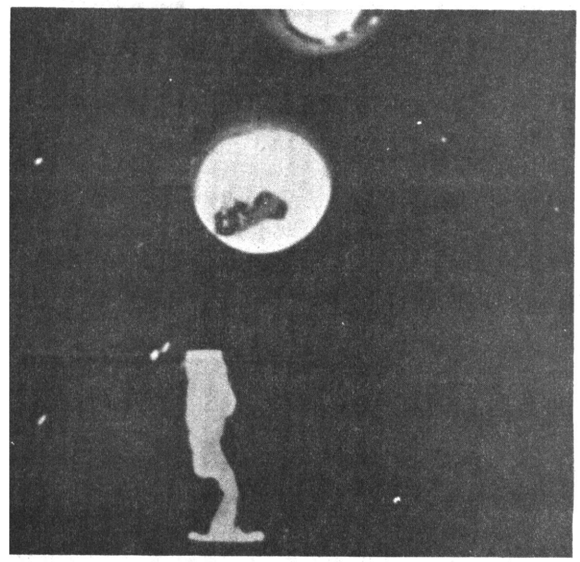
For better observation of the movement of the steel in the fingers, the cope of the mold was removed (Figures 5C and 5D). When pouring first started, the metal flowed past the nearest gate openings to the ends of the runner. After sufficient metal had entered to cause a build-up of metal at each end of the runner, the outer fingers began to feed. Flow continued primarily through the outer fingers as long as pressure was maintained in the system by continued pouring. It was observed here, and throughout this investigation, that once a flow pattern was established in a gating system, it was difficult to change it.

A



B

C

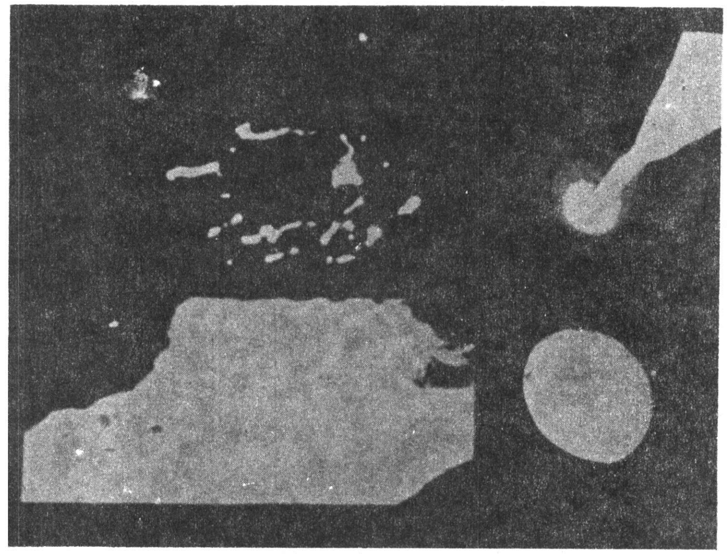


D

Fig. 3 - Whirl Gates

The location of the sprue was next changed from the center to the end of the series of four fingers (Figures 5E through 5H) with no change in the area ratio and finger angle. The second finger from the sprue fed first as indicated in Figure 5F, but most of the metal entered the mold through the finger farthest from the sprue (Figures 5G and 5H). Swirling turbulence became apparent in the mold at the side opposite the sprue. This disturbance lessened as the mold filled, probably because back pressure in the mold caused flow from the fingers to become more uniform.

A



B

Fig. 4 - Riser Gates

With a change in the angle between the fingers and the casting to 30°, or 150° to the direction of flow of metal in the runner, as shown in Figures 6A and 6B, the finger farthest from the sprue fed first.

The effect of reducing the total finger area to equal that of the sprue was next investigated (Figures 7A through 7D). Although the initial flow began from the fingers farthest from the sprue (Figure 7B) flow from all the fingers soon became more uniform. A rolling type of turbulence was observed instead of the swirling kind noted previously with the larger finger-to-sprue ratio. When the location of the sprue was shifted from the center to the end of the runner, (Figure 7C) molten steel entered first through the fingers nearest the sprue (Figure 7D) but shortly thereafter flow from all fingers became relatively uniform and rolling turbulence occurred. When an additional change of finger angle to mold of 30° was made flow began at about the same time through all four fingers with the ones farthest from the sprue carrying the greater quantity of metal. The amount of flow, however, became fairly uniform at an early stage.

This investigation of finger gating indicated that when the combined finger area was greater than that of the sprue, feeding was not uniform and swirling turbulence was the result. When the combined finger area equaled that of the sprue, however, feeding was relatively uniform but was accompanied by a rolling turbulence.

Horn Gating

Horn gates are designed for use on castings which cannot be gated on the edge or where it is not considered advisable to pour metal down

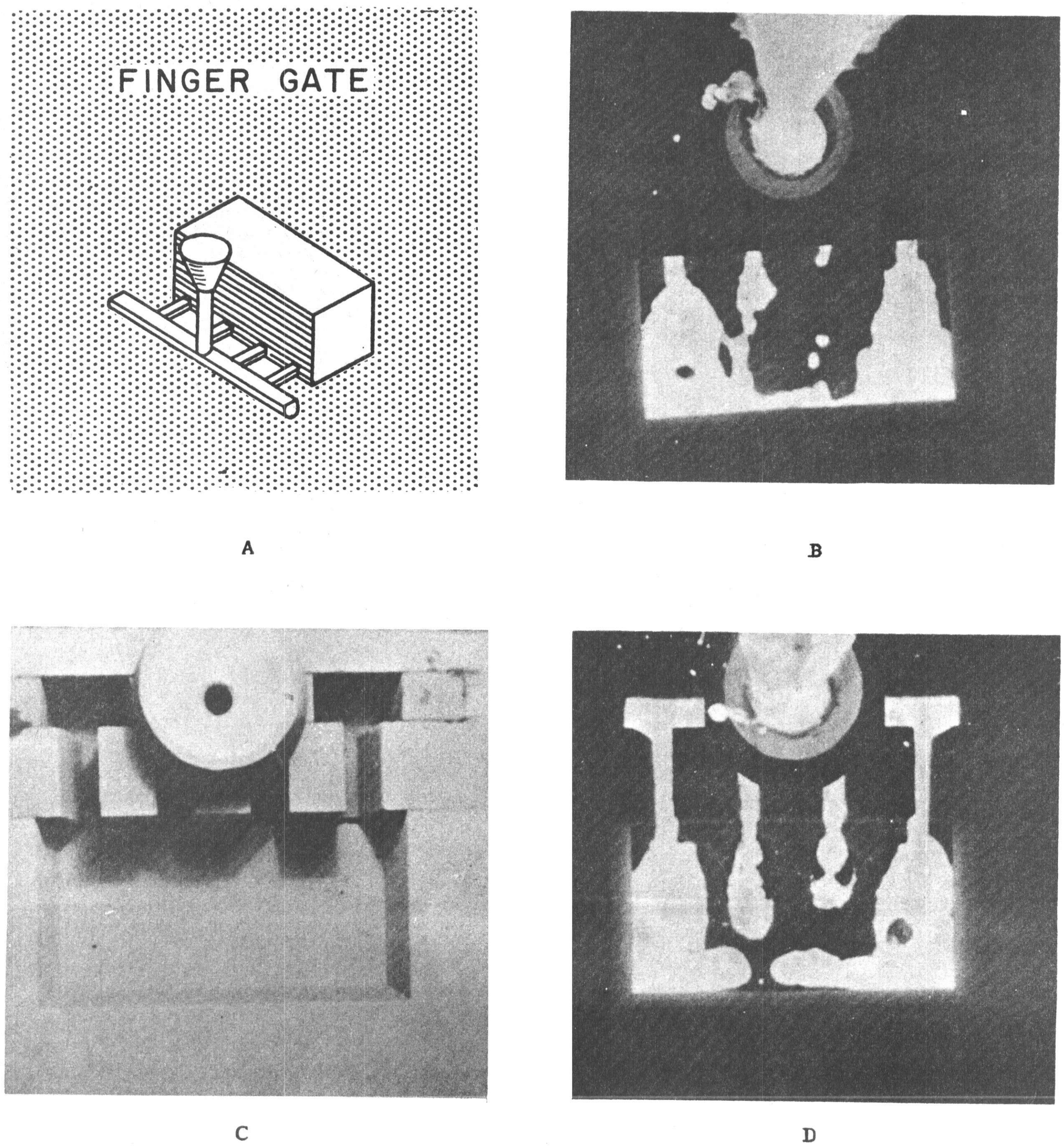
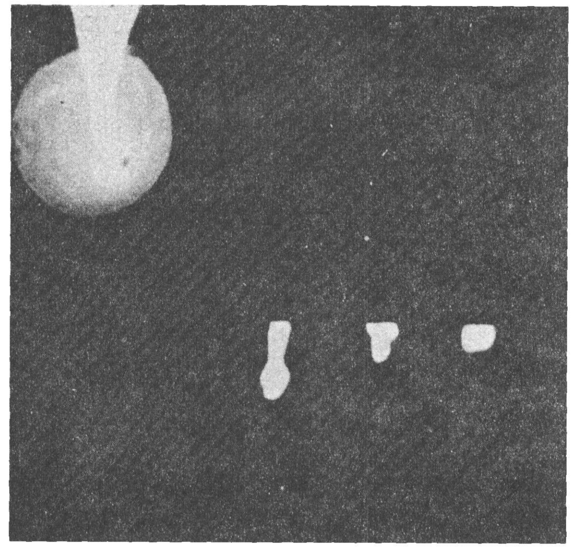


Fig. 5 - Finger Gates with 90° Finger Angle and
2-1 Finger-to-Sprue Area Ratio

through a gate on the top. A normal horn gate is smaller in cross section at the casting than at the down gate and a reversed horn gate is tapered in the opposite direction. A single normal horn gate produced a fountain-like jet and severe rocking of the metal in the mold. The height of this initial fountain-like jet was more apparent in a water-in-glass model. Dye introduced into the pouring stream when the model was

E



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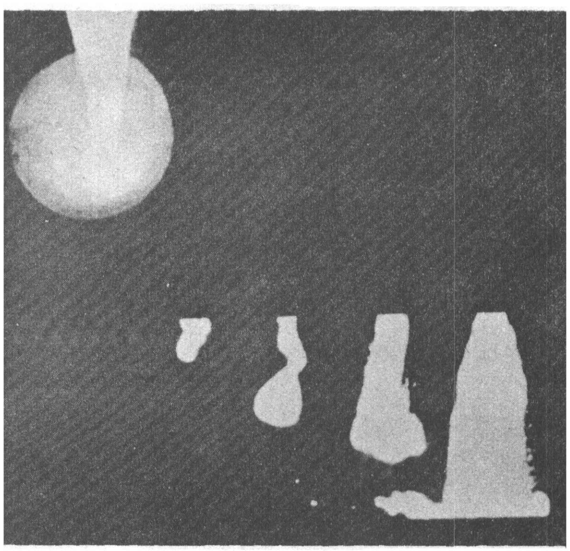
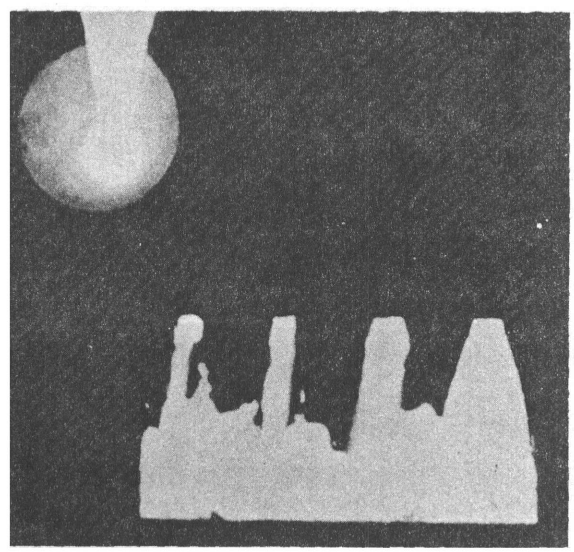


G

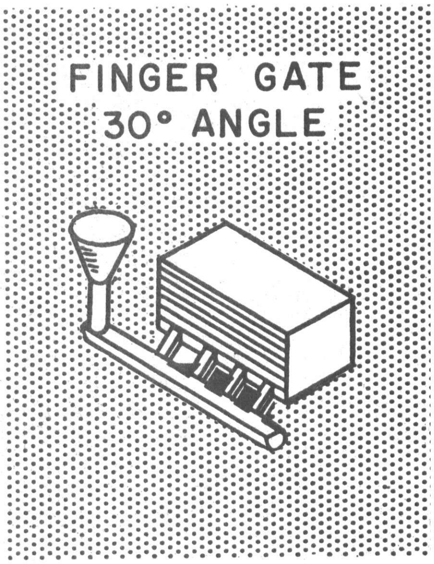


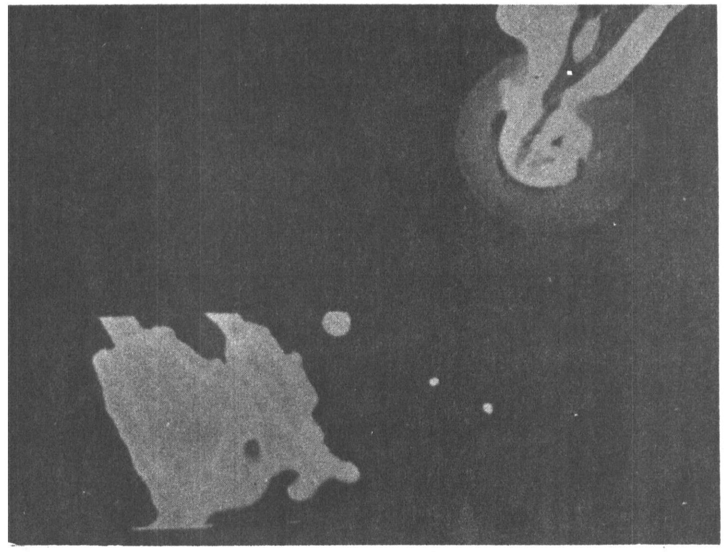
H

Fig. 5 - (Continued)

nearly filled (Figure 8) showed that the incoming liquid continued to rise like a jet through the water in the model even in the later stages of pouring.

The effect of placing three normal horn gates in a row with the sprue located on one end is shown in Figures 9A through 9D. With this design metal entered initially through the horn next to the sprue (Figure 9B) but later

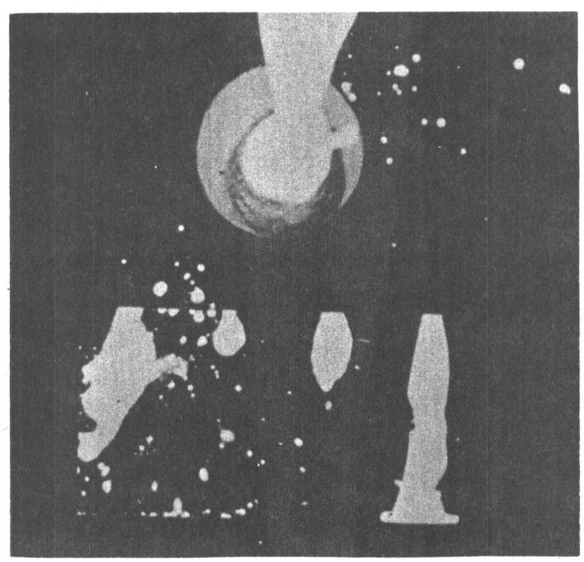




A

B

Fig. 6 - Finger Gates with 30° Finger Angle and
2-1 Finger-to-Sprue Area. Ratio

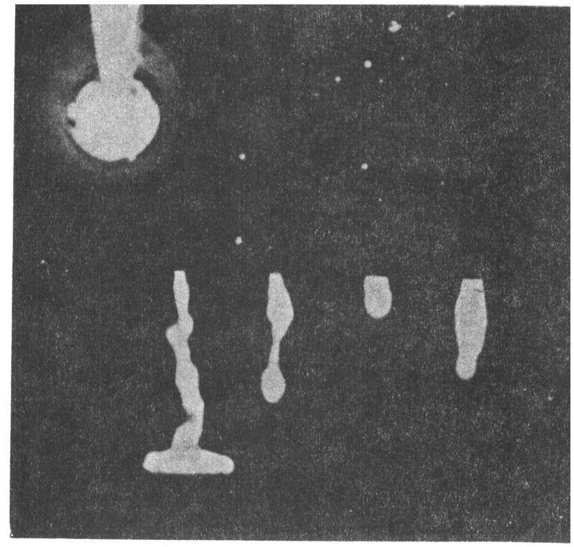


A

B

Fig. 7 - Finger Gates with 90° Finger Angle and
1-1 Finger-to-Sprue Area Ratio

C



D

Fig. 7 - (Continued)

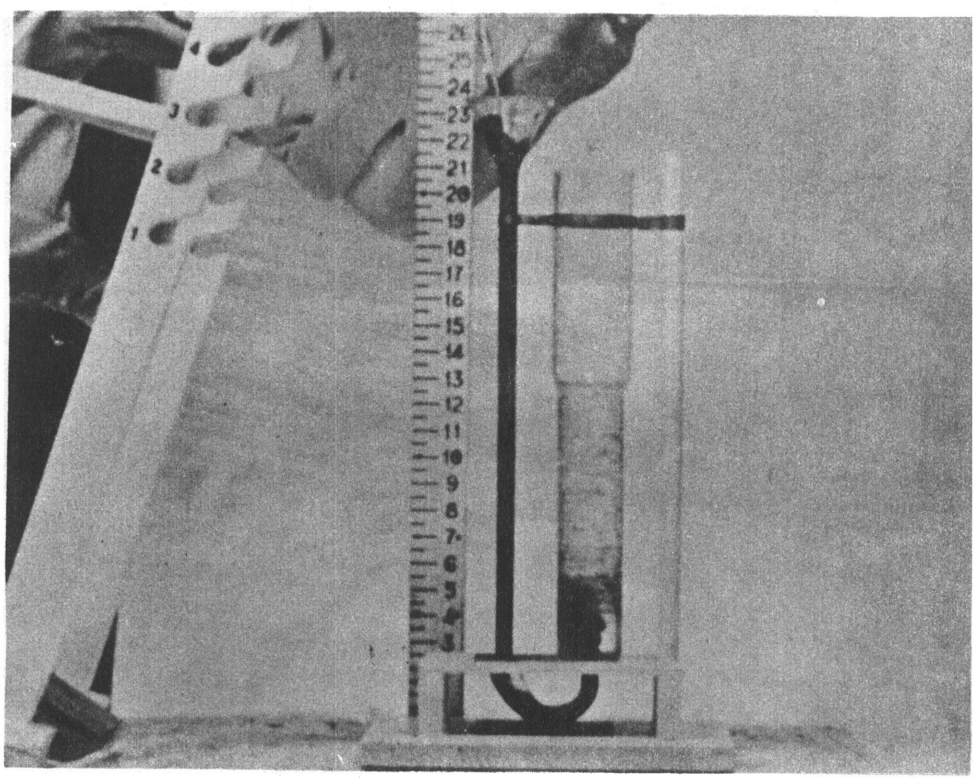
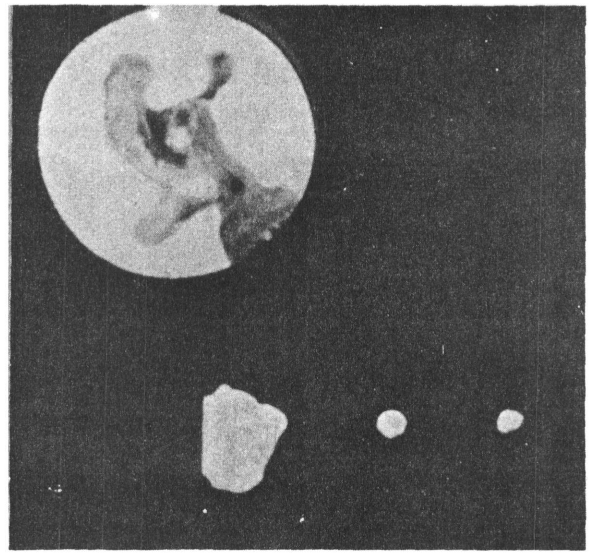


Fig. 8 - Normal Horn Gate Model

A



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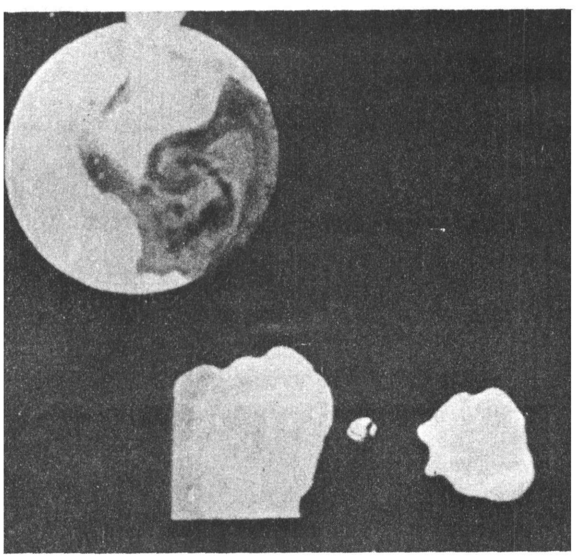

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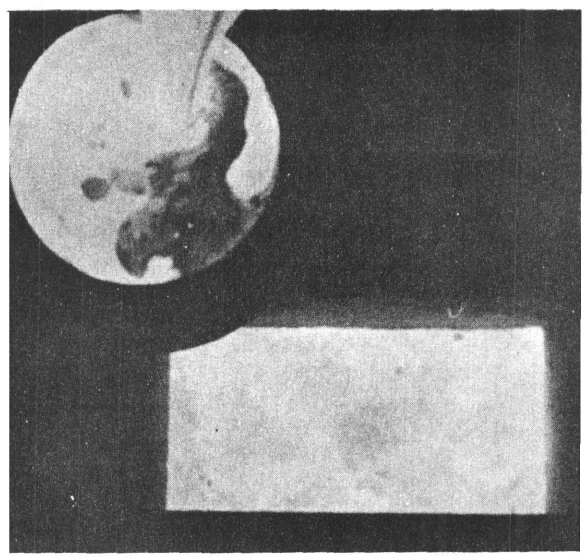


D

Fig. 9 - Normal Horn Gates

most of it entered through the horn farthest from the sprue (Figure 9C) as with finger gates. After the mold was partially filled, the middle horn began to feed (Figure 9D).

Reversed horn gates are commonly believed to pass metal with little turbulence. With a single reversed horn a jet of molten steel again was produced but its height was slightly less than that produced by the normal horn gate. When three reversed horn gates were used in a row with the sprue on one end (Figures 10A and 10B) the horn farthest from the sprue fed first and continued to deliver most of the metal as was observed by the disturbance on the surface. Turbulence at the center of the partially filled mold indicated that the middle horn did feed to some extent at this stage. When the sprue was placed in the center of four reversed horn gates as in Figures 10C and 10D, the horns farthest from the sprue did all the feeding as was shown by the surface turbulence.

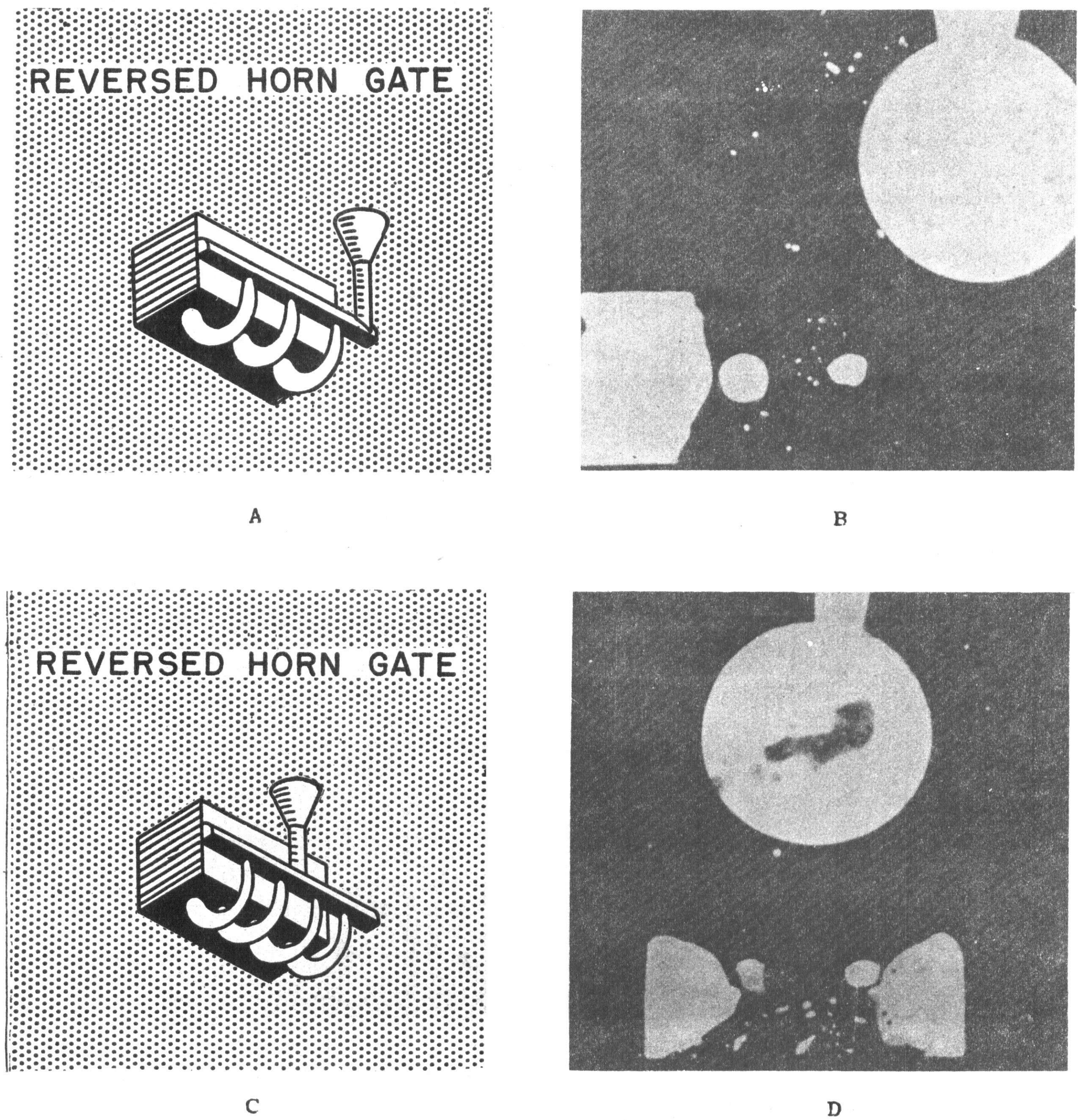


Fig. 10 - Reversed Horn Gates

Step Gating

The purpose of a step gate is to produce a steady temperature gradient from the bottom of the casting to its riser without the spattering characteristic of top pouring. As the metal level in the casting reaches each succeeding higher step, this step should begin and the lower steps stop feeding.

The first step-gate system studied, Figure 11A, was an off-set gate in which the vertical distance between steps was nine inches and each sprue was offset one inch horizontally. The steps were inclined upwards 30° from the horizontal. With this gate, the bottom step fed initially but before the metal reached the middle step, the top step began to feed and the bulk of the metal entered through it.

The next system studied (Figure 11B) was a straight step gate with no change in distance between steps or inclination from the previous example. With this design the metal entered the mold only through the bottom step. As the metal in the mold reached the middle and upper steps, it ran back into the gating system instead of being fed by the steps into the mold.

The next system (Figure 11C) had three horizontal steps only six inches apart. The metal entered mainly through the lower step but a small quantity dribbled through the upper ones before the level of the metal reached them. When the level of metal in the mold finally reached the upper steps, metal ran back into them as in the previous system. With the lowest step inclined upwards 60° from the horizontal, as in Figure 11D, the metal first entered the mold through the step, and as pouring continued the second step fed when the metal level reached it. This was the only step gating system examined that showed an upper step feeding in the desired sequence.

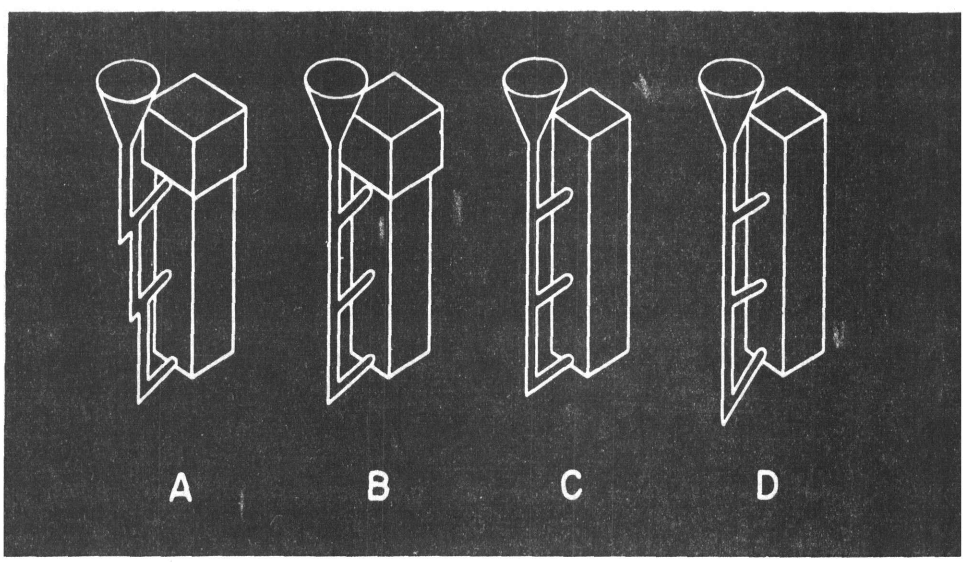
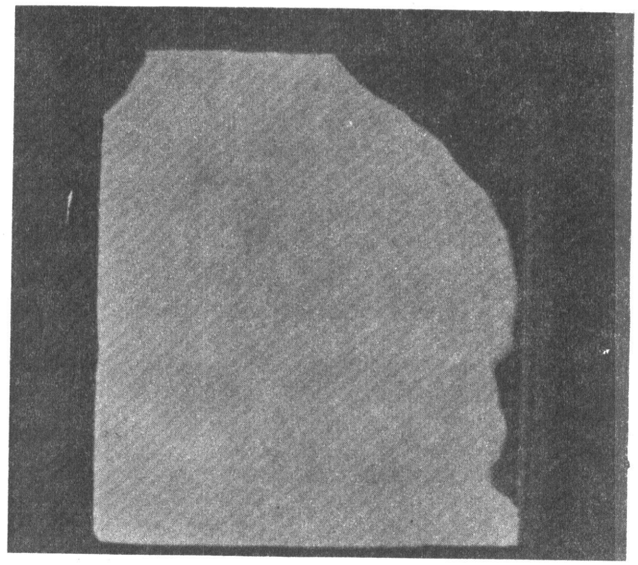


Fig. 11 - Step Gates

Bottom Side Gate

In the bottom side gating system, shown in Figures 12A and 12B, a closed mold cavity was placed before the mold to decrease the velocity of the metal. Metal entered the mold more evenly through this system than through any other studied. Light flashes were noticed on the surface of the metal similar to those observed in the riser gate system.

A



B

Fig. 12 - Bottom Side Gates

CONCLUSIONS

These experiments showed that many gating systems do not function as commonly supposed.

Whirl, riser and horn gates are ineffective in preventing turbulence in the mold. Often in multiple finger gating systems, most of the feeding is accomplished by the fingers farthest from the sprue. When all the fingers do feed uniformly, a rolling type of turbulence appears in the mold. With step gates only one design shows feeding in the desired sequence. No gating systems studied prevented turbulence completely.

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