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CHOKE CONTROL IN FINGER GATING

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ABSTRACT

Various designs of finger-gating systems were studied to evolve general principles of choke control for multiple-finger-gating systems. In a free or nonchoked system, the metal follows preferential paths dictated by the inertia of the metal stream and the geometry of the gating system, resulting in nonuniform flow. It was found that if a choke condition is developed at the finger inlets, the gating system becomes pressurized and forced, and that uniform flow occurs from all fingers regardless of position. The geometric shape of the fingers has been shown to be of secondary importance to choke control. Fingers which provide high frictional resistance to flow add to the choking effect, and thus require less than normal geometric choking to produce pressurization. The relationships between geometric and hydraulic-choked conditions are demonstrated.

PROBLEM STATUS

This is an interim report on the problem; work is continuing.

AUTHORIZATION

NRL Problem MO2-27R
NR 442-270

CHOKE CONTROL IN FINGER GATING

INTRODUCTION

It is generally considered that the smooth, uniform introduction of liquid metal into the casting cavity is not only desirable but often a matter of primary importance to casting quality. Realization of this feature of metal flow requires knowledge of the relationships between gating design and flow conditions. Such information has not been available in the past, and gating systems were necessarily developed by purely empirical practices and without direct knowledge that correct functioning was obtained.

It was apparent from the earlier investigations[1] conducted at the Naval Research Laboratory that metal, flowing freely in a runner, does not necessarily enter all channels which are a part of the gating system, but may continue along preferential straight line paths, ignoring side channels and openings. A later report[2] and film[3] showed that uniform flow may be obtained in "free" or nonchoking finger-gate systems by (a) elimination of pronounced momentum-pressure effects by the use of enlargements, and (b) control of momentum-pressure effects by means of sharp angles, constrictions, or increased flow distance.

The present report deals with an alternative method of obtaining uniform flow by choking or pressurization of the fingers in the gating system. These studies of choke control are based, as in previous investigations, on the observations of the discharge of molten steel into the mold cavities as recorded by motion photography. The most instructive scenes have been assembled into a 16-mm colored sound film entitled "Choke Control in Finger Gating."

The effects of choke control were observed with varying runner diameters, finger diameters, finger geometries, and finger lengths. Four different finger geometries were included: (1) flared (smallest dimension at runner); (2) tapered (smallest dimension at casting); (3) streamlined; and (4) rectangular.

Area ratios were taken as the relative areas of cross section available to metal flow. Thus the sprue area is that of the sprue cross section. If the sprue is at the center, the runner area must be considered as twice the runner cross section since the stream splits

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[1] Johnson, W. H., and Baker, W. O., "Gating Systems for Metal Casting," NRL Report M-3355, September 13, 1948

[2] Johnson, W. H., Baker, W. O., and Pellini, W. S., "Principles of Gating," NRL Report M-3603, January 12, 1950

[3] Johnson, W. H., and Baker, W. O., "Finger Gating," a 16-mm sound color film produced at NRL

into two channels; if, however, the sprue is located on the end of the runner, the runner area then is that of the runner cross section. The finger area is the total cross-sectional area of all four fingers, or four times the area of a single finger.

Area ratios of sprue to runner or sprue to finger are described as geometrically choked if the area ratios in the direction of flow equal one or less than one. In the discussions which follow, it should be noted that systems of moderately choked geometry may or may not produce hydraulically choked conditions (pressurization) depending on certain shape factors. The attainment of a hydraulically choked condition, which should theoretically produce uniform flow from all openings, was evaluated by observations of the actual flow patterns produced by the system in question.

EXPERIMENTAL PROCEDURE

Molten steel was poured at 3000°F into finger-gating systems and the flow characteristics of the metal as it emerged from the gates were recorded by 16-mm Kodachrome cinephotography at 64 frames per second.

Unless noted otherwise, the dimensions of the sprues and runners were one inch in diameter. The runner and fingers in each system were circular in cross section except for a slight squaring on the upper corners to facilitate molding. The runner-to-casting distance, or finger length, was three inches unless otherwise noted. The mold cavity was 6″ x 12″ x 6″. A plugged pouring cup was used because previous work showed that its use increases the constancy of metal flow into the sprue.

OBSERVATIONS OF METAL FLOW

In a previous report it was shown that the type of mold turbulence developed by multiple-finger gating depends on the relative flow volume from each of the fingers. Three types of mold turbulence were observed: swirling, rolling, and rocking. To these, as the result of the present investigation, is now added a fourth, termed "irregular," which is related to the velocity of the metal issuing from the fingers. The origin, mode of occurrence, and appearance of these four types of turbulence is presented schematically in Figure 1. In the descriptions that follow, flow patterns, during the early phases of pouring before the exit streams are covered, were determined directly from the photographs of the flow deltas. Flow patterns during late stages were deduced indirectly from the conditions of turbulence on the surface of the metal in the mold.

EFFECT OF VARIATIONS

Runner Size

The gating systems of Figure 2 show the effects of choke control by varying runner diameters. The sprue and finger diameters were retained constant at 1.0″ and 0.5″, respectively; consequently, the sprue-finger area ratio was always equal. The runner diameters studied were 1″, 0.7″, and 0.5″, providing runner-finger area ratios (RA-FA) of 2-1, 1-1, and 1/2-1, respectively.

In the system with the runner 1″ in diameter (RA-FA=2-1), all of the fingers fed uniformly throughout pouring, (Figure 2A). In the second (R = 0.7″ diameter, RA-FA = 1-1) a slight emphasis on flow from the outer fingers was noted in the beginning (Figure 2B), but a short time later flow became uniform. The half-inch-diameter runner (RA-FA = 1/2-1) caused the outer fingers to feed strongly (Figure 2C) which results in swirling; only near the very end of pouring did rolling turbulence start, indicating uniform flow.

These tests indicate that if a pressure is established in the runner, uniform feeding from all fingers results. Pressurization must be obtained by geometric choking between the fingers and runner; viz., by providing a geometry such that the fingers cannot deliver as much metal as the runner can provide. This in turn requires a sprue sufficiently large to keep the runner full, for if this condition is not met, the runner is emptied with consequent loss of pressure and the development of nonuniform flow from the fingers. It is essential therefore to provide for sprue and runner areas at least as great as the finger areas as shown by the RA-FA = 1-1 systems. A somewhat larger runner area should be employed in practice to ensure that flow into the runner is unhindered. Thus, in evaluating the effect of variations in finger size and design in subsequent tests, runners having an area equal to twice the sprue area were used.

Finger Size

The gating systems in Figure 3 illustrate choke control by variations in finger diameters. The diameters varied in one-quarter-inch steps as follows: 0.75″, 0.5″, 0.25″. In each system the sprue-runner ratio was kept constant, SA-RA = 1-2. The sprue-finger area ratios thus varied as follows: SA-FA = 1-2, 1-1, and 1-1/4.

The first geometrically free system (F = 0.75″ diameter, SA-FA = 1-2) caused most of the steel to enter the mold through the outer fingers (Figure 3A) producing swirling turbulence which persisted throughout pouring. In the second system (F = 0.5″ diameter, SA-FA = 1-1) which is just geometrically choking, all of the fingers fed uniformly, indicating a condition of hydraulic choking (Figure 2B) and rolling turbulence predominated. In the last system, which is severely choked geometrically (F = 0.25″ diameter, SA-FA = 1-1/4), all of the fingers fed with complete uniformity (Figure 2C), but with a very high entrance velocity; the streams hit the opposite wall, a distance of six inches. Irregular turbulence resulted from this jet effect and persisted during most of the pouring. A gating system consisting of straight simple elements will thus develop optimum* pressure conditions when the sprue to runner to finger area ratios are 1->1-1. Larger fingers result in free, unequal flow; smaller fingers cause extreme pressurization, and high entrance velocity which may harm the mold.

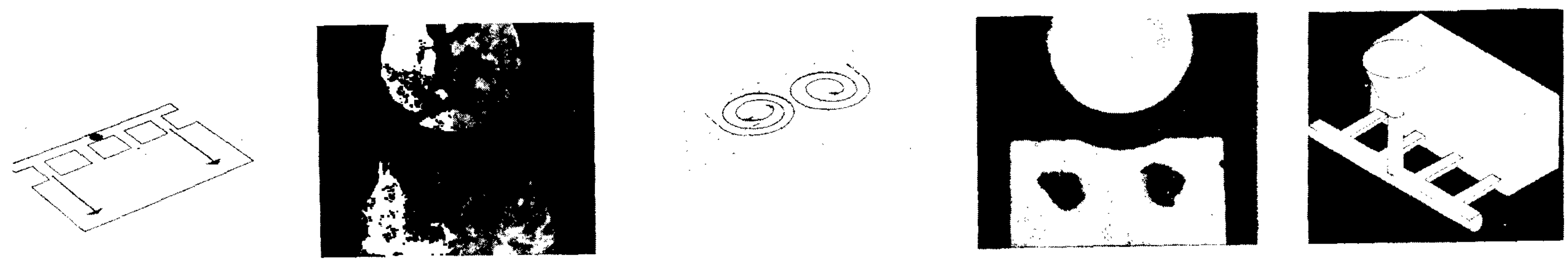
Finger Shape

In the first three groups representing flared, tapered, and streamlined fingers, the finger areas were calculated from the smallest portions of the fingers. In all of the systems in this series the sprue-runner ratio was always one to two, SA-RA = 1-2, and the sprue-finger area ratios varied in three steps as follows: SA-FA = 1-2, 1-1, and 1-1/2.

Flared Fingers - The first systems studied, Figure 4, had fingers which flared out from the runner, i.e., the smallest cross section of the fingers was at the runner and the enlarged portion at the mold cavity. Three finger diameters were used; 0.75″, 0.5″, and 0.375″. The exit ends of the fingers were always 1-1/2″ in width and with a depth corresponding to the respective finger diameters.

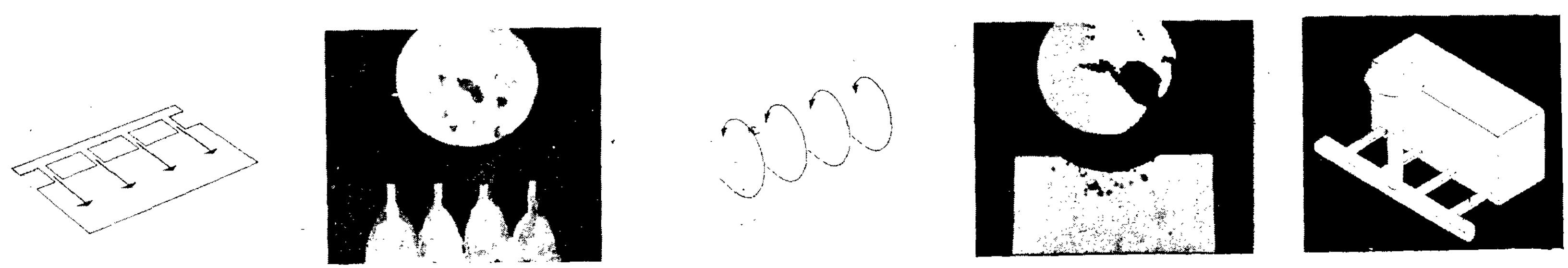
* Optimum pressure condition is defined as a condition of small pressure sufficient to develop uniform flow; pressures greater than this desired minimum act to cause jet flow.

Initial Flow Patterns from Various Gates | Intermediate and Late Stage Flow Patterns | Gating System Producing the Noted Flow Conditions



(A) SWIRLING - Caused by nonuniform flow; **the axis of rotation being perpendicular** to the surfaces of the metal and to the plane of the fingers

Gating System
SA-FA: 1-2

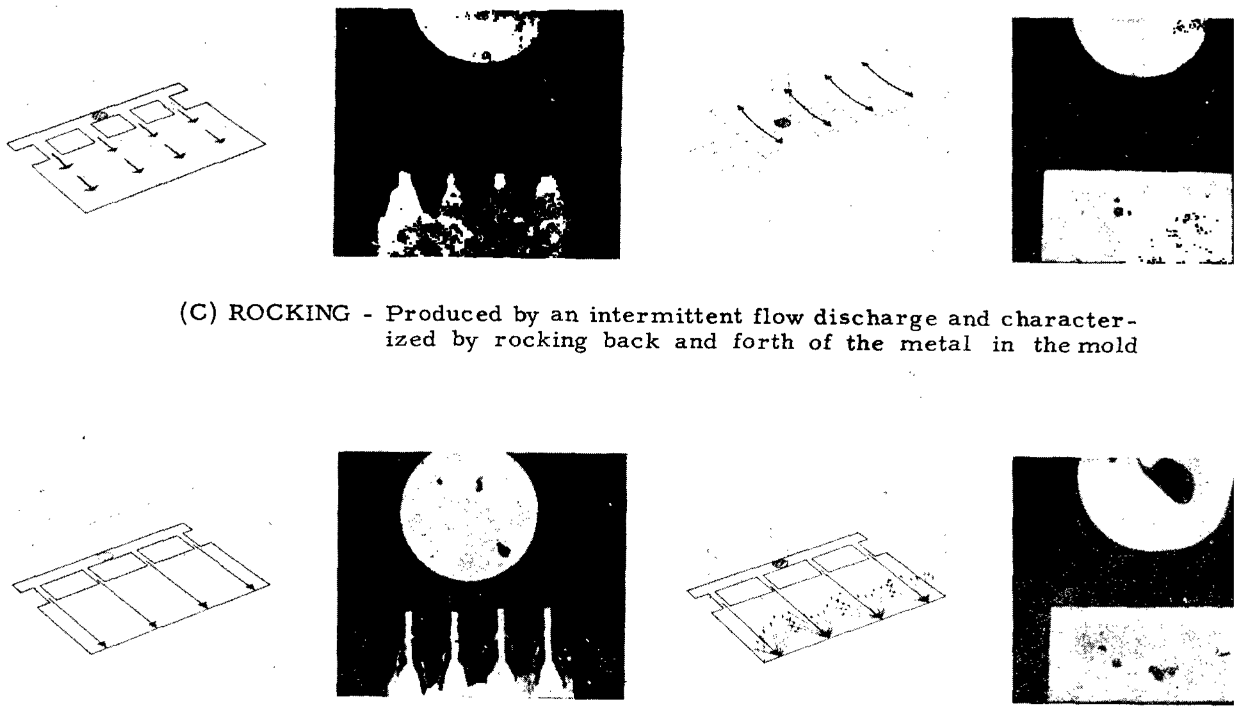


(B) ROLLING - Produced by uniform flow; the axis of rotation of metal within the mold being horizontal and parallel to the plane of the fingers

Gating System
SA-FA: 1-1

Initial Flow Patterns from Various Gates

Intermediate and Late Stage Flow Patteri



(C) ROCKING - Produced by an intermittent flow discharge and characterized by rocking back and forth of the metal in the mold

(D) IRREGULAR - Produced by the high entrance velocities which cause a localized disturbance around each jet issuing from the fingers

Figure 1 - Conditions of mold turbulence

Figure 2A - RA-FA = 2-1

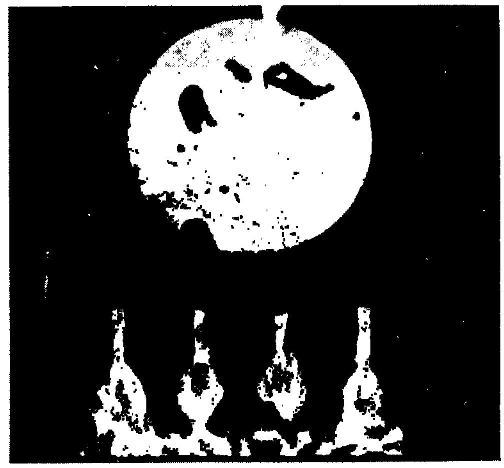


Figure 2B - RA-FA = 1-1

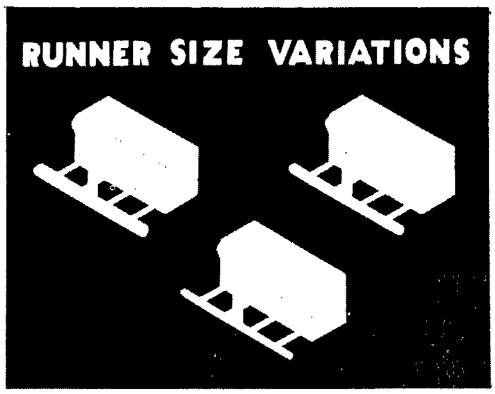


Figure 2

Figure 2C - RA-FA = 1/2-1

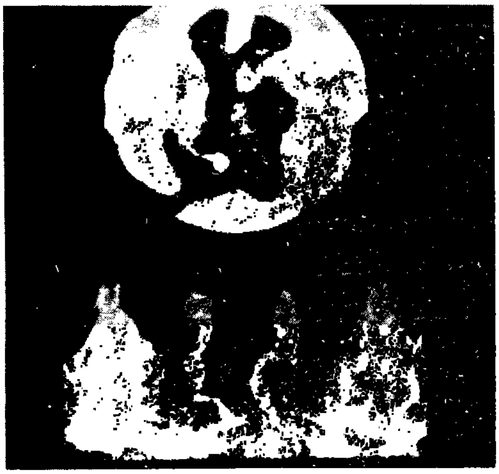


Figure 3A - SA-FA = 1-2

Figure 3B - SA-FA = 1-1

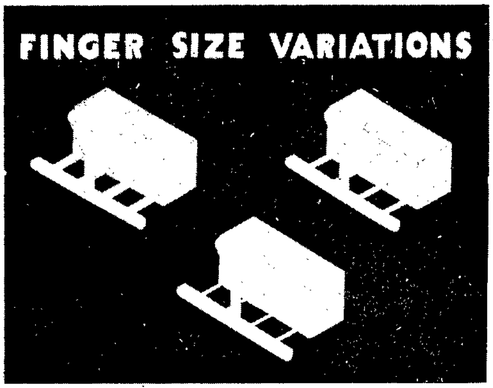


Figure 3

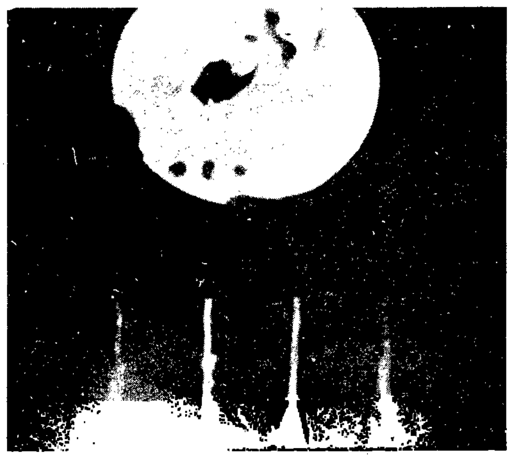


Figure 3C - SA-FA = 1-1/4

Figure 4A - SA-FA = 1-2

Figure 4

Figure 4D - SA-FA = 1-2

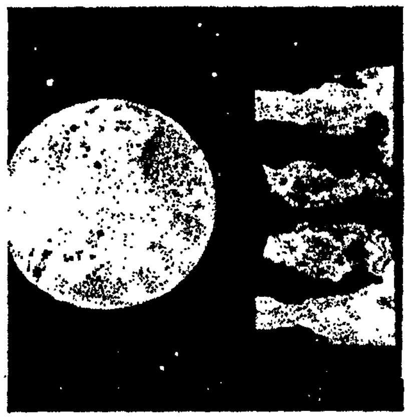


Figure 4B - SA-FA = 1-1

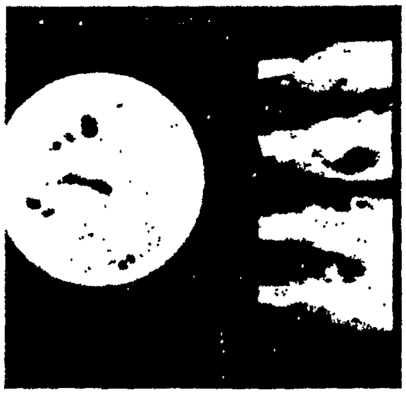


Figure 4C - SA-FA = 1-1/2

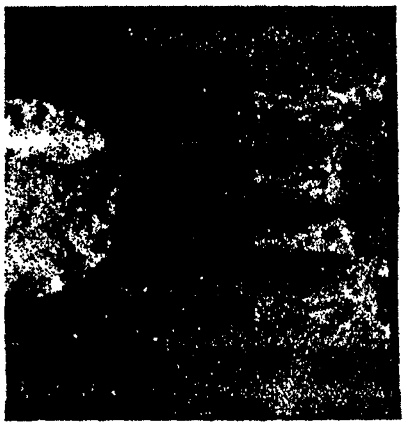


Figure 4E - SA-FA = 1-1

In the first system (F = 0.75" diameter, SA-FA = 1-2) the outer fingers did most of the feeding (Figure 4A) and swirling turbulence was predominant. This was true also, but to a less pronounced extent, with the second system (F = 0.5" diameter, SA-FA = 1-1), Figure 4B. The third system (F = 0.375" diameter, SA-FA = 1-1/2) produced uniform feeding (Figure 4C) throughout pouring.

The effect of increasing the finger length from the usual three inches to six inches was also studied. Increasing the distance in the system in which SA-FA = 1-2 (Figure 4D) did not alter appreciably the uneven flow produced by the system with three-inch fingers. This same increase in length for a system having SA-FA = 1-1 did, however, definitely improve uniformity of flow; in the late stages flow was completely uniform. Flow fro n this system is shown in Figure 4E (compare with 4B).

In systems having SA-FA ratios of 1-1, uniform feeding is obtained when the fingers are straight but not when flared as can be seen by comparing Figures 3B and 4B. Both of these systems are geometrically choked, but only the straight fingers provide definite hydraulic choking. It is thus indicated that the milder choking effect of flared fingers may be compensated for by increasing the length of such fingers relative to the length of the straight fingers. The added friction resulting from increasing the length of the fingers may be considered "frictional" choke.

<u>Tapered Fingers</u> - The gating systems shown in Figure 5 had tapered fingers. These fingers may be considered as similar to the flared fingers studied previously but reversed, so that the smallest cross section of the fingers is at the mold cavity, and the enlarged portion at the runner. In the first system (F = 0.75" diameter, SA-FA = 1-2) the outer fingers fed the most (Figure 5A), and swirling turbulence occurred throughout pouring. In the second system (F = 0.5" diameter, SA-FA = 1-1), the outer fingers again fed the most (Figure 5B), but uniform feeding occurred near the end of pouring. With the third system (F = 0.375" diameter, SA-FA = 1-1/2) all fingers fed uniformly, but with a pronounced jet effect (Figure 5C).

Increasing the distance between runner and casting to six inches in the system in which SA-FA = 1-2 caused no significant improvement in uniformity of flow (Figure 5D). Increasing the distance in a system having SA-FA = 1-1 (Figure 5E) improved flow uniformity, as shown by the changeover from nonuniform to uniform flow at an earlier stage in the pouring. The tendency toward more uniform flow is indicated by comparison of Figure 5B and 5E.

Reversing the direction of flare of the fingers is of only slight benefit in improving flow uniformity, as may be deduced by comparison of 4B and 5B (SA-FA = 1-1 systems). The smaller opening at the casting of the tapered fingers, however, tends to create a detrimental jet effect as indicated by comparison of the SA-FA = 1-1/2 systems, Figure 4C vs. 5C.

<u>Streamlined Fingers</u> - This group of gating systems, Figure 6, had fingers designed to approach streamlined entry of the metal into the mold. The smallest portion of the fingers was midway between the runner and casting.

In the first two systems (F = 0.75" diameter, and 0.5" diameter, SA-FA = 1-2, and 1-1, respectively), a greater quantity of metal entered through the outer fingers (Figures 6A and 6B), and swirling occurred throughout pouring. When the smallest portion of the finger was reduced to F = 0.375" diameter (SA-FA = 1-1/2, Figure 6C), all fingers fed uniformly but with jet effect.

Figure 5A - SA-FA = 1-2

Figure 5

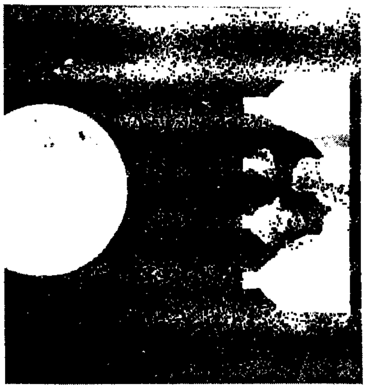


Figure 5D - SA-FA = 1-2

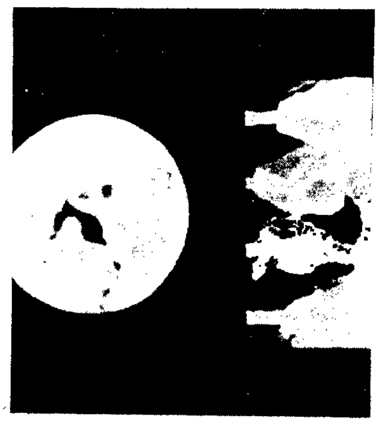


Figure 5B - SA-FA = 1-1

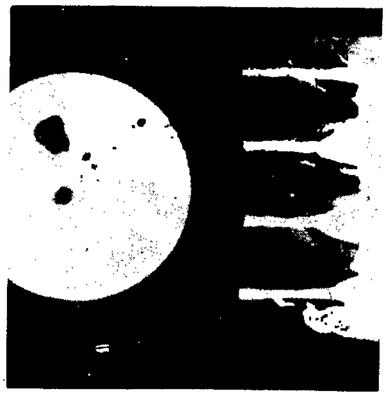


Figure 5C - SA-FA = 1-1/2

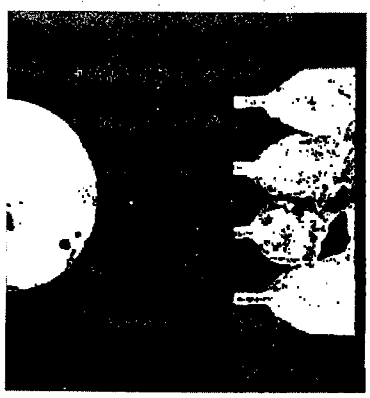


Figure 5E - SA-FA = 1-1

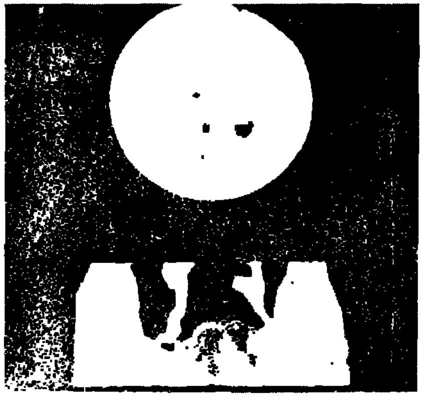


Figure 6A - SA-FA = 1-2

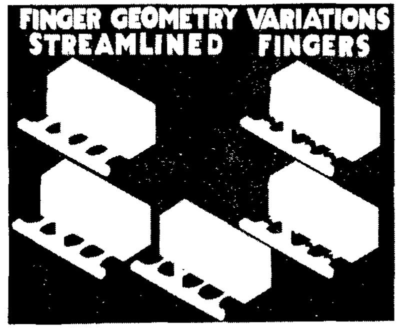


Figure 6

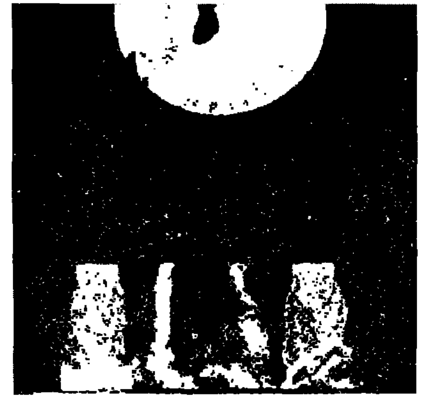


Figure 6D - SA-FA = 1-2

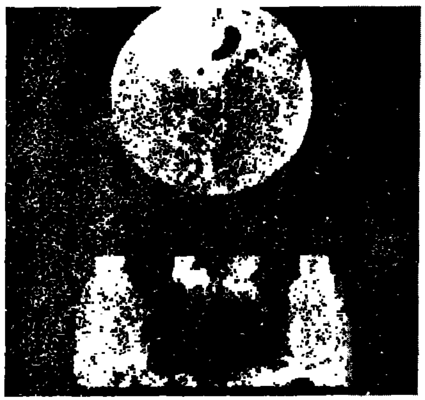


Figure 6B - SA-FA = 1-1

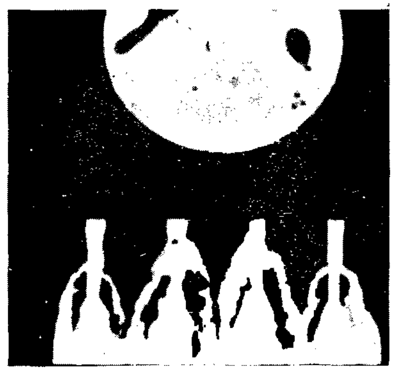


Figure 6C - SA-FA = 1-1/2

Figure 6E - SA-FA = 1-1

Increasing the distance between runner and casting to six inches in a streamlined-finger system (Figures 6D and 6E) was again somewhat beneficial in the system having SA-FA = 1-1, in that it caused flow to become uniform when the mold was only approximately half filled. As was the case with flared and tapered fingers, streamlined fingers offer less flow resistance than straight fingers; hence a more pronounced condition of geometric choking is necessary to cause hydraulic choking.

Rectangular Fingers - The rectangular-shaped fingers (Figure 7), were always one inch wide but varied in thickness to give the desired SA-FA ratios.

The first system, (F = 1″ x 1/2″, SA-FA = 1-2) produced uneven flow at first (Figure 7A) which later became uniform. All of the fingers fed uniformly in the last two systems (F = 1″ x 1/4″ and 1″ x 1/8″; SA-FA = 1-1 and 1-1/2, respectively) of Figure 7B and 7C, but there was a strong jet effect in the latter system which caused an irregular turbulence.

Since systems with rectangular fingers produced partial (late stage) flow uniformity even for geometrically free systems of SA-FA ratios of 1-2, it appears that the maximum finger area which can be tolerated without resulting in nonuniform flow is larger than in the systems with straight, "circular" fingers. Rectangular fingers develop greater hydraulic choking than would be predicted from geometric considerations because of their high surface area to volume relationship, which is a measure of frictional resistance to flow.

SUMMARY AND CONCLUSIONS

Uniform feeding by choke control depends on the development of general pressure in the gating system. Such a condition results in forced flow from all openings into the casting cavity regardless of position or number. To develop such a general pressure condition it is essential that choking be established at the fingers. A choked condition established between runner and sprue serves no purpose except to slow down metal flow. Moreover, pressurization is not extended to the fingers. Accordingly it is best to provide a geometrically free condition in the transition point between sprue and runner. The geometrical choked condition of the system, described as the ratio of the sprue area to the finger area, provides a rough index of the relative liquid transport capacity of the sprue versus the fingers. If the fingers can carry more liquid than the sprue can supply, free flow directed by momentum effects will be developed; such flow is generally non-uniform. On the other hand, if the fingers cannot carry all of the liquid which the sprue can supply, the system becomes pressurized throughout with resulting uniform flow.

Only a slight general pressure is necessary to produce essentially uniform feeding. Such feeding is obtained in parallel-walled fingers when the sprue area and the total finger areas are equal. Too great a general pressure condition, although resulting in completely uniform feeding, is undesirable because it is accompanied by a jet effect which may damage the mold, and also produce an exaggerated turbulence, which, in turn, may result in dross formation and gas absorption. A detailed report of these effects has been issued.[4]

Shape factors can cause the relationship between the geometric and actual choke (hydraulic) conditions to vary. The variations in the critical sprue-finger-area relationships for hydraulic choking are the result of differences in flow resistance in the fingers.

[4] Johnson, W. H., Bishop, H. F., and Pellini, W. S., "Relation of Casting Quality to Gating Practices," NRL Report 3786, January 4, 1951

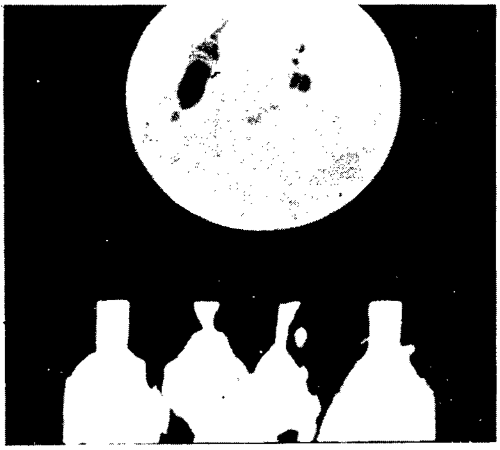


Figure 7A - SA-FA = 1-2

Figure 7B - SA-FA = 1-1

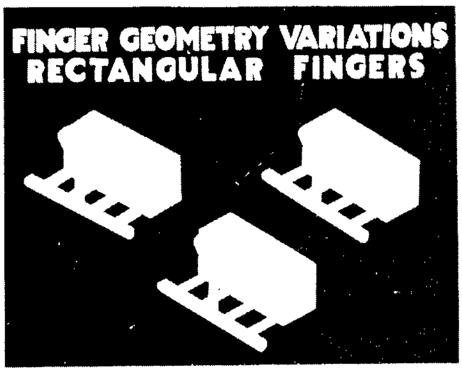


Figure 7

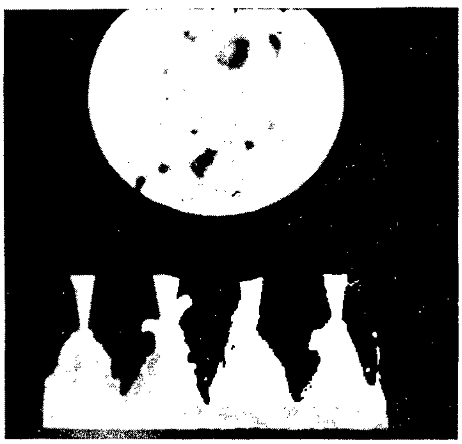


Figure 7C - SA-FA = 1-1/2

This flow resistance, which is equivalent to added choke, may be termed frictional choke. Streamlined, flared, and tapered fingers offer relatively little obstruction to flow. Consequently, very little added frictional choke is provided by such fingers, and systems using such fingers require somewhat greater geometric choking relationship between finger and sprue than would be required for straight-sided fingers. Lengthening the fingers is another means of adding frictional choke.

The functioning characteristics of flared fingers deserve separate mention inasmuch as such fingers are used in practice with the aim of producing fanning of the metal streams. It was shown that the desired functioning of such fingers is difficult to realize in choked multiple-finger systems. Pressurization required for simultaneous flow from all fingers produces sufficient velocity of stream to prevent fanning to the full extent of the flare design. In single-finger systems, pressurization is not a problem; hence low exit velocities requisite for fanning may be obtained with flare designs.

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