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Improvement of Configuration of a Metal Reservoir for Casting with Centrifugation of the Melt

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Abstract—Different designs of metal receivers for casting with melt centrifugation are investigated theoretically and experimentally. It is established that metal receivers of conventional designs with a sharp turn of the flow by 90° do not provide the required mode of filling the mold because of the loss of the initial dynamic force, the sliding of the melt past by the orifices of the collectors, and the appearance of the turbulent flow mode. The configuration of a confusor-type metal receiver, which makes it possible to eliminate the mentioned disadvantages and increase the discharge coefficient to 0.6–0.8, is suggested. The main constructive parameters for this metal receiver are optimized.

Keywords: metal receiver, rotating mold, casting with melt centrifugation, simulation, discharge coefficient, hydrodynamic parameters.

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The element of the gating system (of the cylindrical or conical type) in the axial part of the mold, in which the poured melt is accumulated and subsequently distributed through a radial channel (channels) over the working voids of formation the castings, is usually called a metal receiver in the technology of casting with melt centrifugation (CMC) with the use of an installation with a vertical rotation axis.

The known designs of metal receivers for CMC often do not provide the required fillability of the casting mold and promote obtaining of a considerable percentage of defective castings; therefore, they need improvement. One problem is that the deceleration of the flow rather than its acceleration takes place in a metal receiver of the classical type. The velocity and flowrate of the melt flowing out during centrifugation are often substantially lower than in the steady-state conditions. This is firstly associated with the loss of the initial dynamic force of the jet with the change of motion direction and the turn of the melt flow into a horizontal plane [1]. In addition, as a result of the interaction with the base and walls of a rotating metal receiver, the melt is rotated, which is accompanied by vorticity and spraying, as well as sometimes by splash of metal. Since the directing and stabilizing effect of the centrifugal force on the melt in the axial part of the mold is extremely small, the aggregate exposure of the abovementioned factors leads to passage of the melt by the orifices of collectors [2]. In addition, the melt supplied from this metal receiver into the orifices of radial collectors is in a strongly perturbed and physically nonuniform state. As a result, its motion along the radial collectors proceeds in a forceless pulsed mode, in most cases by a thin jet along one of the walls of the channel. All these factors naturally affect the filling of the casting mold and the quality of castings.

The purpose of this work is to improve the configuration of the metal receiver for casting with melt centrifugation.

Currently, numerous designs of metal receivers are known [3]. In some of them, to improve the fillability of the mold, it is suggested to install distributors of various types in the base of the metal receiver, namely, round, oval, faceted, with blades, etc; in others, it is suggested to change the shape of the internal surface of the metal receiver from round to oval or faceted. Some authors recommend dividing the metal receiver into closed noncommunicated volumes oriented by the number of radial collectors. In these cases, an increase in the flowrate and discharge velocity is, as a rule, accompanied by an abrupt increase in turbulence and physical nonuniformity of the melt, which, as a result, leads to a decrease in the quality of castings.

In order to reveal the main regularities of the melt flow along the channels of rotating casting molds and to improve the configuration of the metal receiver, we performed theoretical investigations and full-scale tests of its different designs and determined the main hydrodynamic parameters of the process. As a result, we developed the configuration of a confusor-type

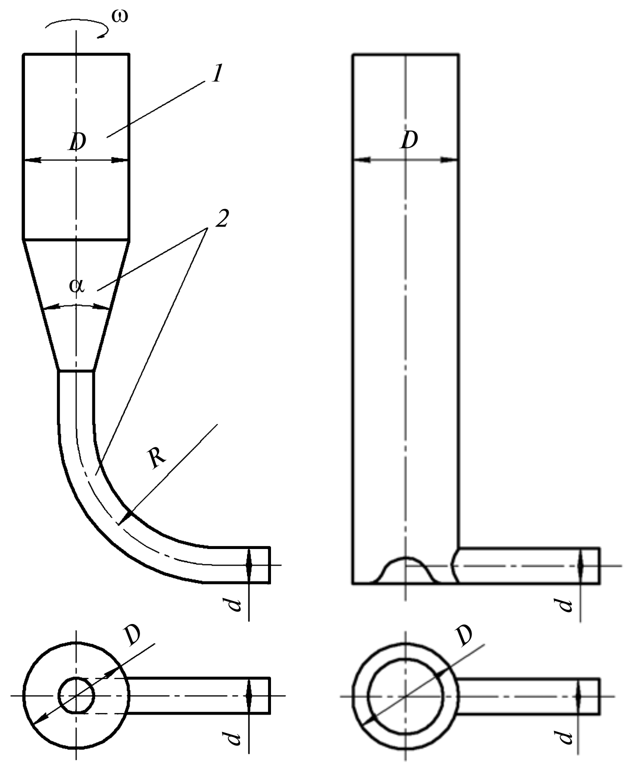

Fig. 1. Metal receivers for casting with metal centrifugation. (a) Confusor-type design and (b) conventional design. (*1*) Receiving void with diameter *D*; (*2*) outlet channel with diameter *d* and turning radius *R* and with a confusor-type head with a conicity angle α.

metal receiver for CMC [4]. This metal receiver (Fig. 1a) prevents the passing of the melt inherent in the overwhelming majority of modern gating systems and, most importantly, promotes the retention of its initial dynamic force, which is necessary to provide favorable flow conditions in the axial part of the mold, where the effect of centrifugal forces is weak and has more likely negative consequences than positive in the absence of an enforced flow.

In the suggested confusor-type design, the melt enters the metal receiver under the effect of the initial dynamic force and flows out of it through the output channel with a steep turn as a unique flow in an enforced mode. The vertical arrangement of the outlet channel completely eliminates passing the melt. A confusor arranged in the base of a metal receiver promotes the increment in the velocity of the flow moving under the effect of the initial dynamic force of the incident jet. This leads to a substantial improvement in the fillability of the molds and an improvement in the quality of the castings. The vorticity in the metal receiver inherent in the CMC process naturally decreases the discharge velocity and flowrate of the melt, but not in the same measure as takes place in the conventional metal receiver.

In this article we present the results of an investigation targeted at improvement of the configuration of the confusor-type metal receiver with a determination of the main hydrodynamic parameters of the casting process via natural simulation with the use of cold fluids.

The main constructive parameters of the confusor-type metal receiver for CMC (see Fig. 1a) are as follows: α is the conicity angle of the head, *R* is the turn radius of the outlet channel, and $h = D/d$ is the degree of narrowing.

Investigations were performed using an installation for the simulation of casting with melt centrifugation with a vertical rotation axis of the mold. To better visualize the process, we used water colored with a white die as the model fluid. A Canon digital camera allowed us to record with a rate of 30 frames per second; this camera was installed on a foot above the rotating mold.

The specified parameters of the process were as follows: the number of revolutions of the mold $n = 0$–800 rpm and the initial flowrate of pouring was 0.278 dm^3/s. The main constructive parameters of the metal receiver varied: the conicity angle of the confusor-type head (α) was from 15° to 60°, the turning radius of the outlet channel (*R*) was from 10 to 50 mm, and the degree of narrowing (*h*) was from 1.6 to 4.9 with the diameter of metal receiver (*D*) from 21 to 49 mm and the diameter of the output channel (*d*) from 10 to 20 mm.

In the course of simulation, we monitored such process parameters as the actual discharge coefficient, and the flowrate and discharge velocity of the melt from the metal receiver. The actual flowrate of the metal receiver was calculated as the ratio of the volume of the poured model fluid to the discharge time from the metal receiver. The actual discharge coefficient (the coefficient of discharge losses) was determined as the ratio of the actual flowrate of the metal receiver to the flowrate upon the discharge of the model fluid from the pouring facility.

The results of our investigations are presented in Tables 1 and 2 and in Fig. 2. As follows from the presented data, the influence of the rotation rate of the mold on the actual discharge coefficient, flowrate, and discharge velocity of the model fluid from the metal receiver is ambiguous. As *n* increases from 0 to 100 rpm, the mentioned controlled parameters decrease, which is explained by the negative influence of vorticity increasing as a result of the action of the centrifugal force in the axial part of the mold. As *n* further increases to 400–500 rpm, the actual discharge coefficient, flowrate, and discharge velocity of a model fluid vary insignificantly. Thus, the use of melt centrifugation in this design of a metal receiver with the rotation frequency up to 400–500 rpm worsens the process parameters when compared with the steady-state conditions. With the further increase in *n* from 500 to 800 rpm,

Table 1. Influence that the conicity angle and turning radius of the channel of the metal receiver has on the actual discharge coefficient

n, rpm	Discharge coefficient at $D = 3$ mm and $d = 10$ mm						
	a, deg				*R*, deg		
	15	30	45	60	10	30	50
0	0.60	0.58	0.55	0.50	0.48	0.50	0.55
100	0.49	0.47	0.43	0.33	0.42	0.45	0.47
200	0.54	0.49	0.36	0.35	0.40	0.49	0.50
300	0.49	0.43	0.43	0.36	0.40	0.42	0.43
400	0.54	0.42	0.39	0.33	0.42	0.42	0.42
500	0.57	0.49	0.45	0.35	0.45	0.43	0.50
600	0.72	0.64	0.51	0.40	0.42	0.54	0.64
700	0.77	0.68	0.60	0.43	0.54	0.60	0.67
800	0.78	0.69	0.61	0.45	0.57	0.61	0.68

Table 2. Influence that the degree of narrowing the metal receiver has on the actual discharge coefficient

n, rpm	Discharge coefficient						
	D, mm (*h*)				*d*, mm (*h*)		
	21 (2.1)	32 (3.2)	42 (4.2)	49 (4.9	10 (3.2)	15 (2.1)	20 (1.6)
0	0.69	0.55	0.545	0.52	0.55	0.64	0.73
100	0.55	0.48	0.41	0.39	0.47	0.54	0.64
200	0.58	0.50	0.42	0.38	0.49	0.51	0.68
300	0.61	0.44	0.44	0.38	0.43	0.51	0.49
400	0.69	0.42	0.42	0.42	0.42	0.49	0.64
500	0.69	0.50	0.46	0.44	0.49	0.57	0.60
600	0.65	0.58	0.52	0.48	0.54	0.60	0.68
700	0.69	0.65	0.58	0.50	0.60	0.64	0.72
800	0.69	0.66	0.61	0.55	0.61	0.65	0.73

the mentioned parameters increase depending on the constructive features of the metal receiver.

The constructive parameters of the metal receiver affect the discharge conditions as follows.

The results of an investigation of the influence of the conicity angle of the metal receiver on the actual discharge coefficient (μ) for various n at constant $D = 30$ mm and $d = 10$ mm are presented in Table 1. It is evident that optimal values $\mu = 0.5–0.8$ were obtained with the use of a confusor-type head with a conicity angle no larger than 30°. At $\alpha > 30°$, the discharge coefficient substantially decreases, which considerably affects the throughput rate of the metal receiver.

The data of Table 1 also allow us to analyze the influence that the turning radius of the outlet channel has on the value of the actual discharge coefficient at various n and the same constant $D = 30$ mm and $d = 10$ mm. It is evident that an increase in radius R provides a proportional increase in the discharge coefficient of the metal receiver, and the highest values $\mu = 0.5–0.7$ were obtained with a ratio R/d no lower than 2.0. However, an excessive increase in the turning radius leads to a substantial increase in the outer dimensions of the metal receiver and the mold in general.

The results of the investigations presented in Table 2 show the interrelation of the actual discharge coefficient and the number of revolutions of the mold for various degrees of narrowing. Optimal values $\mu = 0.5–0.7$ were obtained for a degree of narrowing $h = 1.5–3.0$. A decrease in h below 1.5 leads to a certain increase in μ, but promotes a considerable increase in the outer dimensions of the metal receiver. At $h > 3.0$, a substantial decrease in the discharge coefficient (with the same volume of the poured fluid) and an increase in metal capacity of the metal receiver (while retaining the same force above the orifice of the outlet channel) are observed.

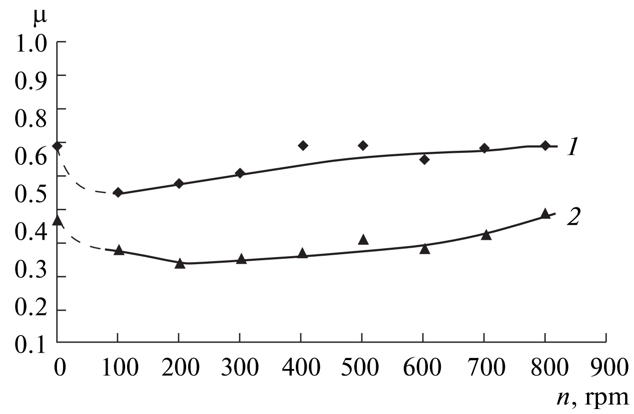

Fig. 2. Comparative analysis of (*1*) confusor-type metal receivers with optimal values of constructive parameters and (*2*) conventional metal receivers with similar sizes of constructive elements.

Using the data of Fig. 2, we can compare confusor-type metal receivers (see Fig. 1a) and those of conventional types (see Fig. 1b) (diameter of the receiving void $D = 21$ mm). It should be noted that the discharge coefficient of both metal receivers upon the rotation of the mold is lower than for the steady-state pouring because of the effect of the centrifugal force in the axial part of the mold, which was already noted previously. However, the confusor-type metal receiver with a steep turn of the flow by 90°, in contrast with the conventional cylindrical metal receiver with a sharp turn of the flow by 90°, provides the most favorable flow conditions, considerably decreases discharge losses, and yields a discharge coefficient that is higher by a factor of 2.

CONCLUSIONS

(i) It is established that metal receivers of conventional designs with a sharp turn of the flow by 90° do not provide the required mode of filling the mold because of the loss of the initial dynamic force, the melt passing by the collector orifices, and the appearance of the turbulent flow mode.

(ii) The configuration of the confusor-type metal receiver is suggested. This configuration makes it possible to eliminate the abovementioned disadvantages and increase the discharge coefficient to 0.6–0.8, which is higher than for a metal receiver of the conventional type by a factor of 2.

(iii) As a result of our investigations, the main constructive features of the metal receiver are optimized; in particular, the conicity angle of the head (α) should be no larger than 30°, the ratio of the turning radius of the vertical channel to its diameter (R/d) should be no lower than 2.0, and the optimal degree of narrowing the head is $h = 1.5$–3.0.

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