ISSN 0036-0295, Russian Metallurgy (Metally), Vol. 2010, No. 6, pp. 544–547. © Pleiades Publishing, Ltd., 2010.
Original Russian Text © M.V. Kolodkin, S.I. Zhul'ev, V.S. Dub, A.N. Romashkin, A.N. Mal'ginov, 2009, published in Elektrometallurgiya, 2009, No. 8, pp. 26–29.

Choice of a Rational Scheme for Casting of a Forging Ingot for Producing Hollow Forgings[1]

M. V. Kolodkin, S. I. Zhul'ev†, V. S. Dub, A. N. Romashkin, and A. N. Mal'ginov

OAO Bummash, VolGTU, OAO NPO TsNIITMASh

Abstract—The solidification of large ingots is simulated, and the results are confirmed in experiments. The application of cold-tapped direct-taper ingots is found to increase the ingot-to-product yield by 7% for the production of hollow billets and to decrease the degree of segregation heterogeneity in an ingot. The total carbon segregation in a cold-tapped ingot is three times lower than that in a comparative ingot.@

DOI: 10.1134/S0036029510060169

OAO Bummash produces steel forgings of a wide range, namely, rings, disks, tubes, shafts, cubes, plates, and so on. The output of hollow forgings accounts for 30% of the total amount of products.

The production of hollow forgings from standard ingots with a dense axial zone is known to be economically irrational, since the metal of the axial ingot zone is removed during piercing.

Therefore, it is a challenging problem for this enterprise to increase the efficiency of the production of hollow forgings by changing the parameters of an initial ingot to increase the efficiency of using a metal.

This problem can be solved by decreasing the volume of the top of an ingot and the motion of a shrinkage hole to its central portion, which can be performed by cooling the upper part of an ingot with a cold top.

A cold top must concentrate a shrinkage hole at the central portion of the ingot and provide a smaller diameter of the shrinkage hole in the cross section of the ingot as compared to the diameter of the axial zone removed during piercing.

To decrease the costs of the introduction of producing ingots of a new type, we used computer simulation and the Crystal software package. In this package, the mathematical simulation of the dynamics of a temperature field and the formation of shrinkage defects during ingot solidification is based on a numerical solution of the equations of the Borisov–Zhuravlev macroscopic solidification theory [1] under given conditions of heat removal from the ingot and the well-known heat capacity and thermal conductivity of a certain steel grade at a given temperature. The algorithm of searching for solutions uses the finite difference method on a grid. The formation of crystalline zones in the volume of a solidifying metal was simulated using an analysis of temperature fields and temperature gradient fields [2, 3].

The simulation demonstrates that the location of a shrinkage hole in an ingot is most favorable when the relative volume of a cooled top part is 7–8%. The placement of the upper end of a mold on a tray provides casting of ingots with direct taper (broadened from top to bottom) and a shrinkage hole diameter that accounts for 22–24% of the ingot diameter. When a mold is placed on a tray to form a reverse taper, the shrinkage hole diameter is 23–27%.

Figure 1 shows the assembly of the casting tool for ingots with a cooled upper part and direct and reverse taper and the simulated relative dimensions of the

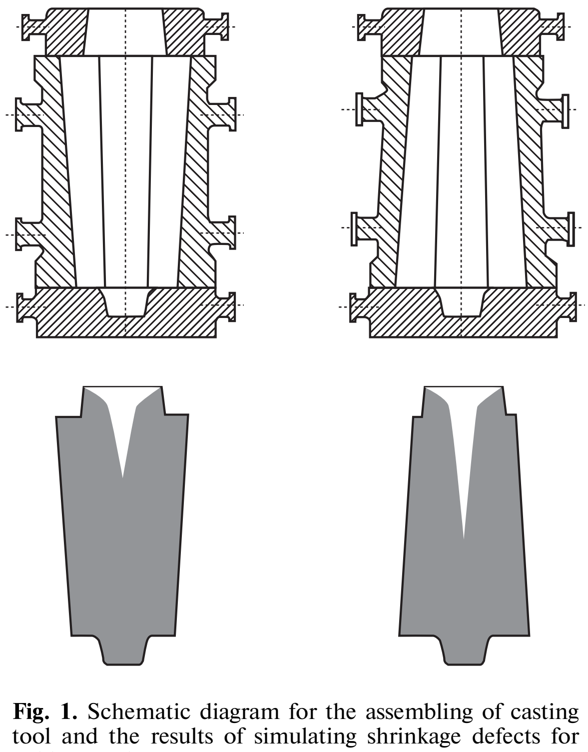

Fig. 1. Schematic diagram for the assembling of casting tool and the results of simulating shrinkage defects for cold-tapped ingots.

[1] The Russian version was not edited.
† Deceased.

shrinkage hole. It is seen that the version with a direct taper (broadened from top to bottom) is most rational among the two versions of casting of ingots with a cold top for the production of hollow forgings, since a shrinkage hole is mainly located in the axial zone in this case.

To check the adequacy of the results of simulating ingot solidification, we cut an experimental direct-taper 2070-kg ingot made of grade 1.2714 steel and cast it into a mold with a cold top (Fig. 2). The ladle sample metal composition during casting was as follows (wt %):

C	Si	Mn	P	S	Cr	Ni	Mo	V	Cu
0.55	0.35	0.73	0.019	0.005	1.06	1.52	0.48	0.09	0.25

The calculated and experimental dimensions of the shrinkage hole agree well with each other (Table 1).

A replacement of a hot top by a cold top of a smaller volume changes the total ingot weight, which ensures its rapid solidification. Moreover, segregation processes are less developed in rapid ingot solidification, which decreases the chemical heterogeneity of the ingot metal and increases the stability of the mechanical properties of the end metal products along their length and cross section.

To compare the chemical heterogeneities of the metals of a standard ingot and a cold-tapped ingot, we analyzed the metal from cold-tapped and hot-tapped steel 38KhN3MFA ingots 1.7 and 1.53 t in weight, respectively.

The hot-tapped ingot contains clearly pronounced regions with positive and negative segregation in the top and bottom parts. The segregation in the cold-tapped ingot is less pronounced (Fig. 3).

The chemical heterogeneity in carbon, sulfur, and phosphorus was estimated on samples cut from templetes of axial plates in the ingots. Segregation coefficient k_i for various elements was calculated by the formula

$$k_i = ([i]_{\min/\max} - [i]_l)/[i]_l \times 100\%,$$

where $[i]_{\min/\max}$ is the minimum (for the calculation of negative segregation) and maximum (for the calculation of positive segregation) content of element i in the ingot metal (%) and $[i]_l$ is the content of element i in the ladle sample metal (%).

The segregation coefficient of elements in the cold-tapped ingot metal is lower than in the hot-tapped ingot metal (Table 2). The total segregation coefficient of carbon in the cold-tapped ingot is three times lower than in the comparative ingot.

The results of computer simulation agree well with the actual dimensions of the shrinkage hole concentrated along the ingot axis, and the cold-tapped ingot metal exhibits higher chemical homogeneity as compared to the metal of standard hot-tapped ingots. Therefore, we implemented the production of cold-

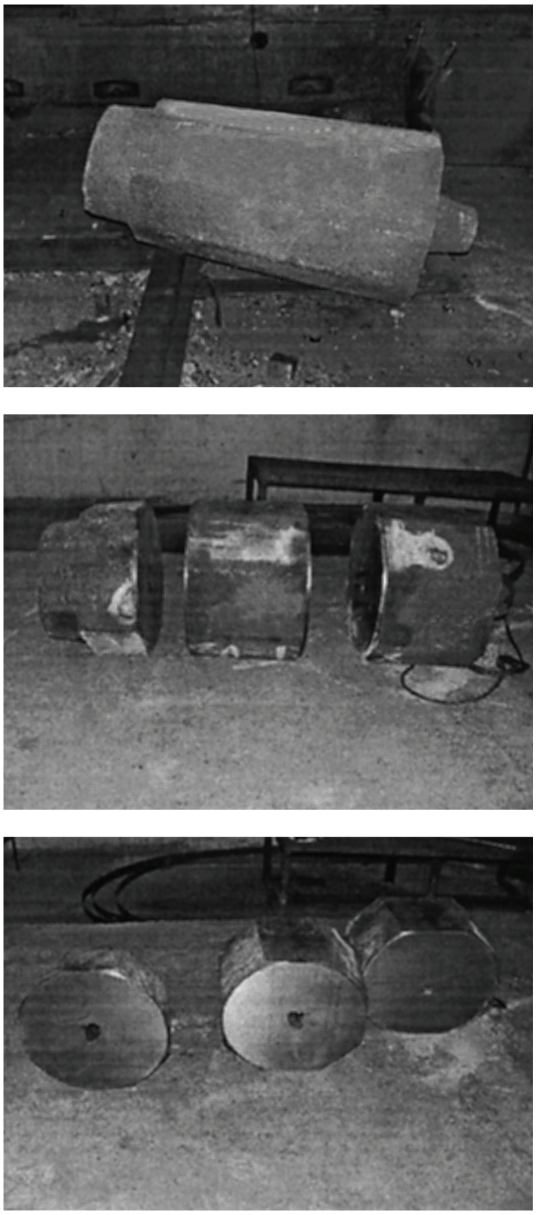

Fig. 2. Sections of a cold-tapped direct-taper ingot 2070 kg in weight.

Table 1. Geometrical dimensions of a 2070-kg ingot and the dimensions of the shrinkage hole

H/D	Ingot taper, %	Relative volume of the top of the ingot, %	Shrinkage hole length, mm		Maximum diameter of the shrinkage hole, mm	
1.8	10	8	@ 611	actual 597	@ 126	actual. 119

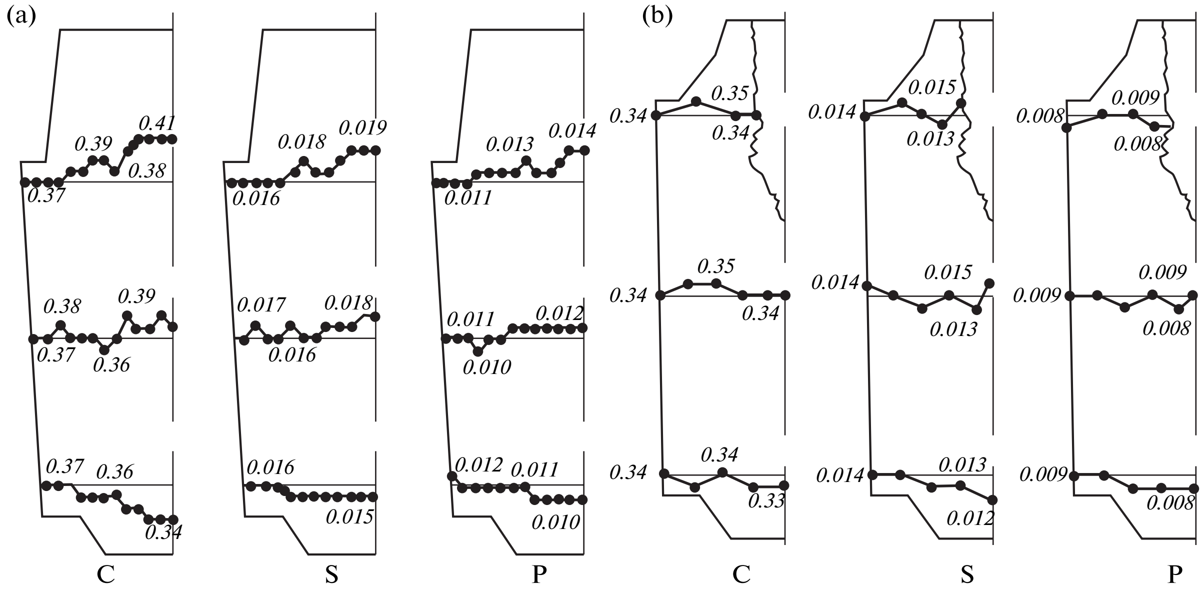

Fig. 3. Distributions of the carbon, sulfur, and phosphorus contents in various horizons of a reverse-taper ingot: (a) hot-tapped ingot 1.7 t in weight and (b) cold-tapped ingot 1.53 t in weight.

tapped direct-taper ingots for the entire range of molds in our enterprise.

Using cold-tapped forging ingots for the production of hollow forgings, we improved the technical and economic indices due to an average increase in the ingot-to-product yield by 7% and saving of heat-insulating materials. Cold-tapped ingots are characterized by high chemical homogeneity, and the assembly of the cast tool for these ingots is less laborious. Casting of ingots does not require a special-purpose range of molds [4].

Table 2. Chemical heterogeneity of reverse-taper steel KhN3MFA ingots

Segregation coefficient, %	A	B
Positive segregation		
carbon	+10.8	+3.0
sulfur	+18.8	+7.1
phosphorus	+18.0	0
Negative segregation		
carbon	−8.1	−3.0
sulfur	−6.3	−14.3
phosphorus	−9.1	−11.0
Σ		
carbon	18.9	6.0
sulfur	25.1	21.4
phosphorus	27.1	11.1

A stands for a hot-tapped ingot 1.7 t in weight;
B stands for a cold-tapped ingot 1.53 t in weight.

CONCLUSIONS

We determined the parameters (geometry and thermal operation of the top) of cold-tapped forging ingots intended for the production of hollow forgings. To cast these ingots, one can use the same range of molds, which is also applied to cast topped ingots with a dense microstructure.

Using cold-tapped rather than hot-tapped ingots and casting of an ingot into a direct-taper mold, we were able to produce ingots with a shrinkage hole concentrated along the ingot axis. The use of a cold tap instead of a lined top decreases the total ingot weight, which decreases the solidification time and, correspondingly, decreases the chemical heterogeneity of the ingot metal.

Using cold-tapped ingots, we increased the ingot-to-product yield for hollow forgings by 7%, saved the heat-insulating materials of tops, and decreased the time it takes for casting tools to be prepared.

REFERENCES

1. V. A. Zhuravlev, *Solidification of Alloys with Heterotransformations* (NiTs Regulyarnaya i Khaoticheskaya Dinamika, Izhevsk, 2006) [in Russian].

1 2. S. I. Zhul'ev, E. I. Buzinov, K. Yu. Bod, et al., "Simulation of the State of Stress in Steel Ingots during Solidification," Stal', No. 7, 20–22 (2006).

3. V. P. Bagmutov and I. N. Zakharov, "Mathematical Simulation of the Thermal Processes during the Solidification of a Large Steel Ingot," Stal', No. 3, 28–33 (2006).

4. M. V. Kolodkin, "Designing of Forging Ingots for some Types of Forgings in OAO Bummash," in *Proceedings of the VIII Congress (Kuznets-2008) on the State, Problems, and Prospects of the Development of Forging–Pressing Machine Building, Forging–Stamping Manufacture, and Metal Forming—Basis of the Machine-Building Complex and the National Safety of Russia, Ryazan', Russia* (OAO Tyazhpressmash, Ryazan', 2008), pp. 274–277.

SPELL: 1. ok