

Figure 3. Dependence of the maximum depth of particle's penetration into the melt from the diameter at different initial velocities

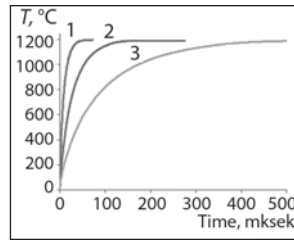


Figure 4. Dependence of the particle's temperature from the time of its being in the melt at different diameters: 1 – 50 mkm; 2 – 100 mkm; 3 – 200 mkm

Using computer modeling the dependences of the maximum depth of penetration of the powder of silicon carbide in the melt (**Fig. 3**) and the kinetics of its heating (**Fig. 4**) from the particles diameter have been found. It is seen that the diameter of the particles and their initial velocity have significant affect on the hydrodynamic and thermal characteristics.

Thus, the mathematical model and the computer program, which allows to determine the important parameters of the process of introduction and dispersion of dispersed and fine-dispersed refractory powders in the molten metal melt for engineering practice have been developed.

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Putting horizontal continuous casting machine into trial operation

In the context of the significant cost of credit resources, construction of giant plants with large metallurgical aggregates becomes quite costly event. The new principles of creation of less capital-intensive metallurgical complexes with shortened technological cycles and greater maneuverability succeed. In recent decades, a greater interest has been shown in the creation of mini steel plants with an annual production of less than 100 thousand tons, and in some cases - even at the level of 5–30 thousand tons. Currently, pilot enterprise for the production of rods with diameter 6–10 mm of high-alloy steels and special alloys is constructed at the LLC "Ferrotrade" (Beloretsk) plant. By the beginning of 2014 a steelmaking facility was built and construction of the rolling mill had begun. The main technological equipment of the steelmaking facility is represented by midrange induction melting furnace ISTO.45 produced by LLC "SPE Kurai" (Ufa) with capacity of up to 0.5 tons and one-strand HCC produced by LLC "Spetsmash" (Moscow) with Ø60 mm section of the billet.

Key words: horizontal continuous casting, rolling, high-alloyed steels, special alloys, mini-metallurgical production, tundish, withdrawal, moulds.

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In the context of the significant cost of credit resources, construction of giant plants with large metallurgical aggregates becomes quite costly event. The new principles of creation of less capital-intensive metallurgical complexes with shortened technological cycles and greater maneuverability succeed. In recent decades, a greater interest has been shown in the creation of mini steel plants with an annual production of less than 100 thousand tons, and in some cases - even at the level of 5-30 thousand tons.

Construction of a mini-metallurgical production requires addressing a number of specific issues related to the complexity of metallurgical production with the steel furnaces of small capacity, when there are no conditions for casting "ladle to ladle". Or, for example, those related to the need to use existing industrial buildings in order to reduce capital costs, which imposes restrictions on the size of the equipment. To reduce the weight and capacity of the rolling equipment, an optimization of billet section is required, that usually means the need to reduce it.

Horizontal continuous casting machine (HCC), whose characteristics are in good agreement with a small

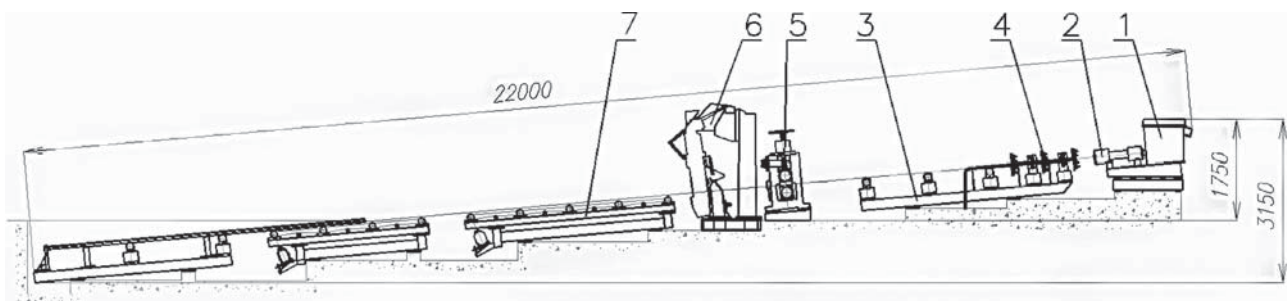


Fig. 1. Scheme of horizontal continuous casting:

1 — tundish; 2 — mould; 3 — secondary cooling chamber; 4 — sprayers; 5 — withdrawal machine; 6 — shears; 7 — runout table & cooling bank

technology industry [1], can play a significant role in addressing these and other problems.

Currently, pilot enterprise for the production of rods with diameter 6–10 mm of high-alloy steels and special alloys is constructed at the LLC “Ferrottrade” (Beloretsk) plant. By the beginning of 2014 a steelmaking facility was built and construction of the rolling mill had begun. The main technological equipment of the steelmaking facility is represented by midrange induction melting furnace IST0.45 produced by LLC “SPE Kurai” (Ufa) with capacity of up to 0.5 tons and one-strand HCC produced by LLC “Spetsmash” (Moscow) with $\text{Ø}60$ mm section of the billet.

Planned capacity is 3000 tons of products per year.

It should be noted that it is the application of the horizontal machine for metal casting that, to a large extent, made possible the creation of an independent metallurgical plant with such low productivity.

Overall dimensions of the machine allowed placing steelmaking facility in an existing building with dimensions of 42×24 m in plain view and 7.0 m in height. A minimization of the billets cross-section allowed to apply a compact rolling mill (one three-roll stand 450 and eight two-roll stands 250) and a device for winding. The size of rolling area in the newly constructed shop is only 60×12 m.

Feature of the work performed by LLC “Spetsmash” is that a continuous casting machine of steel using billets with extremely small cross-section ($\text{Ø}60$ mm) was introduced. Anyway, so far, the sources had information only about as small cross-sections of billets as 75×75 mm [2], and 60×80 mm [3]¹.

HCC diagram is shown in **Fig. 1**. Specifications are listed in **Table 1**.

Mould is tightly connected to the working volume of the tundish. **Fig. 2** shows the connection node. The main element of the node is a break ring of boron nitride (BN), designed to fix the position of the starting point of billet crystallization.

Billet water-to-air cooling area after a mould is one-zone, with a length of 1100 mm. Water flow is regulated in the range of $0.5\text{--}1.5$ m³/h depending on the casting speed. Air flow rate varies in a wide range allowing for

¹ Here we have in mind only the billets produced in facilities with shell-mould relative sliding.

Table 1. Main specifications of HCC

No	Name	Specification
1	Number of strands, pcs	1
2	Cross-section of billets, mm	$\text{Ø}60$
3	Tundish, capacity, kg	300
4	Mould: - type - length, mm, - cooling water flow rate, m ³ /hour	tube 800 45
5	Secondary cooling: - type - water flow rate, m ³ /hour - air flow rate, nm ³ /hour	spray, water-to-air up to 1,5 up to 50,0
6	Withdrawal machine, - type - drive - casting velocity, m/min - billet withdrawal method - frequency of cycles, min ⁻¹	two-roll windrawal device servomotor, 30 kW up to 5 periodic 10 ... 120
7	Dimensional cutting device: - type - working pressure hydro, MPa - cutting force (max), kN	hydraulic pendulum shears 25,0 980
8	HCC dimensions, m: - technological length - overall length - height to tundish top	6,0 22,0 1750

achieving “water-air” flow rate in the interval of 1:20 to 1:100.

Billet withdrawal machine consists of a two-roll withdrawal device with a spring clamp of the upper roller, gear with the distribution of the torque to both the rollers, and a servomotor. Billet withdrawal is carried out in a “pull-pushback-pause” way. To achieve a clear backward running a gear is made with no gaps in the toothing. **Fig. 3** shows an oscillogram for the most dynamic mode: casting speed — 5 m/min, frequency of cycles — 120 min⁻¹. A good agreement between preset and the actual rotation speed of the drive shaft of the servo motor should be noted. Deviation does not exceed 5%.

To ensure consistent quality of the billet surface, it is important to maintain a predetermined stroke length, time of windrawal stroke and a pause at each cycle,

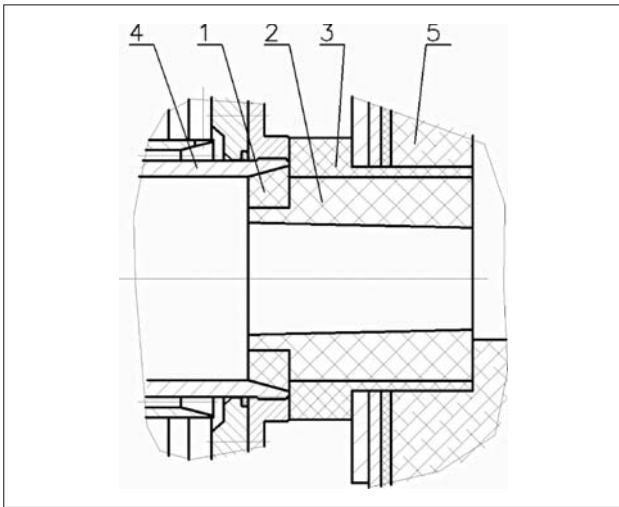


Fig. 2. Tundish-mould assembling device:
 1 — break ring; 2 — refractory tube; 3 — refractory mass; 4 — thin-walled tube of the mould; 5 — tundish

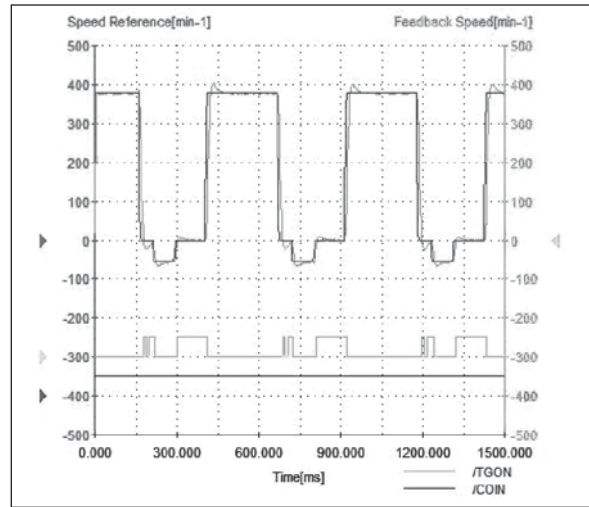


Fig. 3. Oscillogram of the drive shaft speed

which is achieved with the help of the adaptive control system. Its operating principle is to compare the actual parameters with preset ones. In the event of deviation of the actual parameters, the system will adjust the rotation speed and start time of braking of the servo motor shaft in the next cycle of stroke.

It should be noted, that HCC «Spets-mash» at the LLC «Ferrotrade» plant is a new type of technological equipment. At the hot testing of the HCC it was necessary to run testing of mechanical equipment and control system, and, at the same time, adopt new technology for continuous casting. Therefore, for first castings well-mastered low-alloyed steel 35GS was used (analog to DIN488 — BSt420S).

To make steel a passport scrap was used. Ladle lining and tundish were warmed by gas burners to the temperature of the working layer 800–900 °C.

Technological problem of hot testing was to identify patterns of initial stage of billet shell crystallization and to achieve stability in the casting process without breaking of shell in the early part of crystallization.

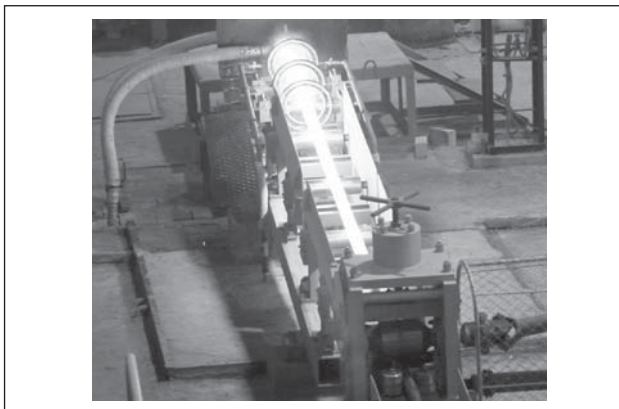


Fig. 4. Casting of steel in the HCC

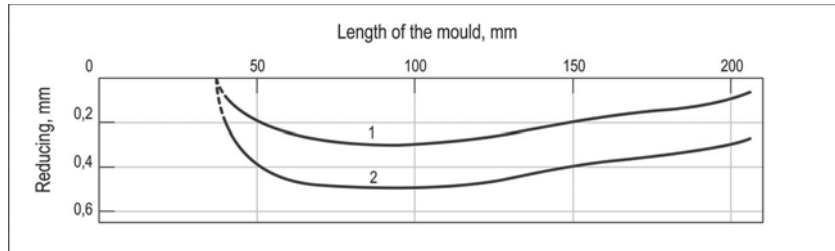


Fig. 5. Residual deformation of the tube:
 1 — after 10 castings; 2 — after 20 castings

In first series of test castings (Fig. 4) it has been found that the stability of the process increases significantly with increase of casting velocity and decrease of time of withdrawal stroke cycle. This, at first glance, an illogical conclusion is explained as follows.

Thin-walled tube of the mould, made of copper alloy, experiencing in the casting process high heat load undergoes elastic-plastic deformation resulting in a narrowing of the cross section in the initial section. Fig. 5 shows the residual deformation of the tube after several casts.

Formation of a billet shell in a mould of HCC occurs in the conditions of pressure of the liquid metal caused by its level in a tundish, and absolute value of billet's shrinkage is the extremely insignificant when cooling. Therefore it is possible to speak about tight contact of the shell with a working surface of the mould. Thus, to pass through the narrowing the shell has to be significantly deformed. It is obvious that with decrease of casting velocity and increase of a cycle time the thickness and, respectively, durability of a shell will grow that can lead to jamming it at pass of narrowing of a tube. With increase of casting velocity and decrease of a cycle time the thickness of a shell decreases that facilitates its deformation in a narrowing place. It was found by practical consideration that stability of the process comes at a casting velocity of 4,0 m/min and cycle time of 1,0 s.

In this regard it should be noted that HCC start which is carried out with a lowered speed appears to be the most

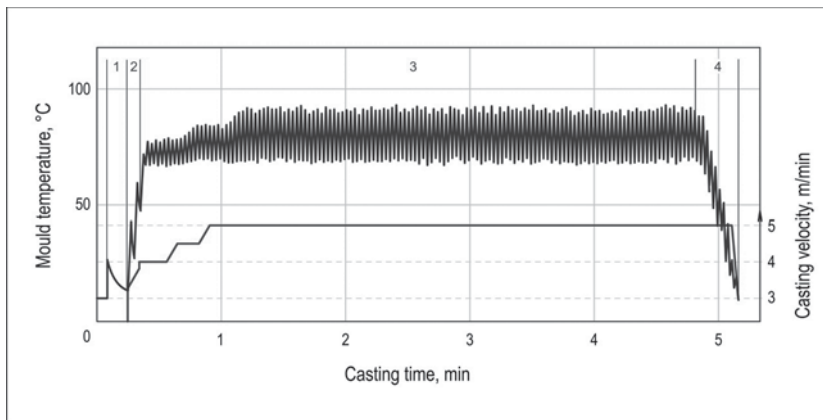


Fig. 6. Schedule of outer mould tube wall temperature

difficult moment in casting. To overcome the feature described above, the decision was made on the contrary, to considerably overestimate at start pauses during first two – three pulls, so that shrinkage of the billet would allow it to pass tube narrowing with the minimum effort, then the drive was set on operation casting velocity and frequency of windrawal stroke cycles.

After completion of a hot approbation stage 12X18H10T steel (analog to DIN17440 – X6CrNiTi 18-10) casting was initiated.

Even at first castings of austenitic steel a steady formation of billet was achieved. Breaking of shell in a mould and breakthrough of liquid metal behind a mould didn't occur.

Control of a casting process was exercised according to indications of sensors of temperature of a mould tube wall in an early part of billet formation. At the stable process the indications of the sensor represents a curve with periodic fluctuations about an average value T_{sr} with amplitude of ΔT . Values T_{sr} and ΔT depend on casting velocity and frequency of withdrawal stroke cycles. The period of fluctuations has to correspond accurately to a time of withdrawal stroke cycle. Sharp reduction of T_{sr} and ΔT together with the change of the period of temperature fluctuations at invariable parameters of casting indicates about breaking of part of a billet shell in the mould.

Fig. 6 shows a characteristic schedule of outer mould tube wall temperature. After filling a mould (part 1 of the schedule) and several starting pulls with a lowered speed (2) drive of the stroke mechanism is set to an operating mode (3). The end of a process (4) is characterized by decrease in average temperature of a tube wall, caused by a fall of metal level in the tundish.

Casting of austenitic steel was performed at the following parameters:

- metal overheating above temperature liquidus, degree C – 20–40;
- casting velocity, m/min – 4,0–5,0;
- frequency of windrawal stroke cycles, min^{-1} – 60–75;

- stroke length, mm – 40–80;
- time of windrawal stroke cycle, s – 0,2–0,25;
- pause time, s – 0,6–0,75;

It should be particularly noted that, both at a stage of HCC hot sampling, and upon its transition to trial operation there were no external longitudinal cracks fixed on the billet. It is very important result because when casting billets of round section the probability of formation of longitudinal cracks is rather high. Nevertheless, this result was expected as at horizontal continuous casting of metals high uniformity of the shell cooling is provided because of

dense contact of the shell being formed with a mould, which reduces ovality of section and, a tendency to a cracks formation decrease respectively.

Putting HCC into trial operation at the LLC «Ferrotrade» plant should be recognized as successful. Development of technology of casting with a frequency of cycles – 90–120 min^{-1} that will allow rolling high-alloyed billets without cleaning the surface will be the immediate task of LLC «Spetsmash».

After commissioning of experimental plant LLC «Ferrotrade» in full strength (with the rolling mill) basic possibility of a construction of independent metallurgical mini-plants for release of light-section rolling production from alloyed and high-alloyed steel, and also from special alloys with the annual program of release at the level of 3,0–30,0 thousand tons will be almost proved.

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