Improving the Cross Section of Continuous-Cast Billet

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Abstract—The introduction of new billet configurations ensuring high quality on initial formation in the mold is considered. These configurations also promote temperature and deformation conditions that stabilize the quality of the billet and subsequent rolled product.

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The production of continuous-cast billet with a traditional rectangular cross section is associated with the corner effect, as a result of the superposition of the heat-transfer fields from adjacent faces [1]. This leads to significant temperature nonuniformity within the billet cross section and, correspondingly, to nonuniform solidification and thermal shrinkage of the ingot. We know that, when casting billet with rectangular and round cross section in the same machine in identical conditions, the rejection rate due to macrostructural defects is 3.35 times less for the round billet (0.45%, as against 1.51%) [2]. In addition, the rejection rate due to external cracks and near-surface bubbles is four times less for round billet (0.05%, as against 0.20%). Hence, axisymmetric billet without the corner effect is promising in terms of stable high quality. Thus, optimization of the billet cross section is of great importance, in order to expand the potential for increasing and stabilizing the quality of continuous-cast billet.

Simulation of the thermal state of cast billet shows that rounding the corners of the mold’s working-cavity cross section with an arc of optimal radius results in a significantly more uniform temperature field of the cast billet [3]. Moreover, this creates conditions for uniform solid-phase growth and the production of uniform crystalline structure over the perimeter of the solidification front, without corner liquidational bands (no solidification triangles are formed), and for uniform shrinkage of the cross section over the mold perimeter. As a result, a favorable stress–strain state with guaranteed macrostructure quality is created, as well as ideal conditions for uniform distribution of the technological lubricant (slag-forming mixture) over the mold perimeter, which permits confident prediction of high surface quality of the billet. The stability of casting is significantly increased on account of improved billet slip and the virtual elimination of snagging of the billet and subsequent rupture of the liquid phase.

In casting billet with a traditional (rectangular) cross section, primary thermal impact in the upper part of the mold is associated with active shrinkage; the corner of the ingot surface practically always moves away asymmetrically from the working surface of the copper mold plates. The asymmetric loss of contact between the billet and the working surface of the copper plates is responsible for the appearance of geometric distortions at the cross-section perimeter, which is often seen in square billet as rhombic distortion. The technological lubricant flows copiously into the gap that forms. As a result, the rapid restoration of effective thermal contact becomes problematic. Therefore, in the upper part of the mold, cooling of the corner region of the cross section is incomplete, and the thickness of the crust in this zone is less than the mean value for the billet cross section (Fig. 1a). In continuous casting of rectangular billet, there is practically always a nonuniform distribution of the technological lubricant over the mold perimeter. This destabilizes the casting processes and the surface quality of the billet.

Numerous experimental and industrial studies have shown that the corner of the cross section is supercooled at the exit from the mold and in the secondary-cooling zone. In the corner, low-temperature isotherms move toward the surface, while the thickness of the solid phase is markedly greater (Fig. 1b). It is also obvious that in the corner (in contrast to most of the cross section) all the structural transformations occur in the range 600–950°C.

![Fig. 1. Temperature field (°C) of solidifying billet with rectangular cross section.](image)
Therefore, in casting billet with a rectangular cross section, the structural inhomogeneity of the metal is inherited and is due to the traditional billet shape. Technologies exist for temperature improvement in the thermal state of rectangular billet: for example, screening or heating of the edges. Such methods call for additional capital and energy outlays.

The need to ensure high billet stability arises and is largely addressed in the first stage of billet formation (in the mold). Instability in the quality of continuous-cast billet is largely due to instability in the casting parameters and the channel dimensions in the casting machine (primarily the mold dimensions).

Consider the wear characteristics of the working surface of copper plates in a mold, when wear is concentrated in the corner of the shaping cavity (in molds for slab production, mainly on the narrow side, in contact with the small billet face), as a result of the cutting effect of the sharp edge of the supercooled billet. The channel depth attained (2.5–3.0 mm) determines the period between mold repairs; it depends greatly on the operating conditions and primarily on the selected working-plate material and the sequence of melts. Note that the mean life of block molds (in standard form) is 50–80 melts; when the copper plates are equipped with wear-resistant inserts, the life increases to 130–200 melts. On applying special coatings, it increases to 400–1000 melts. The increase in working life is accompanied by impairment of the guaranteed surface quality and also by rapid increase in the probability of snagging of the cast billet and subsequent rupture of the liquid phase. Despite the slight wear, the mass losses in repair (shaping) of the plates are relatively large, since the thickness of the layer removed (in standard conditions) is determined by the channel depth.

According to audits of the life of existing molds, the wear of the working surface of the copper plates depends greatly on the conical shape (the basic adjustment parameter) and the sequence of cast melts. The maximum wear is concentrated in the corner, especially at the lower end of the lateral (small) face. Thus, the first important argument for rounding the corners of the mold cavity is to prevent such wear localization. In casting billet with rounded edges, the wear of the working surface of the mold corners approaches the wear in the middle of the lateral face with increase in rounding radius. In other words, it is reduced by a factor of 4–6. On this basis, we may confidently predict an increase in mold life by a factor of at least 2–4. An equally important argument for improving the mold cross section follows from analysis of the stability of the conical shape. Research on the operational stability of the mold dimensions shows that the conical shape falls outside the tolerances in practically every fourth measurement. Inverse conicity is found in about 6% of cases. Note that, with such dimensional instability of the mold’s working surface, there is a very high probability of rupture of the liquid phase (especially in the case of inverse conicity). Instability of the slab cross section in rolling is also observed here.

The creation of a new mold structure is based on the idea of improving the billet’s thermal state by improving its shape. This permits the creation of billet that will interact with the equipment and the surroundings in an energy-saving manner from the earliest stages, with improved casting stability, billet quality, and equipment life.

On the basis of the foregoing, a new mold design has been developed [4]. The distinguishing features of this design are as follows: construction of the lateral copper plates from U-shaped modules; rounding of the internal corners of the modules by a second-order curve; rigid attachment of the lateral modules and copper plates; conical shaping to match the actual shrinkage of the solidifying billet; use of thermal-compensation units for the working plates.

The new mold is rigorously adjusted initially and does not require further adjustment during operation. Monitoring of the mold is undertaken when the continuous-casting machine is shut down: the state of the working cavity is visually evaluated; and the wear is measured, along with the gaps and tightening of the lateral-module attachment.

In the new approach to the continuous-casting machine and the rolling mill, the goals are to ensure stability of the casting process with high billet quality, on account of more uniform temperature field and more uniform structure of the metal, and to improve mold stability. These goals are met by optimizing the billet shape. The optimal rounding radius is found by ensuring sufficient strength of the solid framework over the billet cross section, without the formation of the solidification triangle typical in the solidification of rectangular billet (Fig. 2a). Increasing the rounding radius of the cores improves the thermal state of the solidifying billet and radically improves the structural uniformity of the solid phase that forms. The geometry of the solidification front (Fig. 2b) is then characterized by uniform growth of the solid phase over its whole perimeter, without dendrite growth from the solidification fronts of adjacent faces (lines AL, AK, and BM, BN in Fig. 2a).

Only one growth line AB of the solidification fronts is present here, in the form of an axial-liquation band. Because of the decrease in size of the supercooled solid phase with increase in rounding radius, the cross section of the solid framework loses its mechanical strength. Taking account of this constraint, the radius must be determined against the background of geometric stability of the billet cross section with rounded edges, especially in the bending zone. Since the plastic limit at high temperatures is very temperature-dependent, the optimal rounding radius is determined from the results of mathematical simulation on the basis of