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Cyclic-Deformation System for the Reduction of Continuous-Cast Slabs

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Abstract—Introducing systems capable of profound reduction in a casting and rolling module improves the product quality, on account of the intense working of large continuous-cast slabs over the whole cross section and the production of uniform fine-grain structure of the metal, and also increases the cross section of continuous-cast billet. Analysis of the formation of nonmetallic inclusions and segregation in the axial zone of the thick rolled sheet is followed by analysis of the nonuniform deformation over the slag height in the reduction of large continuous-cast slabs at the 5000 mill at OAO Magnitogorskii Metallurgicheskii Kombinat. The structure of a cyclic-deformation system for preliminary deformation of large continuous-cast slabs is described, and its capabilities are explored. Hammers for preliminary deformation of large continuous-cast slabs are considered. Experimental data are presented for the deformation of continuous-cast steel 45 and 12Kh18N10T steel billet. The structure of the continuous-cast billet is assessed in the course of reduction on the cyclic-deformation system. The basic parameters of the system for preliminary deformation of large continuous-cast slabs are determined. The capabilities of the cyclic-deformation system are outlined in terms of increase in sheet quality. On that basis, the use of the cyclic-deformation system in the continuous-casting line for preliminary reduction of large continuous-cast slabs is recommended: it permits matching of the speed of continuous-casting and cyclic-deformation processes; and ensures 45–90% reduction in a single pass so as to obtain well-worked cast structure over the whole slab cross section. When using the cyclic-deformation system in the continuous-casting line, the continuous-cast slabs are reduced by means of the heat of the cast metal, thereby greatly reducing the energy consumption in billet production. The cyclic-deformation system may be used with thick-sheet and broad-strip mills for preliminary single-pass reduction of the hot slab, with improvement in sheet quality and reduction in the number of passes in the mills.

Keywords: cyclic-deformation system, hammers, rollers, rolling mill, continuous-cast slab, billet quality, billet structure, rolling defects

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In rolling, the development of profound-reduction systems in casting and rolling modules is of great interest for preliminary deformation of the continuous-cast slabs so as to obtain high-quality billet for sheet and bar mills. Thus, globally, the development of systems with profound reduction is associated with rising quality standards for rolled steel, the creation of integrated continuous-casting and rolling processes, and the need for plastic machining of materials that are of low plasticity and are hard to deform [1–9]. The use of profound-reduction systems in casting and rolling modules improves product quality on account of the intense working of large continuous-cast slabs over the whole cross section, permits the production of uniform fine-grain structure of the metal, and also increases the cross section of continuous-cast billet.

The preliminary deformation of large continuous-cast slabs is necessary at the 5000 mill at OAO Magnitogorskii Metallurgicheskii Kombinat. In rolling large slabs (thickness 250 and 300 mm, width 2500 mm) on a four-roller mill, the deformation is very nonuniform over the slab height: the surface layer is greatly deformed, whereas practically no deformation occurs in the central zone. That results in nonuniform structure [7–9]. With nonuniform structure over the thickness of the rolled strip, the distribution of mechanical properties will also be nonuniform: better properties at the surface and poorer properties in the core. Thus, in

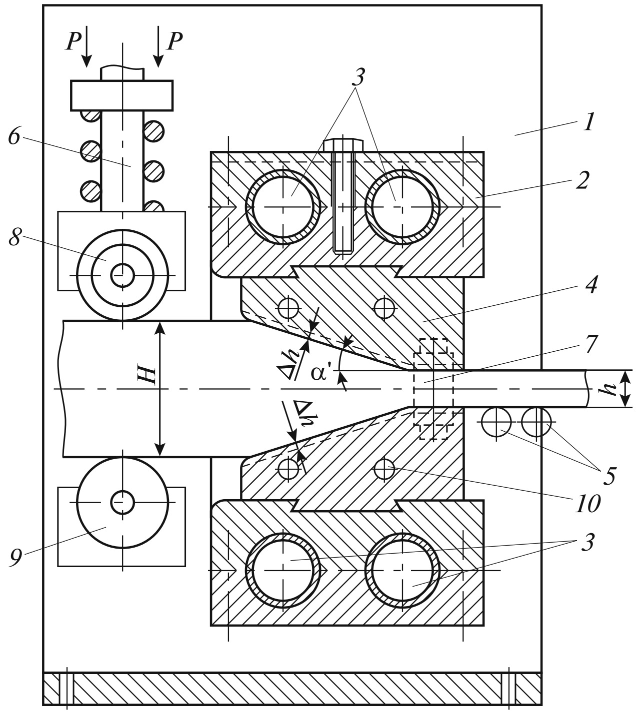

Fig. 1. Cyclic-deformation system: (*1*) frame; (*2*) upper and lower supports; (*3*) eccentric shaft; (*4*) working hammer; (*5*) guide roller; (*6*) clamping mechanism; (*7*) nondriven vertical roller; (*8*, *9*) rollers of the feeder unit; (*10*) cooling channel.

rolling thick strip, the cast structure of the metal will not be adequately worked in the axial zone of the slab. The nonmetallic inclusions and segregations will run along the rolling axis of the metal, with decrease in the physicomechanical properties of the rolled product [10–21]. Accordingly, when large continuous-cast slabs (thickness 300 mm) are rolled on the 5000 mill, the degree of reduction in the first nine roughing passes is 10–15%.

To improve the quality of thick sheet, preliminary deformation of large continuous-cast slabs under the action of high compressive stress is required. That will facilitate the working of the cast metal over the slab thickness and the production of uniform billet structure for subsequent rolling in the thick-sheet mill. A cyclic-deformation system may be effectively used for that purpose [1–6, 22].

As shown in the Fig. 1, the cyclic-deformation system includes a frame *1* and also upper and lower supports *2*, each of which is mounted directly on two synchronously rotating eccentric shafts *3*. The shafts are turned by an electric motor, through a synchronizing gear system. The upper and lower working hammers *4* are attached to the upper and lower supports *2* through a dovetail joint and a wedge unit. The hammers move synchronously over a closed trajectory. That permits simultaneous cyclic deformation and of the billet and its motion along the deformation zone. For shafts with eccentricity $e = 5$ mm, each point of the hammer's working surface moves over a circle with radius 5 mm. In other words, the hammers both reduce the billet and move it longitudinally. In one turn of the shafts (a single cycle), the hammers reduce the billet by $2\Delta h = 10$ mm. The longitudinal velocity of the billet is determined by the shaft speed. Therefore, the operator may regulate the speed of the eccentric shafts in accordance with the required productivity.

The working surface of each hammer corresponds to the billet profile and is inclined at an angle α to the strip-supply axis. Selection of α is based on the conditions of strip capture by the hammers. The value of α and the length of the hammer's working section are determined by the necessary reduction in height of the continuous-cast billet, with up to 90% deformation [1]. For example, with slab height $H = 300$ mm and thickness $h = 160$ mm of the sheet blank, the reduction in a single pass is $\Delta H = 140$ mm, while the degree of reduction $\varepsilon = 46\%$.

To boost the quality of the continuous-cast billet, the cyclic-deformation system has a feeder unit consisting of two rollers and a clamping mechanism. Only the lower roller *9* is driven. Nondriven roller *8* is connected to the clamping mechanism *6*. To equalize the lateral faces of the continuous-cast slabs, two nondriven vertical rollers *7* at the calibrating sections of the hammers are employed. Special channels *10* permit water cooling of the hammers.

The basic parameters of the cyclic-deformation system for preliminary deformation of large continuous-cast slabs are as follows:

—$\alpha = 15°$, the inclination of the hammers' working surfaces;

—$e = 5$ mm, the eccentricity of the eccentric shafts;

—$l = 0.3$ m, the length of the hammer's inclined working surface;

—$H_0 = 300$ mm, $B_0 = 2500$ mm, the thickness and width of the continuous-cast slab;

—$h = 160$ mm, the thickness of the sheet blank after cyclic deformation;

—$n = 50$ rpm, the speed of the eccentric shafts;

—$V_{ex} = 1.8$ m/min, the exit speed of the slab from the hammers;

—$P_{max} = 70000$ kN, the maximum deforming force;

—$N = 5100$ kW, the power of the electric motor;

—the system's productivity (320 t/h).

We assess the capabilities of the system and the effectiveness of cyclic deformation both theoretically and experimentally [1, 2, 4, 17].

Theoretical analysis indicates high compressive stress at the contact surface and in the deformation zone; that prevents the opening of surface cracks. In addition, the defects in the contact layer do not reach the billet surface and therefore cannot cause surface cracks [1, 9].

Experiments on cyclic deformation by a force of 3500 kN show that the quality of the continuous-cast billet is improved when the cyclic-deformation system is introduced in the casting and rolling module [1]. This may be attributed to intense working of the slabs' central zone; the production of uniform fine-grain structure of the metal; and the high compressive stress at the contact surface, which prevents the opening of surface cracks, seals defects and pores in the slab's contact layer, and prevents the formation of new defects. In addition, the experiments show that defects in the contact layer do not reach the billet surface and therefore cannot cause surface cracks.

The cyclic-deformation system is produced by AO Uralmash for Omutninsk Metallurgical Plants. Its characteristics are as follows: maximum billet cross section 120 × 150 mm; rate of billet supply to hammer 2 m/min; degree of reduction in a single pass 70–80%; power of the electric motor 800 kW; motor speed 0–300 rpm. The existing design of the cyclic-deformation system for continuous-casting alloy-steel slab proves effective, simple, and reliable in operation [1].

In experiments on the deformation of 30 × 70 mm strip cut from 200 × 1000 mm continuous-cast steel 45 and 12Kh18N10T steel slabs, with 60–70% reduction in a single pass, the change in structure of the metal after reduction is studied, as well as the behavior of the defects at the strip surface and in the contact layers. Pores and defects in the surface layer formed at a depth no greater than 15 mm are sealed in the course of hammer deformation [1, 17, 22]. Pores and cracks that reach the surface are hardly closed, but their depth is reduced. In other words, they do not open in deformation by the plane hammers.

Thus, the use of the cyclic-deformation system for preliminary reduction of large continuous-cast slabs in a single pass significantly improves the quality of the sheet blanks, for the following reasons.

(1) Intense working of the core of the continuous-cast billet, which eliminates structural inhomogeneity of the cast metal and facilitates the production of fine-grain structure of the metal.

(2) The high compressive stress at the contact surface, such that casting defects do not open, defects and pores in the surface layer at a depth no greater than 15 mm are sealed, and no new defects are formed.

(3) The ability to control the roughness of the hammer's working surface over the length of the deformation zone. The initial working section of the hammer surface may be made rough so as to improve slab capture, while the output section may be ground to improve the surface quality of the sheet blanks.

In view of the capabilities of the cyclic-deformation system, it may be most effectively used in the line of a continuous-casting machine for preliminary reduction of large continuous-cast slabs. That permits harmonization of the speeds of continuous casting and deformation; 45–90% reduction of the slab in a single pass; thorough working of the slab's cast structure; and reduction of the continuous-cast slabs in the continuous-casting line without preliminary trimming, by means of the heat of the cast metal, with significant energy savings [22, 23]. Another possibility is to introduce the cyclic-deformation system in the lines of thick-sheet and broad-strip mill for preliminary reduction of hot continuous-cast slabs in a single pass. That improves the quality of the sheet blanks and minimizes the number of passes in the mills.

CONCLUSIONS

The improvement in the quality of sheet blanks for thick-sheet mills when using a cyclic-deformation system for preliminary reduction of large continuous-cast slabs is analyzed. The structure and basic parameters of such systems are presented.

REFERENCES

1. Lekhov, O.S. and Komratov, Yu.S., *Sovmeshchennye protsessy nepreryvnogo lit'ya i deformatsii dlya proizvodstva prokata* (Combined Processes of Continuous Casting and Deformation for Rolling Stock Production), Yekaterinburg: Ural. Gos. Tekh. Univ., 2009.
2. Lekhov, O.S. and Baranov, M.V., Prospects for the introduction of processes of cyclic deformation of blanks, *Trudy nauchno-tekhnicheskoi konferentsii "Teoriya i tekhnologiya protsessov plasticheskoi deformatsii"* (Proc. Sci.-Tech. Conf. "Theory and Technology of Plastic Deformation Processes"), Moscow: Mosk. Inst. Stali Splavov, 1997, pp. 174–178.
3. Khoiyas, G. and Khain, O., Design and application of forging and rolling units, *Chern. Met.*, 1980, nos. 25–26, pp. 15–21.
4. Lekhov, O.S., Baranov, M.V., and Minakov, V.S., Analysis of the stress-strain state of metal in the focus of cyclic deformation in the production of sheet in a continuous casting and deformation plant, *Izv. Vyssh. Uchebn. Zaved., Chern. Metall.*, 2004, no. 2, pp. 25–27.
5. Kokh, G. and Kopp, R., Progress in the field of deformations with large compression, *Chern. Met.*, 1979, no. 21, pp. 3–11.
6. Teterin, P.K., Matorin, V.I., and Skornyakov, A.N., Rolling with high compression—a new perspective direction in metal forming, *Stal'*, 1982, no. 3, pp. 15–21.
7. Rauer, G., Bertram, K., and Kenitseridr, N., The second slab caster at the Thyssen plant in Benquervert, *Chern. Met.*, 1981, no. 23, pp. 32–43.
8. Pechke, Yu. and Noimnetts, D., Methods of continuous casting combined with rolling, *Chern. Met.*, 1981, no. 22, pp. 9–13.
9. Yamada, K., Vatanave, T., Abe, K., and Funkda, T., Continuous casting of small pieces, *Chern. Met.*, 1981, no. 10, pp. 18–23.
10. Bogatov, A.A., Nukhov, D.Sh., and P'yankov, K.P., Finite-element modeling of plate-rolling, *Metallurgist*, 2015, vol. 59, no. 1, pp. 113–118.

11. Salganik, V.M., Shmakov, D.O., and Pustovoitov, S.A., Features of formation of the stressed-deformed state of the mill products in roughing passages with reference to mill 5000 of JSC “MMK”, *Proizvod. Prokata*, 2009, no. 11, pp. 10–14.
12. Efron, L.I., *Metallovedenie v “bol’shoi” metallurgii. Trubnye stali* (Metallurgy in “Large” Metallurgy. Pipe Steel), Moscow: Metallurgizdat, 2012.
13. Pogorzhel’skii, V.I., *Kontroliruemaya prokatka nepreryvnolitogo metalla* (Controlled Rolling of Continuously Casted Metal), Moscow: Metallurgiya, 1986.
14. Erenberg, Kh.-Yu., Casting and rolling from the casting of thin slabs at the factory of “Mannesman Rhenen-Verke AG” Company, *Metall. Proizvod. Tekhnol. Metall. Protsess.*, 1990, no. 1, pp. 46–56.
15. Eberle, A., Vollner, G., Gabel, D., et al., Continuous casting and rolling of thin slabs, *Stal’ Zhelezo*, 1990, no. 1, pp. 81–88.
16. Vyunnenberg, K., Production of continuously cast billets meeting the highest quality requirements, *Trudy shestogo mezhdunarodnogo kongressa zheleza i stali* (Proc. Sixth Int. Congress on Iron and Steel), Moscow: Mashinostroenie, 1990, vol. 3, pp. 364–376.
17. Lekhov, O.S., Guzanov, B.N., Lisin, I.V., and Bilalov, D.Kh., The combined process of continuous casting and cyclic deformation for production of steel sheets, *Stal’*, 2016, no. 1, pp. 59–62.
18. Shkatov, V.V. and Bogomolov, I.V., Transformation of grain structure of austenite in cycle “deformation-primary recrystallization,” *Fiz. Met. Metalloved.*, 1996, vol. 81, no. 2, pp. 149–158.
19. Khlestov, V.M. and Frolova, Z.V., Effect of parameters of controlled rolling on austenitic and final structure of steel 09G2FB, *Izv. Vyssh. Uchebn. Zaved., Chern. Metall.*, 1989, no. 4, pp. 68–71.
20. Vyunnenberg, K. and Yakobi, Kh., Internal structure of continuously cast blanks, *Chern. Met.*, 1981, no. 14, pp. 30–39.
21. Dorozhko, G.K., Khlestov, V.M., and Sokolov, K.N., Effect of deformation on the kinetics of the transformation of austenite and the structure and properties of steel 10KhSND, *Met. Sci. Heat Treat.*, 1977, vol. 19, no. 12, pp. 1029–1032.
22. Lekhov, O.S., *Optimizatsiya mashin dlya deformatsii nepreryvnolitykh zagotovok* (Optimization of Machines for Deformation of Continuously Casted Billets), Yekaterinburg: Nauka, 1995.
23. Spittel, T. and Hensel, A., *Rationeller Energieeinsatz bei Umformprozessen*, Leipzig: Deutsch. Verlag Grundstoffind., 1983.

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