

CALCULATION OF PENETRATION ZONE DIMENSIONS IN SURFACING OF ROLLS FOR BILLET CONTINUOUS CASTING MACHINES

V.N. MATVIENKO, L.K. LESHCHINSKY and V.A. MAZUR

State Higher Education Institute Pryazovsky State Technical University
7 Universitetskaya Str., 87500, Mariupol, Ukraine. E-mail: matviyenko@gmail.com

It is shown that in surfacing rolls of billet continuous casting machines (BCCM) the dimensions of the penetration zone are affected by chemical composition and thermophysical properties of the material of the roll or deposited sublayer. The calculated values of the cross-sectional area, penetration depth and volume of molten metal are presented. They were obtained by numerical modeling on the basis of solving the nonlinear three-dimensional differential equation of thermal conductivity, taking into account the approximated temperature dependence of thermal conductivity coefficient. It was established by calculation and confirmed by experiment that the dimensions of penetration zone increase at submerged-arc surfacing with strip electrode of a sublayer of martensitic-ferritic high-chromium steel and to a higher extent at surfacing of a sublayer of chromium-nickel steel as compared to surfacing of the roll material or of a sublayer of low-carbon low-alloyed steel. 10 Ref., 3 Tables, 3 Figures.

Keywords: *roll of a billet continuous casting machine, base metal, submerged-arc surfacing, strip electrode, penetration zone, dimensions, numerical modeling, deposited layer, sublayer, chemical composition, thermophysical characteristics, thermal conductivity coefficient*

In manufacture and reconditioning of the rolls of billet continuous casting machines (BCCM) the longitudinal bending of the roll can be reduced, and the probability of defect initiation can be lowered by reducing the volume of deposited metal by limiting the number of deposited layers [1, 2]. In the case of application of surfacing with two layers, namely sublayer (intermediate layer) and outer layer [3], the required content of alloying elements in the outer layer depends both on electrode composition, and on the degree of outer layer dilution by the sublayer, and when surfacing through the sublayer it depends on roll material. Even small changes of the degree of dilution can lead to noticeable deviations in the content of alloying elements in the outer layer. Such deviations from the composition of Kh13 type (in particular, 08Kh13N3M1AFB, widely applied for surfacing the outer layer of BCCM rolls) lead to lowering of the resistance to corrosion-mechanical wear, thermal cycles, and thermal fatigue fracture [4, 5]. Here, the possibility of producing the composition of Kh13 type in the outer layer depends not only on substantiation of selection of materials and surfacing mode parameters, but also on the dimensions of the penetration zone, that leads to increase of the requirements to the accuracy of prediction of its dimensions.

Initial data for calculation of penetration zone dimensions. Selection of initial data for calculation was performed, proceeding from preliminary analysis of the composition and thermophysical properties of

both the base material of BCCM rolls, and composition of metal for deposition of the sublayer and outer layer. From materials used for roll manufacture, we should single out heat-resistant steel 25Kh1M1F of pearlitic class, steel 25Cr1Mo1V of close composition, as well as steel 42CrMo4 with higher content of carbon and lower content of chromium and molybdenum [3–5]. Application of low-carbon low-alloyed steels 06KhN2G1M, 10Kh1M1G1N, 10GS, 12Kh1MF ensures producing a ductile sublayer [2]. At two-layer surfacing the sublayer composition with a higher (than that in the outer layer) content of chromium, for instance, of Kh17 type, as well as other alloying elements, primarily, nickel and molybdenum, can be chosen [3]. Steels 08Kh17N12M2, 0Kh18N10, 0Kh19N11M3 can be regarded as sublayer compositions with such a content of chromium, which, at the same time, provide an austenitic structure with a high ductility. Unlike the above-mentioned materials, used for manufacturing BCCM rolls and sublayer deposition, the thermophysical properties of which are similar, the properties of austenitic steels, also used for the sublayer, differ considerably. Proceeding from that, calculation of penetration zone dimensions and subsequent analysis were performed for heat-resistant pearlitic steel 25Kh1M1F, martensitic steel 42CrMo4, chromium-nickel austenitic steel 08Kh17N12M2, as well as for high-chromium martensitic-ferritic steel 20Kh13 applied in the sleeves of composite rolls. Chemical composition (Table 1) and structure of the considered steels determine the presented in Table 2

Table 1. Chemical composition of steels used in calculations, wt.%

Steel grade	C	Mn	Si	Cr	Ni	Mo	V
25Kh1M1F	0.25	0.6	0.3	1.65	0.25	0.75	0.25
42CrMo4	0.42	0.7	0.4	1.10	0.19	0.20	–
20Kh13	0.20	1.5	1.0	13.0	–	–	–
08Kh17N12M2	0.08	2.0	1.0	17.0	12.0	2.5	(0.4 Ti)

Table 2. Physical properties of steels used in calculations (at 20–100 °C) [6, 7]

Steel grade	Coefficient of thermal conductivity λ , W/(m·K)	Specific heat, °C, J/(kg·°C)	Coefficient of thermal diffusivity, $a \cdot 10^6$, m ² /s	Melting temperature T_m , °C
25Kh1M1F	52	486	12.2	1522
42CrMo4	38	506	7.6	1520
20Kh13	23	452	5.0	1510
08Kh17N12M2	16	468	5.0	1400

thermophysical properties: thermal conductivity coefficient λ , specific heat C , coefficient of thermal diffusivity a , melting temperature T_m . Calculations with application of these data, as well as experimental verification, were conducted for the process of surfacing with strip electrode Sv-12Kh13 of 40 mm thick plates, using AN-26P flux. Mode of RPDC surfacing for 45×0.7 mm strip was as follows: current of 650 A, voltage of 32 V, deposition rate of 12 m/h; for 60×0.5 mm strip — current of 700 A, voltage of 32 V, deposition rate of 10 m/h; strip electrode extension of 40 mm. Surfacing was performed using AD-231 machine and VDU-1202 power source.

Results of calculation of penetration zone dimensions. Dimensions of the heating zone, limited by the position of $T = T_m$ isotherm, were calculated by applying a mathematical model [8, 9], which is based on numerical solution by finite element method of non-linear three-dimensional differential equation of thermal conductivity, which allows for the influence of temperature on thermophysical properties of the base metal. Used for this purpose were equations of continuous functions, characterizing the temperature dependence of the coefficient of thermal conductivity

for the considered steels, derived by processing the experimental and calculated data of works [6, 7].

Temperature dependence of the coefficient of thermal conductivity

25Kh1M1F $y = -0.0161x + 43.429$
 42CrMo4 $y = -0.0127x + 39.424$
 20Kh13 $y = 29.113e^{-0.0002x}$
 08Kh17N12M2 $y = 0.0073x + 13.887$

Calculation results allow assessment of the current values of heating temperature, as well as quantitative characteristics of the thermal field in the zone of base metal melting.

It follows from calculation results (Figure 1) that at unchanged conditions of the process of surfacing with 45×0.7 mm strip electrode, the cross-sectional area, penetration depth and molten metal volume are much smaller for material of the roll from steel 25Kh1M1F, than for a sublayer from steel 08Kh17N12M2. This is confirmed by sections of three-dimensional model of the thermal field of the item in the plane normal to the processed surface, obtained at modeling (Figure 2). Here, it should be noted that as the thermophysical properties of low-carbon low-alloyed steels for sublayer deposition are little different from those of steel 25Kh1M1F, the dimensions of the penetration zone of roll material and such a sublayer also differ only slightly.

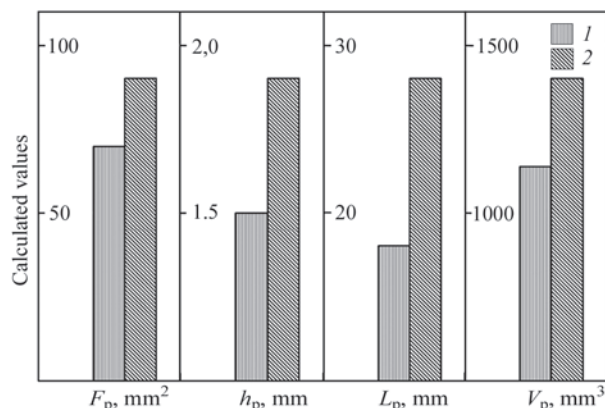
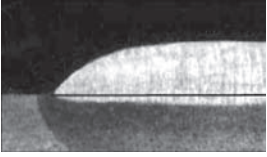



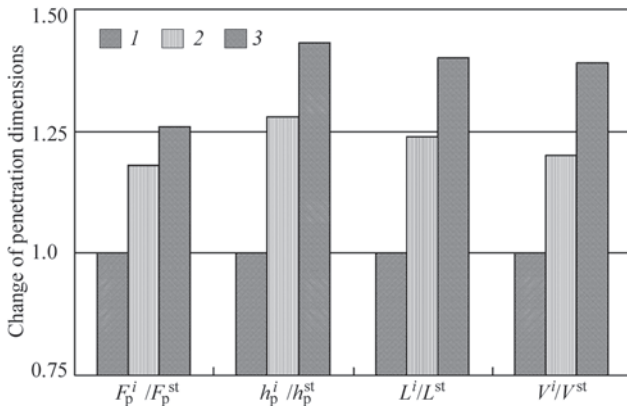
Figure 1. Calculated values of penetration zone dimensions (cross-sectional area F_p , depth h_p , length L_p , molten metal volume V_p) (45×0.7 mm strip): 1 — deposition on steel 25Kh1M1F; 2 — on sublayer from steel 08Kh17N12M2



Figure 2. Boundary of T_m isotherm in the plane normal to the processed surface (45×0.7 mm strip): a — deposition on steel 25Kh1M1F; b — on sublayer from steel 08Kh17N12M2

Table 3. Comparison of calculated and experimental data

Penetration parameters	Roll material steel 25Kh1M1F		Sublayer material steel 08Kh17N12M2	
	Calculation	Experiment	Calculation	Experiment
Area, F_p , cm ²	68–72	67–73	89–92	88–93
Depth, h_p , mm	1.50–1.55	1.54–1.58	1.90–1.95	1.92–1.98
Transverse macrosection of the deposited bead				

**Figure 3.** Ratio of calculated dimensions of the penetration zone at deposition (60×0.5 mm strip): 1 — on sublayer from steel 42CrMo4; 2 — on steel 20Kh13; 3 — on sublayer from steel 08Kh17N12M2

Influence of substrate metal composition and properties on the ratio of calculated dimensions of the penetration zone is of considerable interest. At surfacing with 60×0.5 mm strip electrode the dimensions of penetration zone on steel 20Kh13 are 1.25 times, and those on steel 08Kh17N12M2 are more than 1.35 times greater than these values for steel 42CrMo4 respectively (Figure 3). Molten metal volume differs to an even greater extent. Comparison of calculated and experimental data on the influence of the composition and properties of steels 25Kh1M1F and 08Kh17N12M2 on penetration area and depth at surfacing with 45×0.7 mm strip electrode (Table 3), confirms the adequacy of the calculation procedure. More precise determination of the geometry of penetration zone by application of the proposed calculation procedure allows substantiation of the change of surfacing mode parameters at development of the technology of reconditioning BCCM rolls. This led to the differentiated approach to selection of the mode, at which the values of heat input in deposition of the surface layer and the sublayer are different, and are determined by their composition and properties [10].

Conclusions

1. At manufacture and reconditioning of BCCM rolls by surface layer deposition with strip electrode, the penetration zone dimensions depend on chemical composition and thermophysical properties of base metal (roll material), and at deposition on the sublayer they depend on sublayer composition and properties.
2. At deposition on a sublayer from martensitic-ferritic high-chromium steel, and, to a greater extent, on a sublayer from austenitic chrome-nickel steel, the calculated values of cross-sectional area, penetration depth and molten metal volume become higher, compared to deposition on the roll material (pearlitic steel) and on a sublayer from low-carbon low-alloyed steel.

1. Ryabtsev, I.A., Babinets, A.A., Ryabtsev, I.I. (2011) Effect of sub-layer on heat resistance of multilayer deposited metal. *The Paton Welding J.*, **10**, 18–21.
2. Ryabtsev, I.A., Senchenkov, I.K. (2013) *Theory and practice of surfacing operations*. Kiev, Ekotekhnologiya [in Russian].
3. Kirchu, I.F., Stepanova, T.V., Suprun, M.V. (2015) Prospects of application of steel with nitrovanadium hardening for rolls of slab BCCM instead of steel 25Kh1M1F. *Metall i Litio Ukrainy*, **1**, 18–22 [in Russian].
4. Dombrovsky, F.S., Leshchinsky, L.K. (1995) *Operability of surfaced rolls of billet continuous casting machines*. Kiev, PWI [in Russian].
5. (2014) *Cored wires for cladding and thermal metal spraying*. Welding Alloys Group.
6. Mills, K.C. (2002) *Recommended values of thermophysical properties for selected commercial alloys*. England, Cambridge, Woodhead Publishing.
7. Peet, M.J., Hasan, H.S., Bhadeshia, H.K. (2011) Prediction of thermal conductivity of steel. *Int. J. of Heat and Mass*, **54**, 2602–2616.
8. Matvienko, V.N., Mazur, V.A., Leshchinsky, L.K. (2015) Evaluation of shape and sizes of weld pool in surfacing using combined strip electrode. *The Paton Welding J.*, **9**, 28–31.
9. Mazur, V.A., Leshchinsky, L.K., Matvienko, V.N. (2018) Influence of thermophysical properties of base metal on geometry of penetration zone in strip electrode surfacing. *Svarochn. Proizvodstvo*, **3**, 10–14 [in Russian].
10. Matvienko, L.K., Mazur, V.O. (2017) *Method of surfacing of rolls of continuous casting machines*. Pat. 116526, Ukraine, Int. Cl. B23K 9/04 [in Ukrainian].

Received 14.05.2018