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LADLE-NOZZLE OPENING AND GENETIC PROGRAMMING

ODPIRANJE IZLIVKA PONVE S PODŽIGANJEM IN GENETSKO PROGRAMIRANJE

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Štore Steel Ltd. faces a huge problem with the ladle nozzle opening during the production of a wide variety of steel grades. After a ladle treatment the steel melt is poured from the ladle through the sliding gate and the nozzle into the tundish on the continuous casting machine. Due to frequent clogging the ladle nozzle must be opened with oxygen which can cause melt pollution. The purpose of this paper is to present an attempt to reduce ladle-nozzle openings. In this attempt the genetic-programming method was used. The experimental data on 115 consecutively cast heats was used. The steelmaking-technology number, the batch sequence number, the time spend for secondary metallurgy, the sustainability of the upper-nozzle brick, the sustainability of the nozzle seating block, the sustainability of the lower-nozzle brick, the ladle number, the sustainability of the ladle and of the foreman of secondary metallurgy and the melt chemical composition (Al, C, Mn and Si) were taken into account for the prediction of the ladle-nozzle opening. The best genetically developed model for the ladle-nozzle-opening prediction correctly predicts 107 out of 115 situations of opening the ladle. The results of the genetic-programming-based modeling have been used in practice to change several steelmaking technologies.

Keywords: secondary metallurgy, ladle-nozzle opening, modeling, genetic programming

Štore Steel, d. o. o., se spopada s težavo podžiganja izlivka ponve pri izdelavi ogromnega števila različnih kvalitet jekla. Po obdelavi na ponovčni peči se taline skozi drsno zapiralo in izlivek prelije v vmesno ponovco na kontinuirni livni napravi. Zaradi pogostega mašenja se izlivki odpirajo s kisikovim kopjem, kar lahko povzroča onesnaženje taline. Namen študije je bil zmanjšati število podžiganj. Uporabljena je bila metoda genetskega programiranja. Pri napovedovanju podžiganja smo upoštevali številko tehnološkega postopka izdelave jekla, zaporedno številko šarže pri sekvenci, čas sekundarne metalurgije, vzdržnost zunanjega izlivka ter ponovce, ponovčarja in kemično sestavo taline (Al, C, Mn in Si). Najboljši genetsko dobljeni model je napovedal 107 od 115 dejansko izvršenih podžiganj. Rezultati modeliranja z genetskim programiranjem so privedli do sprememb več tehnologij izdelave jekla.

Ključne besede: sekundarna metalurgija, podžiganje, modeliranje, genetsko programiranje

1 INTRODUCTION

Steelmaking begins with scrap melting in an electric-arc furnace. After scrap and carburizing agents melting the carbon, the carriers, in general, are coke, anthracite, graphite and slag additives, regulating basicity, viscosity, thermal and electric conductivity, desulphurization, dephosphorization, neutrality towards the furnace fireproof linings and the non-metallic inclusion-filtration capability.[1,2]

The melting bath heated up to the tapping temperature according to the further treatment procedures is discharged into the casting ladle after electric-arc furnace melting. After discharging the melting bath is deoxidized and desulphurized, the nonmetallic inclusions are filtered out, the slag metallic oxides are reduced, the hydrogen and nitrogen are partly degassed, the melting bath and the temperature field are homogenized, the formed slag is exchanged and the major alloying is completed.

After melting and alloying in the electric-arc and ladle furnace, billets are continuously cast from the melting bath. The melting bath flows through the sliding-gate system (**Figure 1**) and the ladle shroud towards the tundish. After filling up the tundish, a mould filling system with tundish stoppers and submerged pouring tubes is established. The billets with a square section of 180 mm or 140 mm are cast. After reaching a certain melting-bath level the potentiometer starts the flattening system which drags the billet out of the mould. In this way continuous casting is established. The billet goes through the cooling zone toward the gas cutters, where it is cut and laid off onto a cooling bath.

After a melt has been cast, the ladle has to be emptied of the remains of the slag. These are scraped using a construction machine. Especially the top of the ladle has to be carefully cleaned so as to prevent the slag remains from mixing with the steel melt. The next step of the process is to clean the sliding gate at the bottom of the ladle, which is, at first, done manually and then with an oxygen lance.

When the slide-gate parts, the upper- and lower-nozzle bricks, the nozzle seating block, the inner and collector nozzles and the slide-gate plates, are damaged they are replaced.

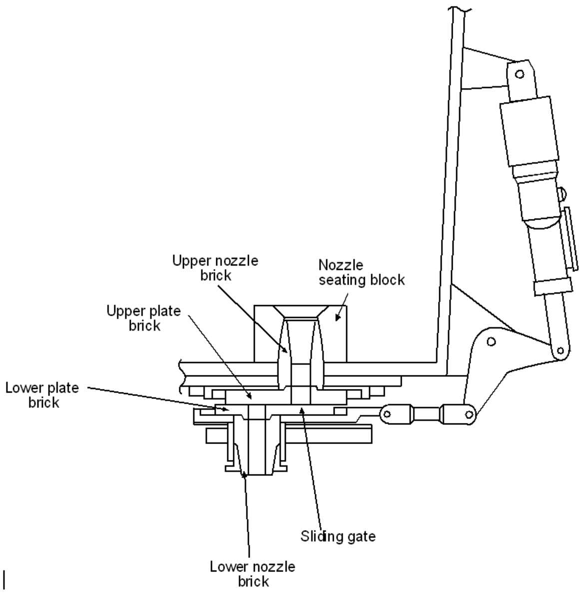

Figure 1: Ladle and opening system in Štore Steel Ltd.
Slika 1: Sistem odpiranja ponovce v podjetju Štore Steel, d. o. o.

The ladle is then positioned vertically; the top part is thoroughly checked and repaired if necessary. After that it goes to the reheating station, where a mixture of natural gas and air heats the ladle to the correct temperature. The slide-gate filling sand is poured through a tube to the slide gate just before the ladle is positioned in the casting pit. There is a standard amount of the filling sand that has to be used.

The ladle then goes to the ladle furnace where chemical and temperature homogeneities are achieved.

In recent years there has been a significant increase in the number of heats, when an oxygen lance has to be used to cut through the ladle slide gate and allow the liquid steel to pour through. In good steelmaking practice, we want to avoid, as much as possible, having these kinds of heats, because the oxygen that is blown in the melt causes a reoxidation of the melt and impurities may be formed.

In the present paper the dependence between the ladle-nozzle opening, the steelmaking parameters, the chemical composition and the fire-proof material is discussed. For the ladle-nozzle-opening modeling the genetic-programming method was used. The experimental data was collected during the standard production.

2 EXPERIMENTAL BACKGROUND

The data for the analysis was collected on the basis of 115 consecutively cast heats in Štore Steel Ltd. (**Table 1**). The data is taken from the technological documentation of the cast heats and from the chemical archive. The goal was to get as wide a range of variables as possible.

There are several different steelmaking technologies used:

- aluminum killed steel (#1),
- silicon killed steel (#2),
- aluminum killed calcium-free steel (#3) and
- extra machinability steel (#4).

It is also important to know how many batches of the same steel grade are cast in a sequence. The conditions for casting a single batch are different from the ones for casting several batches, one after another, with respect to

Table 1: Experimental data
Tabela 1: Eksperimentalni podatki

#	Steelmaking technology number	Batch sequence number	Time spend for secondary metallurgy (min)	Sustainability of the upper nozzle brick (number of batches)	Sustainability of the nozzle seating block (number of batches)	Sustainability of the lower nozzle brick (number of batches)	Ladle number	Sustainability of the ladle (number of batches)	Foreman of secondary metallurgy	*w*(Al) /%	*w*(C) /%	*w*(Mn) /%	*w*(Si) /%)	Nozzle opening: Yes=1, No=0
1	1	0	60	4	10	4	11	10	1	0.004	0.51	0.79	0.26	1
2	2	1	110	11	11	3	6	53	3	0.023	0.27	0.82	0.28	0
3	2	2	70	3	32	3	8	32	3	0.028	0.28	0.79	0.24	0
4	2	0	70	13	25	3	12	25	2	0.024	0.22	1.31	0.22	0
5	2	0	110	5	11	1	11	11	8	0.021	0.75	0.74	0.34	0
6	2	0	100	12	12	4	6	54	2	0.023	0.45	0.62	0.26	0
7	2	0	140	14	26	4	12	26	2	0.026	0.2	1.16	0.28	1
8	2	0	95	6	12	2	11	12	10	0.017	0.28	1.45	0.59	1
9	2	0	128	1	13	1	6	55	10	0.025	0.49	0.73	0.27	1
10	2	0	110	1	27	1	12	27	6	0.021	0.15	1.03	0.27	1
11	2	0	90	7	13	3	11	13	7	0.026	0.22	1.23	0.22	0
12	3	0	125	2	14	2	6	56	7	0.009	0.99	0.34	0.23	0
13	1	1	90	2	28	2	12	28	1	0.005	0.47	0.74	0.26	1
14	1	2	70	8	14	4	11	14	1	0.005	0.48	0.71	0.25	0
15	4	0	38	3	29	3	12	29	1	0.022	0.18	1.17	0.26	0
115	4	1	38	1	15	1	11	15	2	0.024	0.17	1.1	0.23	0

the casting temperature, the time and fire-resistant material conditions.

According to the ladle and tundish system the data on the sustainability of the inner nozzle, the well block, the collector nozzle and the ladle is needed.

Secondary metallurgy also influences the pouring of the melted steel from the ladle to the tundish. That is why alloying (the melt chemical composition in the ladle) and steelmaking (timing and organization) are also important.

3 NOZZLE-OPENING MODELING WITH GENETIC PROGRAMMING

Genetic programming is probably the most general evolutionary optimization method.[3–6] The organisms that undergo an adaptation are in fact mathematical expressions (models) for a nozzle-opening prediction consisting of the available function genes (i.e., the basic arithmetical functions) and terminal genes (i.e., independent input parameters and random floating-point constants). In our case the models consist of: the function genes of addition (+), subtraction (–), multiplication (*) and division (/), the terminal genes of the steelmaking technology number (*tech*), the batch sequence number (*seq*), the time spend for secondary metallurgy (*t*), the sustainability of the upper-nozzle brick (s_*unb*), the sustainability of the nozzle seating block (*s_nsb*), the sustainability of the lower-nozzle brick (*s_lnb*), the ladle number (*ladle*), the sustainability of the ladle (*s_l*), the foreman of secondary metallurgy (*man*), the weight percentage of Al (*Al*), C (*C*), Mn (*Mn*) and Si (*Si*).

Random computer programs of various forms and lengths are generated by means of selected genes at the beginning of the simulated evolution. Afterwards, the varying of the computer programs during several iterations, known as the generations, by means of genetic operations is performed. For the progress of the population only the reproduction and crossover are sufficient. After the completion of the varying of the computer programs, a new generation is obtained that is evaluated and compared with the experimental data, too.

The process of changing and evaluating the organisms is repeated until the termination criterion of the process is fulfilled. This is the prescribed maximum number of the generations.

For the process of simulated evolutions the following evolutionary parameters were selected: the size of the population of organisms 500, the greatest number of generation 100, the reproduction probability of 0.4, the crossover probability of 0.6, the greatest permissible depth in creating population 6, the greatest permissible depth after the operation of the crossover of two organisms 10 and the smallest permissible depth of organisms in generating new organisms 2. Genetic operations of reproduction and crossover were used. For the selection of organisms the tournament method with a tournament size of 7 was used. For the evaluation of the organisms the number of the correct predictions of ladle-nozzle openings was used.

We have developed 100 independent civilizations of mathematical models for the nozzle-opening prediction. Each civilization has the most successful organism – a mathematical model for the nozzle-opening prediction. The best most successful organism from all of the civilizations is presented here:

$$
\begin{aligned}
&\Bigg((2c+mn-seq)\,s\_unb\Bigg(\frac{tech+s\_unb}{s\_lnb}+(ladle-man+tech+s\_lnb)\Bigg(-si-tech+al(c-s\_lnb)+s\_unb+\frac{s\_unb(-al-tech+s\_lnb+s\_unb)}{seq\left(-man+\frac{tech}{seq}\right)(-ladle+s\_unb)}\Bigg)\Bigg)\Bigg)\Big/\\
&\Bigg((al\,ladle\,man+s\_unb)\Bigg(s\_l+\frac{-man+\frac{tech}{seq}}{-si-2\,tech+al(c-s\_lnb)+s\_unb+\frac{s\_unb(-al+s\_lnb+s\_unb)}{seq\left(-man+\frac{tech}{seq}\right)(-s\_lnb+s\_unb)}}\Bigg)\Bigg(-s\_lnb+(ladle+man)\Bigg(1+\frac{-man+\frac{tech}{seq}}{-ladle+s\_lnb+s\_unb}\Bigg)\Bigg)\\
&\Bigg(-al+mn+(ladle+s\_unb)\left(ladle+\frac{s\_unb}{man}\right)+man\Bigg(-si-tech+al\,s\_lnb+s\_unb+\frac{\left(-man+\frac{mn+tech}{seq}\right)(-al+c+mn-tech-s\_lnb)(-seq+s\_unb)}{\left(-man+\frac{tech}{seq}\right)(-mn+s\_unb)(-al-tech+s\_lnb+s\_unb)}\Bigg)\Bigg)\\
&\Bigg(s\_lnb+(tech+s\_unb)\Big/\Bigg(al\,ladle\Bigg(c-seq+\frac{s\_unb(-al+s\_lnb+s\_unb)}{(ladle+man)\,mn\,seq\left(-man+\frac{tech}{seq}\right)}\Bigg)\Bigg(s\_lnb+ladle\left(ladle+\frac{s\_unb}{man}\right)\Bigg)\Bigg)\Bigg)\Bigg)
\end{aligned}
\tag{1}
$$

and it correctly predicts 107 out of 115 situations of the ladle-nozzle opening.

The influences of individual parameters are presented in the following figure (**Figure 2**). For example, we can see that the steelmaking-technology number can increase the number of ladle-nozzle openings from 4 to 10 with respect to 115 consecutively cast heats. On the other hand, an Al addition can reduce the number of ladle-nozzle openings up to 11 heats with respect to 115 consecutively cast heats.

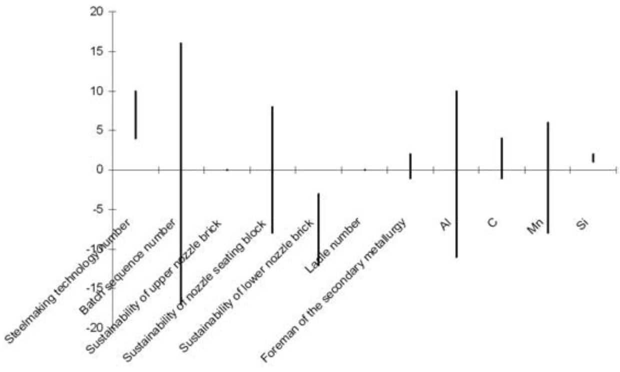

Figure 2: Influences of individual parameters on the ladle-nozzle opening with respect to 115 consecutively cast heats

Slika 2: Vplivi posamičnih parametrov na podžiganje glede na podatke 115 zaporedno odlitih šarž

4 CONCLUSION

The purpose of this paper was to reduce the ladle-nozzle openings where an oxygen lance is used and an unwanted reoxidation of the melt can occur. In this attempt the genetic-programming method was used. The experimental data on 115 consequently cast heats was used. The steelmaking-technology number, the batch-sequence number, the time spend for secondary metallurgy, the sustainability of the upper-nozzle brick, the sustainability of the nozzle seating block, the sustainability of the lower-nozzle brick, the ladle number, the sustainability of the ladle, the foreman of secondary metallurgy and the melt chemical composition (Al, C, Mn and Si) were taken into account for the prediction of the ladle-nozzle opening. The best genetically developed model for the ladle-nozzle-opening prediction correctly predicts 107 out of 115 situations of opening the ladle. It was also found that the batch-sequence number, the sustainability of the nozzle seating block, the percentage of Al and Mn in the melt are the most influential parameters.

If a heat is cast later in the sequence, it is less likely that clogging will happen. This is due to the fact that the heats cast later in the sequence have a shorter melting time in the ladle. It is important that heats are cast on time and, for this reason, some heats have to be prepared beforehand. The more the melt is in contact with the nozzle seating block, the more likely it is for clogging to occur. So, replacing the ladle and the opening system is also essential. The Al and Mn additions are connected with different steelmaking technologies and different steel grades. So, a change in the steelmaking technologies with respect to the most critical grades (i.e., the spring steel and the steel for the applications in forging) was also required. The results of the research have been used in practice.

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