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LADLE NOZZLE OPENING AND GENETIC PROGRAMMING

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Abstract

Štore Steel Ltd. faces a huge problem with ladle nozzle opening during the production of a wide variety of steel grades. After the 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 often cloggings the ladle nozzle must be opened with the oxygen which can cause melt pollution. The purpose of this paper is to present the attempt for reducing ladle nozzle openings. In this attempt genetic programming method was used. The experimental data on 115 consequently cast heats was used. The steelmaking technology number, batch sequence number, time spent for secondary metallurgy, sustainability of upper nozzle brick, sustainability of nozzle seating block, sustainability of lower nozzle brick, ladle number, sustainability of the ladle, foreman of the secondary metallurgy and melt chemical composition (Al, C, Mn and Si) were taken into account for the prediction of ladle nozzle opening. The best genetically developed model for 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 for the changing of several steelmaking technologies.

Key words: secondary metallurgy, ladle nozzle opening, modeling

1. INTRODUCTION

Steelmaking begins with scrap melting in electro-arc furnace. After scrap and carburizing agents melting the carbon carriers in general are coke, anthracite, graphite and slag additives, which regulates basicity, viscosity, thermal and electric conductivity, desulphurization dephosporization, neutrality towards furnace fireproof linings and the nonmetallic inclusions filtration capability (Fruehan, 1998; Ghosh 2001).

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

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

After a melt has been cast the ladle has to be emptied of the remains of slag. This are scraped

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using a construction machine. Especially the top of the ladle has to be carefully cleaned so as to prevent slag remains with mixing with the steel melt. Next step of the process is to clean the sliding gate at the bottom of the ladle, which is at first manually and then using an oxygen lance.

When slide gate parts, upper and lower nozzle brick, nozzle seating block, inner and collector nozzle and slide gate plates are damaged they are replaced.

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. Slide gate filling sand is poured through a tube to the slide gate immediately 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 goes then to the ladle furnace where the chemical and temperature homogeneity is 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 make the liquid steel pour through. In good steelmaking practice, we want to have this kind of heats as little as possible, because oxygen that is blown in melt causes reoxydation of the melt and a chance for impurities to be formed.

A literature review shows that only tundish nozzle clogging modeling has been discussed in the area of running and gating of steel castings (Fangming, 2006; Su-zhou, 2010). So, in the present paper the dependence between ladle nozzle opening, steelmaking parameters, chemical composition and fire-proof material was discussed. For ladle nozzle opening modeling the genetic programming method was used. The experimental data was collected during 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 are 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.

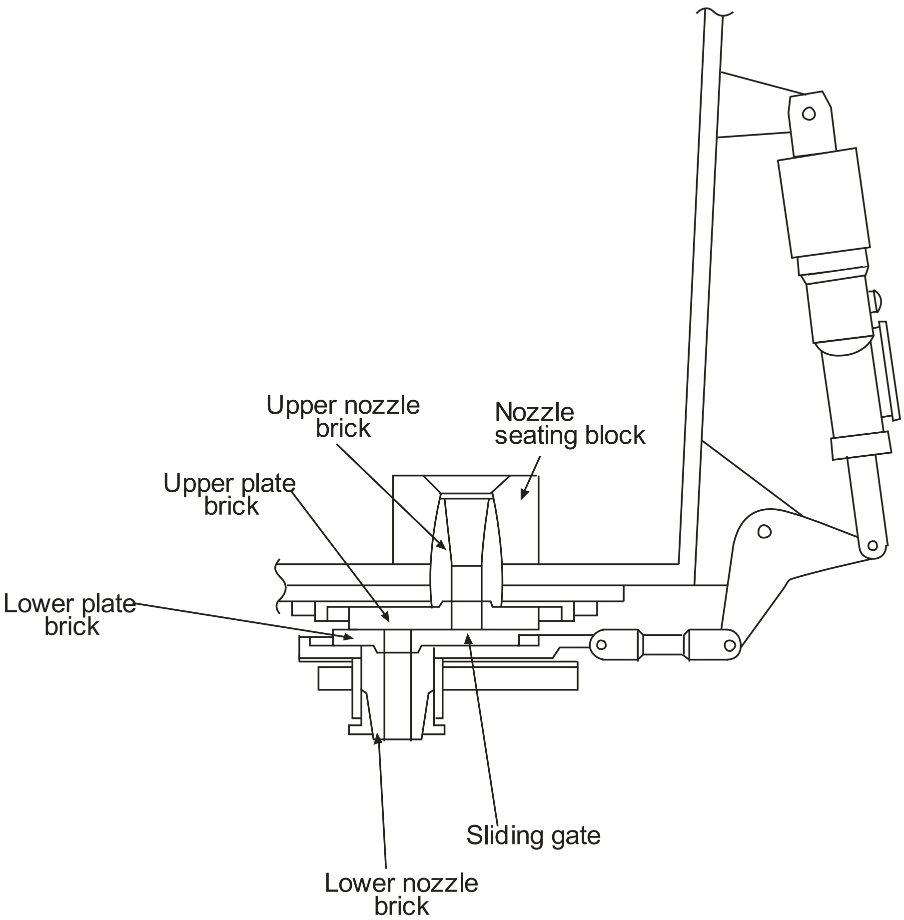

Fig. 1. Ladle and opening system in ŠTORE STEEL Ltd.

Table 1. *Experimental data.*

#	Steelmaking technology number	Batch sequence number	Time spend for secondary metallurgy [min]	Sustainability of upper nozzle brick [number of batches]	Sustainability of nozzle seating block [number of batches]	Sustainability of lower nozzle brick [number of batches]	Ladle number	Sustainability of the ladle [number of batches]	Foreman of the secondary metallurgy	Al [%]	C [%]	Mn [%]	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

There are several different steelmaking technologies used:

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

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

The secondary metallurgy also influences on pouring the melted steel from ladle to tundish. Thats why alloying (melt chemical composition in the ladle) and steelmaking (timing and organization) are also improtant.

3. NOZZLE OPENING MODELING BY GENETIC PROGRAMMING

Genetic programming is probably the most general evolutionary optimization method (Koza, 1999; Kovačič et al., 2007; Kovačič & Šarler, 2009; Kovačič & Senčič, 2012). The organisms that undergo adaptation are in fact mathematical expressions (models) for nozzle opening prediction consisting of the available function genes (i.e., basic arithmetical functions) and terminal genes (i.e., independent input parameters, and random floating-point constants). In our case the models consist of: function genes of addition (+), subtraction (-), multiplication (*) and division (/), terminal genes of steelmaking technology number (*tech*), batch sequence number (*seq*), time spend for secondary metallurgy (*t*), sustainability of upper nozzle brick (s_*unb*), sustainability of nozzle seating block (*s_nsb*), sustainability of lower nozzle brick (*s_lnb*), ladle number (*ladle*), sustainability of the ladle (*s_l*), foreman of the secondary metallurgy (*man*), 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 simulated evolution. Afterwards, the varying of computer programs during several iterations, known as generations, by means of genetic operations is performed. For the progress of the population only the reproduction and crossover are sufficient. After completion of varying of computer programs a new generation is obtained that is evaluated and compared with the experimental data, too.

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

For the process of simulated evolutions the following evolutionary parameters were selected: size of population of organisms 500, the greatest number of generation 100, reproduction probability 0.4, crossover probability 0.6, the greatest permissible depth in creation of population 6, the greatest permissible depth after the operation of 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 selection of organisms the tournament method with tournament size 7 was used. For evaluation of the organisms the number of correct predictions of ladle nozzle openings was used.

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

$$\begin{gathered}
\Bigg((2\,\mathrm{c} + mn - seq)\, s_unb \Bigg(\frac{\mathrm{tech} + s_unb}{s_lnb} + (ladle - man + tech + s_lnb) \\
\Bigg(-si - tech + al\,(c - s_lnb) + s_unb + \frac{s_unb\,(-al - tech + s_lnb + s_unb)}{seq\left(-man + \frac{tech}{seq}\right)(-ladle + s_unb)}\Bigg)\Bigg)\Bigg) \Big/ \\
\Bigg((al\,ladle\,man + s_unb)\Bigg(s_l + \frac{-man + \frac{tech}{seq}}{-si - 2\,tech + al\,(c - s_lnb) + s_unb + \frac{s_unb(-al+s_lnb+s_unb)}{seq\left(-man+\frac{tech}{seq}\right)(-s_lnb+s_unb)}}\Bigg) \\
\Bigg(-s_lnb + (ladle + man)\Bigg(1 + \frac{-man + \frac{tech}{seq}}{-ladle + s_lnb + s_unb}\Bigg)\Bigg) \\
\Bigg(-al + mn + (ladle + s_unb)\left(ladle + \frac{s_unb}{man}\right) + man \\
\Bigg(-si - tech + al\,s_lnb + s_unb + \frac{\left(-man + \frac{mn+tech}{seq}\right)(-al + c + mn - tech - s_lnb)(-seq + s_unb)}{\left(-man + \frac{tech}{seq}\right)(-mn + s_unb)(-al - tech + s_lnb + s_unb)}\Bigg)\Bigg) \\
\Bigg(s_lnb + (tech + s_unb)\Big/\Bigg(al\,ladle\Bigg(c - seq + \frac{s_unb\,(-al + s_lnb + s_unb)}{(ladle + man)\,mn\,seq\left(-man + \frac{tech}{seq}\right)}\Bigg) \\
\left(s_lnb + ladle\left(ladle + \frac{s_unb}{man}\right)\right)\Bigg)\Bigg)\Bigg)
\end{gathered} \tag{1}$$

which correctly predicts 107 out of 115 situations of ladle nozzle opening.

The influences of individual parameters is presented on the next figure (figure 2). For example we can see that the steelmaking technology number can increase number of ladle nozzle openings from 4 to 10 regarding 115 consecutively cast heats. On the other hand Al addition can lower the number of ladle nozzle openings up to 11 heats regarding 115 consecutively cast heats.

4. CONCLUSION

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

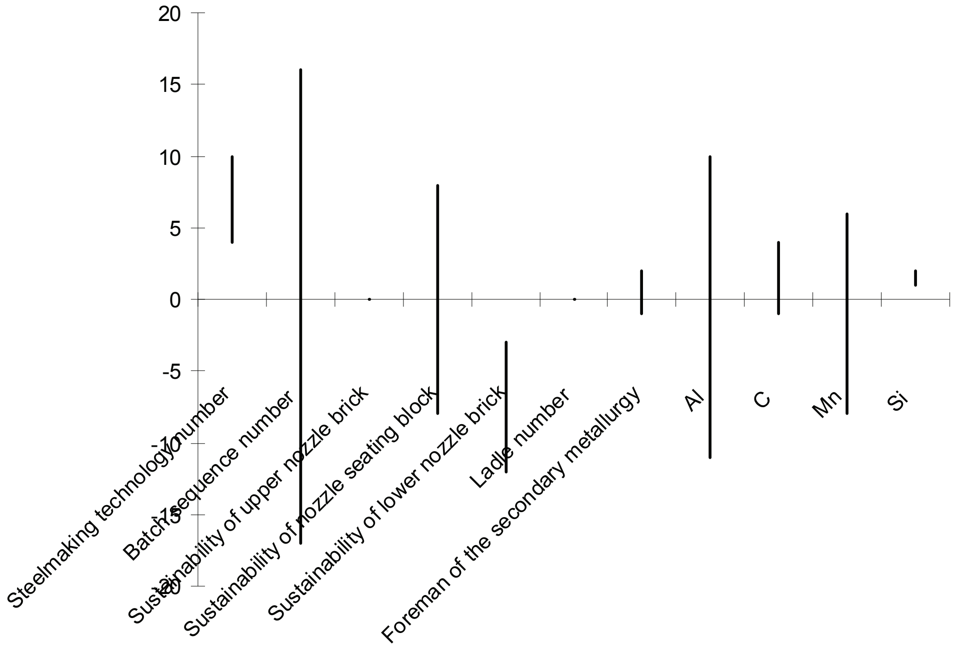

Fig. 2. *The influences of individual parameters on ladle nozzle opening regarding 115 consecutively cast heats.*

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

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PROGRAMOWANIE GENETYCZNE W STEROWANIU OTWIERANIEM DYSZY KADZI

Streszczenie

Firma Store Steel Ltd. napotkała na poważne problemy związane z otwieraniem wylotu kadzi podczas produkcji szerokiej gamy gatunków stali. W procesie ciągłego odlewania, po stopieniu stali w kadzi otwierana jest przesuwna zasuwa i stal przepływa przez dyszę do kadzi pośredniej. Z powodu częstego zatykania się dyszy kadzi jest ona otwierana przy pomocy tlenu, co powoduje zanieczyszczenie wytopu. Celem niniejszej pracy jest opracowanie technologii eliminującej problem z otwieraniem dyszy kadzi. Do jego realizacji wykorzystano metodę programowania genetycznego. Model oparto na zbiorze danych z różnych wytopów liczącym 115 przypadków. Pojedynczy przypadek zawierał informacje o numerze technologii produkcji stali, numerze partii wytopu, czasie rafinacji pozapiecowej, trwałości górnych cegieł wylotu, trwałości bloków osadzania wylotu, trwałości dolnych cegieł wylotu, numerze kadzi, trwałości kadzi, technologu nadzorującym rafinację pozapiecową oraz składzie chemicznym stopu (Al, C, Mn and Si). Najlepiej dopasowany w oparciu o programowanie genetyczne model otwierania dyszy kadzi przewidywał prawidłowo 107 na 115 przypadków. Wyniki modelowania zastosowano w praktyce usprawniając kilka technologii produkcji stali.

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