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Modelling and optimization of sulfur addition during 70MnVS4 steelmaking: An industrial case study

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ABSTRACT

Štore Steel Ltd. is one of the major flat spring steel producers in Europe. Among several hundred steel grades, 70MnVS4 steel is also produced. In the paper optimization of steelmaking of 70MnVS4 steel is presented. 70MnVS4 is a high-strength microalloyed steel which is used for forging of connecting rods in the automotive industry. During 70MnVS4 ladle treatment, the sulfur addition in the melt should be conducted only once. For several reasons the sulfur is repeatedly added and therefore threatening clogging during continuous casting and as such influencing surface defects occurrence and steel cleanliness. Accordingly, the additional sulfur addition was predicted using linear regression and genetic programming. Following parameters were collected within the period from January 2018 to December 2018 (78 consequently cast batches): sulfur and carbon cored wire addition after chemical analysis after tapping, carbon, manganese and sulfur content after tapping, time between chemical analysis after tapping and starting of the casting, ferromanganese and ferrosilicon addition and additional sulfur cored wire addition. Based on modelling results it was found out that the ferromanganese is the most influential parameter. Accordingly, 12 consequently cast batches (from February 2019 to October 2019) were produced with as lower as possible addition of ferromanganese. The additional sulfur addition in all 12 cases was not needed. Also, the melt processing time, surface quality of rolled material and sulfur cored wire consumption did not change statistically significantly after reduction of ferromanganese addition. The steel cleanliness was statistically significantly better.

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1. Introduction

Producing melted steel is commonly called primary steelmaking (i.e., primary metallurgy). The melted steel (made from ore or scrap) can be additionally treated – typically in ladles. These essential processes in modern steelmaking are called ladle treatment or secondary steelmaking (i.e., secondary metallurgy). They are slag formation, deoxidation, alloying, inclusions modification, desulfurization, dephosphorization, analyses of chemical composition of steel and slag, heating (i.e., temperature adjustment), stirring, refining (i.e., melt purification), homogenization and degassing [1-3].

The addition of alloys is preferably conducted during secondary steelmaking. They can be added also during casting, into the tundish, using bulk material or as wired products. The dissolution of alloys in liquid steel is influenced by their physical and chemical properties, melt superheat, location of addition and stirring. Most important are melting point and density which determine either the additive will float (and entrained in melt or slag) or sink during assimilation. Consequently, for efficient alloying following areas have been developing: scrap (input material) design [4-6], alloys design [7-10], and interactions with the liquid bath [11, 12].

The price of produced steel is mostly influenced by – beside the electric energy consumption – the added alloys which are at high temperatures and presence of oxygen prone to burning-off [13, 14]. Accordingly, the alloys consumption could be increased together with the need of adding the alloys several times threatening the production pace, melt homogenization, purification and further melt solidification (e.g. timing, temperature, clogging). The burn-off of alloys prediction is aggravated due to the diversity of steelmaking technologies and equipment.

In this study sulfur addition (i.e., sulfur burn-off) during 70MnVS4 steelmaking in Štore Steel Ltd. was modeled. During ladle treatment, instead of only one sulfur addition, the sulfur was repeatedly added several times threatening clogging during continuous casting and as such influencing surface defects occurrence and steel cleanliness. Accordingly, the additional sulfur addition was predicted using multiple linear regression and the genetic programming. The genetic programming has been used several times in Štore Steel Ltd. for modelling and optimization (e.g., [15-19]).

In the beginning of the paper the problem regarding repeatedly added sulfur is presented together with the steelmaking technology. Afterwards, the sulfur addition prediction using multiple linear regression and genetic programming is presented including the implementation of findings in the actual steelmaking process. At the end of the paper, the conclusions are drawn and future work is emphasized.

2. Materials, methods and execution of experiment

70MnVS4 is a high-strength microalloyed steel which is used for forging of connecting rods in the automotive industry. In Štore Steel Ltd., which is one of Europe's major flat spring steel producers, 70MnVS4 steel is produced from scrap that is melted using an electric arc furnace. After melting the first chemical composition analysis is conducted.

After reaching tapping temperature, the melt is discharged into the ladle. The ladle is transported to the ladle furnace. The average batch weighs 50 t. The slag is formed using dolomite, quartz and fluorite. The melting bath is deoxidized using ferromanganese and ferrosilicon. Also alloying using ferrovanadium and homogenization (i.e., argon stirring) are carried out. Then the second chemical composition analysis is conducted. Based on this analysis the sulfur is added for the first time using sulfur cored wire. The melt is homogenized again and also the third chemical composition is conducted. Based on the chemical composition slight adjustments of alloying elements can be made using ferrosilicon, ferromanganese and ferrovanadium. Also for several reasons, the sulfur cored wire should be added again. It is well known that the sulfur forms inclusions which cause clogging of tundish submerged entry nozzles during continuous casting and as such influencing surface defects occurrence and steel cleanliness. After chemical composition adjustments the fourth chemical composition analysis is performed.

The ladle is transported to the continuous caster. The melt pours into the tundish after the ladle sliding gate is opened, with continuous casting being established throughout a casting system with impact pod, stoppers, submerged entry nozzles and water-cooled copper molds. During casting also the final chemical composition is determined which is also stated on the inspection certificate. For casting of the 180 mm square billets, a two strand continuous caster with 9 m radius is used. The solidification is conducted throughout primary cooling in the mold and secondary cooling using water sprays. The billets are cooled down on turnover cooling bed.

The billets are reheated up to rolling temperature and rolled into round bars with a diameter of up to 50 mm. The same rolled bar surface is also examined using the automatic control line. The surface control is based on the flux leakage method, meaning that the surface of the material is locally magnetized and that deviations of magnetic flux (i.e., flux leakage) at the opened surface defects are detected. During surface control the data on number of examined bars, bars with defects and defects length are stored in the informational system.

Table 1 Parameters collected within the period from January 2018 to December 2018 for 78 consequently cast batches of 70MnVS6 steel

Batch	Carbon content after the second chemical composition analysis after tapping (C2), (%)	Manganese content after the second chemical composition analysis after tapping (MN2), (%)	Silicon content after the second chemical composition analysis after tapping (SI2), (%)	Sulfur content after the second chemical composition analysis after tapping (S2), (%)	Carbon cored wire addition after the second chemical composition analysis after tapping (CW2), (m)	Sulphur cored wire addition after the second chemical composition analysis after tapping (SW2), (m)	Time between the second chemical analysis after tapping and final chemical composition analysis at starting of the casting (T2F), (min)	Ferro-manganese (FEMN), (kg)	Ferrosilicon (FESI), (kg)	Additional sulfur cored wire addition (SWA), (m)
76124	0.56	0.80	0.20	0.022	30	237	106	25	54	11
76487	0.54	0.74	0.15	0.019	80	223	103	75	44	80
76488	0.54	0.79	0.16	0.020	180	223	82	23	107	27
76516	0.61	0.76	0.14	0.023	50	250	82	54	79	0
76517	0.61	0.72	0.18	0.030	120	200	90	76	53	25
76518	0.59	0.74	0.20	0.028	80	180	95	64	117	25
76519	0.59	0.73	0.20	0.030	40	170	97	75	122	10
76520	0.61	0.78	0.23	0.023	40	200	83	32	90	0
76561	0.55	0.71	0.18	0.021	40	230	81	95	75	0
76668	0.58	0.79	0.18	0.026	50	215	84	27	34	0
76669	0.55	0.77	0.19	0.022	70	193	79	47	128	15
76670	0.57	0.80	0.18	0.024	0	193	80	23	133	0
76671	0.62	0.78	0.20	0.022	0	228	87	28	44	0
76672	0.60	0.79	0.22	0.024	120	187	73	29	79	30
76673	0.62	0.82	0.24	0.030	0	173	93	0	73	15
76674	0.63	0.79	0.24	0.024	20	220	101	21	0	14
76675	0.61	0.75	0.19	0.023	0	192	81	51	77	0
76676	0.60	0.77	0.20	0.018	30	200	89	41	73	10
76767	0.57	0.74	0.19	0.024	90	200	90	55	124	45
76768	0.56	0.76	0.20	0.021	0	210	24	59	97	60
77048	0.53	0.81	0.16	0.027	270	193	85	18	98	0
77049	0.57	0.84	0.19	0.021	0	197	83	0	88	27
77076	0.52	0.79	0.18	0.023	200	240	104	25	64	50
77077	0.56	0.76	0.19	0.018	80	220	82	56	130	0
77078	0.57	0.76	0.19	0.022	60	200	91	56	54	45
77082	0.54	0.77	0.20	0.018	40	243	87	45	44	0
77083	0.61	0.81	0.20	0.023	70	200	81	22	118	13
77085	0.60	0.77	0.20	0.019	90	237	97	42	33	0
77086	0.63	0.74	0.20	0.024	100	190	82	72	110	190
77161	0.58	0.79	0.17	0.020	0	227	107	25	46	0
77162	0.60	0.78	0.19	0.025	60	190	87	36	119	0
77409	0.61	0.73	0.19	0.012	80	190	98	84	51	28
77410	0.55	0.78	0.17	0.017	160	220	77	35	97	0
77411	0.56	0.76	0.17	0.023	70	207	87	44	91	38
77412	0.61	0.78	0.19	0.024	50	193	85	32	94	0
77413	0.54	0.81	0.19	0.018	200	237	92	16	45	0
77414	0.59	0.81	0.22	0.017	40	227	68	16	89	0
77415	0.54	0.80	0.20	0.023	0	218	76	16	81	0
77416	0.60	0.84	0.19	0.018	120	213	87	0	102	22
77501	0.58	0.76	0.20	0.030	0	197	90	58	54	12
77766	0.58	0.75	0.18	0.021	210	237	88	65	65	0
77767	0.60	0.78	0.17	0.025	200	190	87	32	117	0
77768	0.60	0.77	0.16	0.022	40	190	95	44	128	0
77769	0.63	0.78	0.18	0.027	40	185	84	34	104	0
77770	0.63	0.74	0.17	0.013	120	217	86	70	50	22
77771	0.60	0.77	0.17	0.022	160	200	87	44	119	27
77772	0.60	0.79	0.18	0.026	340	183	102	23	109	0
77773	0.61	0.78	0.18	0.018	80	215	113	35	107	0
77783	0.61	0.76	0.17	0.019	200	233	90	54	64	9
77784	0.61	0.73	0.17	0.025	80	190	91	88	129	0
77792	0.60	0.79	0.18	0.018	150	237	83	38	44	0
77978	0.69	0.78	0.17	0.019	0	227	88	36	62	32
77979	0.59	0.70	0.16	0.024	110	207	74	115	135	37
77980	0.56	0.74	0.18	0.027	130	175	106	77	116	27
77981	0.56	0.76	0.16	0.026	0	190	97	67	116	19
77982	0.54	0.71	0.15	0.029	30	190	93	104	63	30
77983	0.56	0.75	0.16	0.025	120	197	86	74	116	0
77984	0.55	0.71	0.16	0.030	180	180	83	106	117	8
78224	0.58	0.78	0.19	0.022	60	213	101	40	52	50
78225	0.66	0.81	0.19	0.013	0	227	90	22	123	63
78376	0.55	0.74	0.22	0.029	100	200	86	75	122	80
78420	0.53	0.73	0.15	0.014	100	227	95	95	64	12
78421	0.57	0.75	0.16	0.024	100	200	79	57	126	32
78681	0.63	0.74	0.17	0.020	50	237	89	73	65	17
78682	0.61	0.73	0.16	0.025	0	197	83	84	132	0
78683	0.67	0.79	0.18	0.029	0	182	92	33	107	7
78903	0.53	0.70	0.18	0.017	80	250	83	105	56	8
78904	0.59	0.77	0.21	0.022	40	224	91	52	113	30
78905	0.54	0.72	0.21	0.027	40	200	95	94	110	30
78906	0.57	0.73	0.21	0.026	120	210	90	83	114	24
78907	0.56	0.75	0.17	0.015	160	248	75	62	78	20
78908	0.56	0.75	0.18	0.018	90	237	94	63	120	20
78909	0.61	0.78	0.18	0.022	0	207	127	45	118	0
78910	0.66	0.80	0.18	0.025	80	200	92	19	103	20
79233	0.62	0.77	0.19	0.210	80	213	93	41	46	0
79234	0.62	0.70	0.15	0.035	0	150	90	113	132	0
79604	0.57	0.81	0.16	0.001	40	247	100	11	57	30
79605	0.59	0.76	0.17	0.022	40	232	105	52	107	32

The following parameters were collected within the period from January 2018 to December 2018 for 78 consequently cast batches of 70MnVS6 (Table 1):

- Carbon (C2), manganese (MN2), silicon (SI2) and sulfur (S2) content after the second chemical composition analysis after tapping in weight percentage (%). Carbon, manganese and sulfur are required according to technical delivery conditions. Manganese and silicon also help deoxidization. Manganese and sulfur form the manganese sulfide inclusions in the steel which improve machinability and enable cracking during connection rod production.
- Sulphur (SW2) and carbon (CW2) cored wire addition after the second chemical composition analysis after tapping in meters (m). Their addition depends on their actual content in the melt and also final chemical composition required by technical delivery conditions.
- Time between the second chemical analysis after tapping and final chemical composition analysis at starting of the casting (T2F) in minutes (min). This time is related with ladle treatment time – from tapping until continuous casting where based on slag formation, alloying, refining and homogenization the chemical reactions took place including sulfur burn-off.
- Ferromanganese (FEMN) and ferrosilicon (FESI) addition in kilograms (kg). Ferromanganese and ferrosilicon are used as deoxidizers and also alloys.
- Additional sulfur cored wire addition (SWA) in meters (m). Due to possibility of undesirable clogging of tundish submerged entry nozzles during continuous casting this additional sulfur cored wire addition should be minimized.

For the purpose of this research, we used two methodological approaches: a multiple linear regression method and the genetic programming method.

In multiple linear regression, the linear relationship between a scalar response (i.e., dependent output variable) and one or more explanatory variables is established (i.e., input variables) [19]. Conventional linear regression method is based on a deterministic approach. A multiple linear regression method is widely used technique in different engineering fields [20].

In contrast to linear regression, however, the genetic programming is a non-deterministic evolutionary optimization approach that mimics a biological evolution [21]. The genetic programming is similar to a very well-known method of genetic algorithm. Both methods are evolutionary computation techniques frequently used for complex optimization tasks in various fields (see for example [19, 21-25]).

The genetic programming usually involves very complex structures (i.e., organisms and/or potential solutions of the problem) that are manipulated during simulated evolution [19]. The shapes of the organisms depend on the problem to be solved. Organisms in the genetic programming are composed of functional and terminal genes. Functional genes are most often basic mathematical operations (e.g., addition, subtraction, multiplication, division, power function, exponential function). Terminal genes are usually explanatory variables of the system under study. A set of constants can be added to a set of terminal genes. The goal of the genetic programming is to find an individual organism (a mathematical model) that best solves the problem we deal with [19].

3. Modelling of additional sulfur cored wire addition

On the basis of the collected data in Table 1, the prediction of additional sulfur cored wire addition was conducted using linear regression and genetic programming. For the fitness function, the average absolute deviation between predicted and experimental data was selected. It is defined as:

$$\Delta = \frac{\sum_{i=1}^{n} \left| Q_i - Q'_i \right|}{n} \tag{1}$$

where n is the size of the monitored data and Q'_i and Q_i are the actual and the predicted additional sulfur cored wire addition in meters, respectively.

3.1 Modelling of additional sulfur cored wire addition using multiple linear regression

On the basis of the multiple linear regression results, it is possible to conclude that the model does not significantly predict the additional sulfur cored wire addition ($p > 0.05$, ANOVA) and that only 7.21 % of total variances can be explained by independent variables variances (R-squared). Accordingly, there are also no significantly influential parameters ($p>0.05$).

$$\begin{aligned}\mathrm{SWA} = 45.73 \cdot C2 + 265.49 \cdot SI2 - 143.37 \cdot MN2 - 114.30 \cdot S2 + 0.024 \cdot CW2 + 0.042 \cdot SW2 - \\ -0.112 \cdot \mathrm{T2F} + 0.389 \cdot \mathrm{FEMN} + 0.049 \cdot FESI - 188.14\end{aligned} \quad (2)$$

The average absolute deviation from experimental data is 17.25 meters (m).

Regardless ANOVA results, the influences of individual parameters on the additional sulfur cored wire addition while separately changing individual parameter within the individual parameter range were calculated (Fig. 1). It is possible to conclude that according to multiple linear regression results the most influential is ferromanganese addition (FEMN).

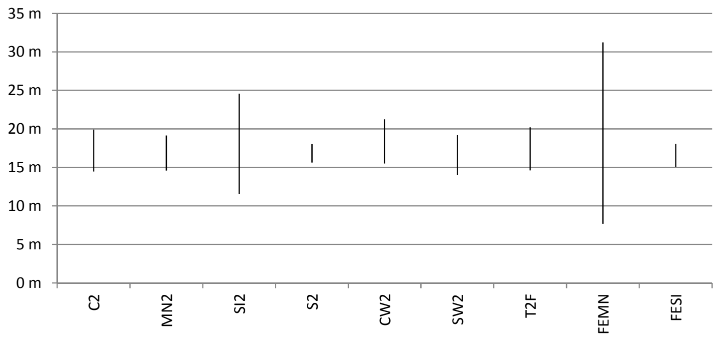

Fig. 1 Calculated influences of individual parameters on additional sulfur cored wire addition using the multiple linear regression model

3.2 Modelling of additional sulfur cored wire addition using genetic programming

For the purpose of this research, we used the basic arithmetical operations of addition, subtraction, multiplication and division (i.e., function genes), as well as independent variables (i.e., terminal genes) of the process to construct a potential successful solution. Each organism in each generation is evaluated for all fitness cases (i.e., for all combinations of input variables) and compared with the corresponding experimental values of dependent output variable according to the Eq. 1. The processes of genetic altering and evaluating of organisms is repeated until the successful solution is obtained [19].

We used in-house genetic programming system developed in AutoLISP programming language with the following evolutionary parameters: population size 2000, maximum number of generations 500, reproduction probability 0.3, crossover probability 0.7, maximum permissible depth of organisms in the creation of the population 6, maximum permissible depth after the operation of crossover of two organisms 30. Genetic operations of reproduction and crossover were used. We implemented tournament selection method with the tournament size of 7. Modelling experiment involved 200 runs.

The best mathematical model for prediction of additional sulfur cored wire addition obtained from 200 runs of genetic programming system is given in Eq. 3. Its average absolute deviation from experimental data is 10.80 m.

Similarly, as in case of multiple linear regression, we calculated the influence of individual parameter on the additional sulfur cored wire addition while separately changing individual parameter value within its range (Fig. 2). It is possible to conclude that according to the genetic programming results the most influential input variable is ferromanganese (FEMN) and ferrosilicon (FESI) additions.

$$
\begin{aligned}
\mathrm{SWA} = {} & \frac{0.541\left(2FEMN+\frac{0.541\cdot FESI}{FEMN\cdot FESI\left(\frac{0.541}{C2(1-SI2)+FESI\cdot SI2}\right)}\right)}{C2-FEMN-\frac{0.541\cdot FESI}{C2-SI2}-\frac{FESI}{C2-FEMN\cdot SI2^{2}}}+ \\
& SI2\left(FEMN-SI5+\frac{0.541\cdot FESI}{C2-FEMN\cdot SI2}+\right. \\
& SI2\left(\frac{FESI}{C2-FEMN+\frac{0.541\cdot FESI}{C2(1-SI2)+FESI\cdot SI2}-\frac{FESI}{C2-FEMN\cdot SI2^{2}}}+\frac{0.541(C2-FEMN\cdot SI2)\left(2\cdot FEMN+\frac{0.541\cdot FESI}{C2+\frac{0.541\cdot FESI}{C2-FEMN\cdot SI2}}\right)}{C2^{2}-1.293\cdot FESI+C2\cdot FEMN(-2.082-SI2)+2.082\cdot FEMN^{2}\cdot SI2}\right)+ \\
& \left.\frac{2\cdot FEMN+\frac{0.541\cdot FESI}{C2+\frac{0.541\cdot FESI}{C2-FEMN\cdot SI2}}}{C2-C2\cdot SI2+\frac{FESI(-1+SI2)+SI2(C2-FEMN\cdot SI2)\left(FEMN(-1+SI2)+SI2^{2}\right)}{C2-FEMN\cdot SI2}}\right)
\end{aligned}
\tag{3}
$$

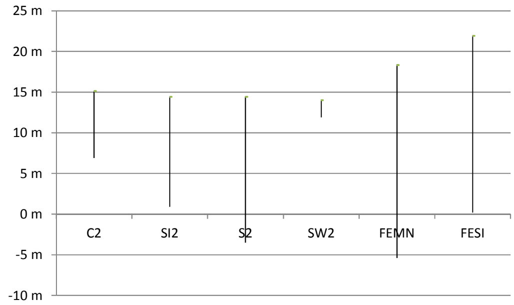

Fig. 2 Calculated influences of individual parameters on additional sulfur cored wire addition using the genetic programming model

4. Results and discussion

Regardless ANOVA results obtained using linear regression, the steelmaking process was changed. In the period from February 24, 2019 to October 17, 2019, a total of 12 batches of 70MnVS6 were produced with minimal ferromanganese additions (FEMN). Please bear in mind that during steelmaking, both ferromanganese and ferrosilicon were used for deoxidization. The results are gathered in the Table 2. It is possible to conclude that the additional sulfur cored wire addition was not necessary.

The average absolute deviation from experimental data gathered within period of changed steelmaking process is 19.54 m and 3.99 m at linear regression model and genetically obtained model, respectively. The genetic programming model outperformed the linear regression model for 4.90-times.

Also the role of other parameters which were not changed should be clarified. Carbon, manganese and silicon content after the second chemical composition analysis after tapping varies due to different scrap chemical composition (i.e., input material chemical composition) and additions and alloys which are added during tapping. They are also affected by later carbon, manganese and silicon addition. The same is with time between the second chemical analysis after tapping and final chemical composition analysis at starting of the casting which is influenced by technological and maintenance delays and also peak electricity period [17, 26]. The only possible changes could be attributed to ferromanganese and ferrosilicon additions.

After implementation of changes into production the addition of ferromanganese significantly decreased for 233.03 %, i.e., from 50.29 kg to 21.58 kg (t-test, $p < 0.05$). It must be emphasized that micro cleanliness before and after changes in production was also analyzed. According to technical delivery conditions, the K3 and K4 values without taking into account sulfur type of inclusions, determined according to DIN 50 602 were required. Micro cleanliness has been improved statistically significantly after changing of steelmaking process (t-test, $p < 0.05$). K3 and K4 values decreased from 6.49 to 4.58 and from 3.49 to 1.58, respectively.

Table 2 Parameters collected within the period from February 2019 to October 2019 for 12 consequently cast batches of 70MnVS6 using minimal ferromanganese additions

Batch	Carbon content after the second chemical composition analysis after tapping (C2), (%)	Manganese content after the second chemical composition analysis after tapping (MN2) , (%)	Silicon content after the second chemical composition analysis after tapping (SI2), (%)	Sulfur content after the second chemical composition analysis after tapping (S2), (%)	Carbon cored wire addition after the second chemical composition analysis after tapping (CW2), (m)	Sulphur cored wire addition after the second chemical composition analysis after tapping (SW2), (m)	Time between the second chemical analysis after tapping and final chemical composition analysis at starting of the casting (T2F), (min)	Ferro-manganese (FEMN), (kg)	Ferrosilicon (FESI), (kg)	Additional sulfur cored wire addition (SWA), (m)
80210	0.018	0.57	0.82	0.19	100	240	88.00	46	53	0
80211	0.032	0.55	0.76	0.24	30	180	74.00	47	107	0
80212	0.032	0.56	0.81	0.25	0	160	119.00	11	93	0
80214	0.033	0.62	0.79	0.19	0	163	87.00	32	119	0
80215	0.029	0.65	0.80	0.19	40	180	81.00	23	124	0
80595	0.027	0.57	0.79	0.21	0	180	97.00	29	99	0
81393	0.033	0.53	0.80	0.20	160	213	85.00	21	98	0
81394	0.028	0.58	0.82	0.18	120	239	94.00	0	52	0
81692	0.026	0.63	0.80	0.21	200	178	93.00	21	96	0
81881	0.007	0.58	0.81	0.21	60	259	79.00	12	38	0
81882	0.016	0.64	0.83	0.25	140	220	78.00	0	82	0
82076	0.028	0.60	0.80	0.19	60	170	75.00	17	106	0

Time between the second chemical analysis after tapping and final chemical composition analysis at starting of the casting, scrap rate of rolled material after automatic control line inspection, and casting, based on evaluation score, have not been changed statistically significantly after changing of steelmaking process (t-test, $p < 0.05$). Please mind that casting evaluation score is obtained using in-house software which evaluate casting based on casting parameters (e.g., stopper rod movements, vibrators, melt level in the mold).

5. Conclusion

In this paper the prediction of additional sulfur addition (i.e., sulfur burn-off) during 70MnVS4 steelmaking in Štore Steel Ltd. was presented. During ladle treatment, instead of only one sulfur addition, the sulfur was repeatedly added several times threatening clogging during continuous casting and as such influencing surface defects occurrence and steel cleanliness.

Accordingly, following parameters were collected within the period from January 2018 to December 2018 for 78 consequently cast batches of 70MnVS6:

- carbon, manganese, silicon and sulfur content after the second chemical composition analysis after tapping,
- sulphur and carbon cored wire addition after the second chemical composition analysis after tapping,
- time between the second chemical analysis after tapping and final chemical composition analysis at starting of the casting,
- ferromanganese and ferrosilicon addition,
- additional sulfur cored wire addition.

Based on these data additional sulfur addition was predicted using linear regression and genetic programming. On the basis of the linear regression results, it is possible to conclude that the model does not significantly predict the additional sulfur cored wire addition ($p > 0.05$, ANOVA) and that only 7.21 % of total variances can be explained by independent variables variances (R-squared).

Similarly, additional sulfur addition was predicted using genetic programming system. Also the influences of individual parameters on the additional sulfur cored wire addition while separately changing individual parameter within the individual parameter range were calculated. It is possible to conclude that the most influential are ferromanganese and ferrosilicon addition.

Based on modelling results the steelmaking process was changed. In the period from February 2019 to October 2019 a total of 12 batches of 70MnVS6 were produced with minimal ferromanganese additions. The additional sulfur cored wire addition was not necessary.

After implementation of changes into production, the addition of ferromanganese significantly decreased, micro cleanliness has been improved statistically significantly after changing of steelmaking process. Some other parameters discussed earlier have not been changed statistically significantly after changing of steelmaking process (t-test, $p < 0.05$).

In the future burn-off of other alloys and cost reduction analysis for most important steel grades produced in Štore Steel Ltd. will be conducted.

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