Assessment of Scrap-based Production for Low Phosphorous Stainless Steel

Wenjing Wei[1,2], Rutger Gyllenram[1], Peter Samuelsson[2] and Pär G. Jönsson[2]

(1. Kobolde&Partners AB, Stockholm, Sweden;2. Department of Materials and Engineering, Royal Institute of Technology, Stockholm, Sweden)

Abstract: Low phosphorous contents in austenitic stainless steels favours a resistance to stress corrosion cracking and reduces the susceptibility to hot cracking. An industrial problem is that phosphorous cannot be removed from chromium alloyed steels, since oxidation of chromium occurs before phosphorous oxidation. This brings a challenge for scrap-based stainless steelmakers since an accumulation of phosphorous in the steel cycle should be avoided. In this paper, the effects of the phosphorus content in stainless steel scrap have been studied when producing AISI 304-type of stainless steel with low phosphorus level demands. These steels are often produced by melting scrap by using the EAF-AOD route. The influence of scrap with varied phosphor contents on steels has been assessed by using RAWMATMIX®, which is a web-based raw material optimization software.

Key words: phosphorous, stainless steel, scrap-based steelmaking

1. Introduction

For stainless steel, the raw material costs can account for 70% of the total production cost[1]. A good EAF production planning would make a better use of alloy elements such as chromium and nickel from scrap materials which can therefore decrease the primary alloy additions in the AOD process. If the final product has a higher demand of low impurity level, such as phosphorus, it may contribute to an even higher raw material cost. As a residual element, excess phosphorous content has a negative impact on the hot cracking susceptibility for austenitic stainless steel[2]. However, due to the higher oxygen affinity of chromium compared to phosphorus, it is a common problem for phosphorous to be accumulated in the steel cycle. Before a commercial-scale dephosphorization technology is realized, activities such as sorting and selection of raw materials are of importance as well as dilution with primary material such as hot metal, HBI and DRI. It is also of major importance for steel producer to select the most economical mix of raw material and make an optimizing charging of both an EAF and an AOD converter to reach the most profitable production. This paper is aiming to investigate how the scrap quality will affect the stainless steel's economic and environmental performance.

2.Method

100 tonne AISI 304 series 18-8 stainless steel is selected as the aim product (18%Cr, 8%Ni, 0.04%C, P<0.02%, S<0.03%, Si<0.75%, Mn<2%, Cu<0.2%). Carbon steel scraps (1.2%C,0.8%Si,0.1%Cr, 0.08%Ni, 0.05%Cu, 0.5%Mo, 0.001%P, 0.01%S,1%Mn) are mixed with five stainless steel scraps (0.08%C,0.2%Si,17%Cr, 7%Ni, 0.2%Cu, 0.1%Mo,0.1%Co, 0.02-0.032%P,0.01%S,0.8%Mn) which have different phosphorous levels (P=0.02%, 0.023%,0.026%,0.029%,0.032%) and defined as charging case: reference, case 1, case 2, case 3 and case 4. The cost-effectiveness of stainless steel scraps with different phosphorous contents was assessed by using RAWMATMIX™, which is a web-based optimization software. Steel is produced in a modern electric arc furnace and refined in an AOD converter with the module setting as shown in Table 1. The following assumptions are made when performing optimization production model:

- A carbon content C>1% in EAF motel melt to supply enough heat during the AOD process
- A lime amount is calculated to keep an EAF slag basicity of 1.5 and an AOD slag basicity of 2, which favours a lower slag viscosity, a lower solubility of chromium oxide and therefore a less Cr loss[3].
- The amount of FeSi charged is aiming to reach a high silicon content of 0.4% in the molten melt, which enhances the recovery of chromium from the electric arc furnace and transfer ladle[4].
- 8% materials are charged in AOD converter for cooling purpose and final analysis adjustment.
- The AOD process is only considering raw material and slag treatment costs. Thus assumed that no extra energy sources is added in the AOD process and that only chemical oxidation heat is generated in process.
- The refining time is calculated as 15 min (charging+ analyse sample) +O_2 injection time. O_2 injection time is relying on the total O_2 consumption in AOD and an estimated average injection rate 0.36Nm^3/ton*min[4].

Table 1. Typical EAF-AOD production data and cost data

Parameter	Amount	Unit	Parameter	Amount	Unit
EAF-AOD production data					
Casting weight	100	ton	Dust from lime	10	%
EAF Tapping temperature	1650	˚C	Power on time	~60	min
AOD Tapping temperature	1650	**˚C**	Ave. power on	45	MW
Temperature loss after EAF	150	˚C	Ave. power off time	15	min
Furnace burners (Fuel: LPG)	3000	kWh/charge	Power on heat loss	5	MW
Oxygen for EAF slag foaming	~1200	Nm3/charge	Power off heat loss	1	MW
Coal injection	400	Kg/charge	Gas treatment in AOD	1000	Nm3/charge
Electrode consumption	4.2	kg/ton	Slag carry over amount	100	kg/charge
Dust from metallics in EAF	1	%	Argon injection	1000	Nm3/Charge
Fixed cost data					
Staff cost	10(75)	MEUR(MCNY)/year	Capital cost*	67.75(508)	MEUR(MCNY)/year
Maintenance	10(75)	MEUR(MCNY)/year	Overhead cost	1(7.5)	MEUR(MCNY)/year
Varied cost data					
Slag handling fee	20(150)	EUR(CNY) / t slag	Burnt lime	120(900)	EUR(CNY)/ton
Dust handling fee	40(300)	EUR(CNY) / t dust	Coal	300(2250)	EUR(CNY)/ton
FeSi	890(6675)	EUR(CNY)/ton	Electrode	4(30)	EUR(CNY)/kg
FeCr	2330(17475)	EUR(CNY)/ton	LPG	20(150)	EUR(CNY)/GJ
Ni alloy	11020(82450)	EUR(CNY)/ton	Electricity	0.05(0.375)	EUR(CNY)/kWh
carbon steel scrap	247(1853)	EUR(CNY)/ton	Oxygen gas	0.1(0.75)	EUR(CNY)/Nm3
Argon gas	0.6(4.5)	EUR(CNY)/Nm3			
CO_2 data for input**					
Carbon steel scrap	21 [5]	kg CO_2eq/t	Coal (99.96%C)	224 +3059 [6]	kg CO_2eq/t
Stainless steel scrap	21 [5]	kg CO_2eq/t	Electrodes (100%C)	0.65+3.663[6]	kg CO_2eq/kg
FeCr (65%Cr,6%C)	6300 [7]	kg CO_2eq/t	LPG ***	8+64[5]	kg CO_2eq/GJ
Ni(100%Ni)	7430 [8]	kg CO_2eq/t	Electricity (coal fired)	1.058[9]	kg CO_2eq/kWh
FeSi(75%Si,0.2%C,1.5%Al)	5000	kg CO_2eq/t	Oxygen	0.355[6]	kg CO_2eq/Nm3
Burnt Lime (98%CaO,2%MgO)	1390 [6]	kg CO_2eq/t	Argon	0.103	kg CO_2eq/Nm3

*Capital cost is calculated based on an investment cost 340MEUR,10 years depreciation time and 15% interest rate. 1EUR=7.5CNY
**CO_2 data of coal, electrode and LPG includes upstream and process CO_2 while the other input process sources are upstream CO_2 data.
***LPG consumes 5.11Nm^3 O_2/Nm^3, heat content is 93.24MJ/Nm^3

3. Results

3.1 Effect of phosphorous content on charge mix

Figure 1 shows the optimized charging ratio for different charging cases. The reference charge uses a clean stainless steel scrap. The optimization results indicate that, the higher residue element phosphorous content in stainless steel scrap, the less amount of stainless steel scrap could be charged. Meanwhile, charging of phosphorous polluted scrap will result in an increasing need of carbon steel scrap for diluting the melt. The charging of carbon steel is in consequence of a higher addition of primary alloy materials.

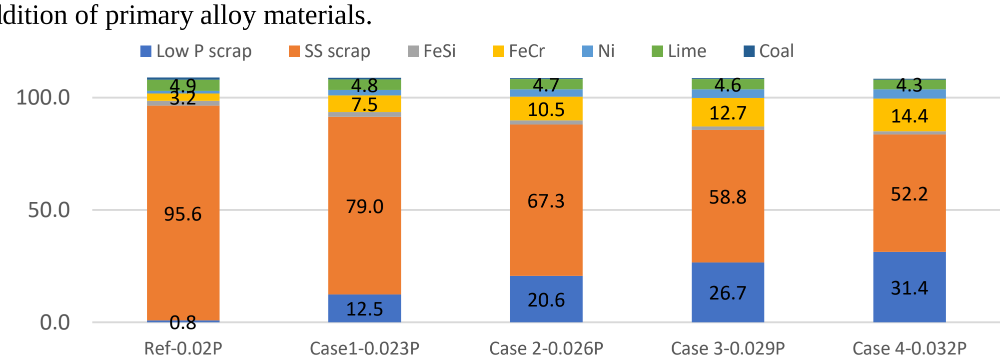

Figure 1. Charging amount of different charging case (unit: ton)

3.2 Effect of phosphorous content on cost

Table 2 shows that the increasing of phosphorous in scrap will significantly increase the raw material cost, which mainly contributes from primary alloy cost. On the other hand, the cost of the reduction agents FeSi and lime declines. The saving of FeSi addition is due to a higher content of Si in carbon steel scrap, which requires less FeSi additions when more carbon steel scrap is charged. This change also has an impact on lime addition due to constraints of the basicity of the slag.

Table 2 Production cost of 100 ton steel excluding stainless steel scrap cost

	Ref-0.02P		Case1-0.023P		Case 2-0.026P		Case 3-0.029P		Case 4-0.032P	
	EUR	CNY	EUR	CNY	EUR	CNY	EUR	CNY	EUR	CNY
Carbon steel scrap	203	1525	3081	23109	5100	38246	6599	49491	7756	58173
FeCr	7344	55082	17393	130449	24472	183536	29592	221943	33571	251780
Ni	13997	104978	26588	199412	35448	265857	41888	314159	46878	351582
FeSi	1911	14331	1795	13462	1706	12792	1463	10975	1262	9462
Lime	583	4374	571	4284	558	4185	546	4095	510	3825
Energy cost	2085	15637	1968	14757	1885	14141	1901	14259	1911	14333
Operation cost	1854	13905	1850	13877	1847	13850	1851	13881	1848	13858
Fixed cost	9999	74991	9989	74918	9989	74918	10067	75501	10117	75879
Total	37976	284823	63236	474269	81004	607527	93907	704303	103852	778891

3.3 Effect of phosphorous content on production time, dust and slag amount

Figure 2 is giving the influence of scrap quality on production time, dust and slag amount. Charging of ‘dirty’ stainless steel scrap gives a result of increasing production time and slag amount. The dust amount is not varied much for the different charging cases.

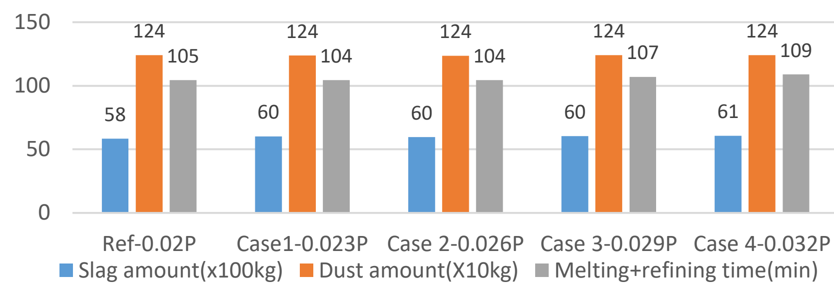

Figure 2. Effect of charging on slag, dust amount and production time

3.4 Value-in-use price of scrap and price estimation for stainless steel scrap

Considering the cost effect in Table 2, stainless steel scrap price should vary with respect to the scrap quality in order to make a profitable production economy. If set high quality scrap (P=0.02%) price as 1020EUR/ton(7650CNY/ton) and its production cost as a standard production economy for the plant (Figure 3), price of scraps with higher phosphorous contents can be calculated according to its value-in-use. Value-in-use price of stainless steel scraps (P=0.023%, 0.026%,0.029% and 0.032%) should be 915EUR/t (6860CNY/t), 810EUR/t (6071CNY/t), 707EUR/t (5303CNY/t) and 606EUR/t (4543CNY/t) respectively. An estimation equation can be extracted between the phosphorous content and scrap price as shown in Figure 4. From the equation, it is possible to estimate stainless steel scrap value-in-use price according to its phosphorous content. In general, with phosphorous content increasing 10ppm, the price of scrap should be reduced with around 36 euro/t (270CNY/t).

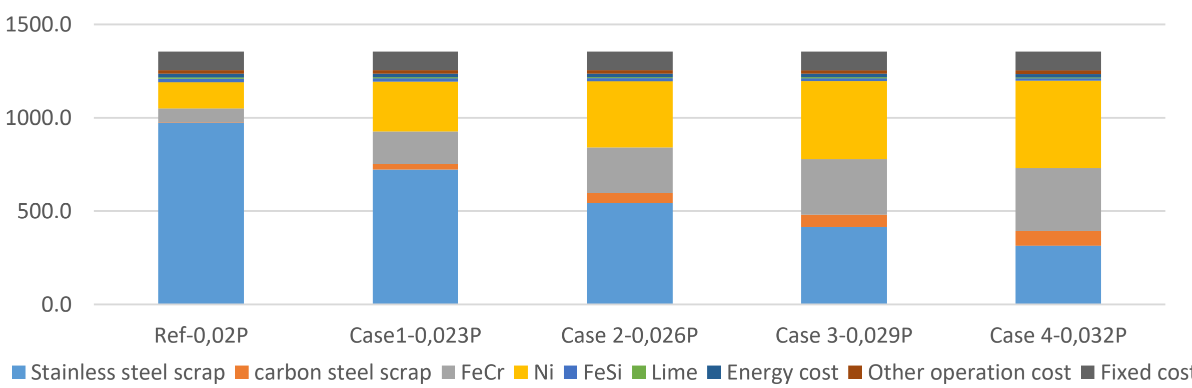

Figure 3. Production cost including the value-in-use price of stainless steel scrap EUR/100ton

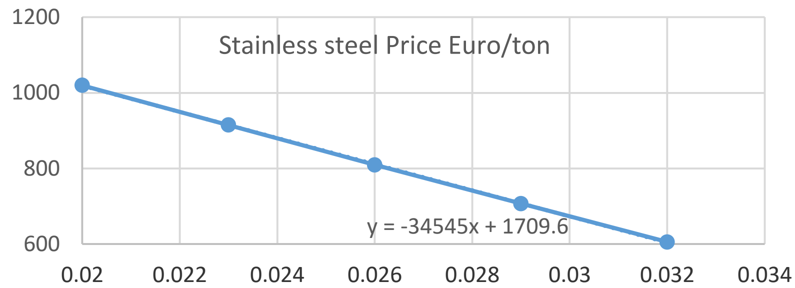

Figure4. The relationship between P% in scrap and the stainless steel price Euro/ton

3.5 Effect of phosphorous content on CO_2 emission

As illustrated in Table 3, different charging choices have varied effect on product's total carbon footprint. For high ratio charging of stainless steel scraps (> 70% of total material charge), for instance the reference case and case 1 which consequently lowers the initial carbon. Extra carbon sources have been added in EAF to keep a proper carbon content(C>1%) in the tapped melt in order to provide a sufficient reaction heat in AOD process. The more stainless steel scrap charged in production, the higher charging amount of extra carbon and higher carbon footprint for the product. For cases 2, 3 and 4, the carbon footprint is mainly influenced by the use of primary ferroalloy materials. With a higher phosphorous content in scrap, the environment impact of the product becomes larger.

Table 3. Carbon footprint of product (kgCO2eq/t)

	Ref-0.02P	Case1-0.023P	Case 2-0.026P	Case 3-0.029P	Case 4-0.032P
Upstream CO2	3 445	2 887	2 498	2 672	2 808
Process CO2	70	70	70	78	84
Total	3515	2957	2568	2750	2892

4. Conclusions

This study shows that the use of stainless steel scraps with low phosphorous contents can reduce the slag amount, production time, consumption of ferroalloys, total production cost and carbon footprint. However, if the stainless steel scrap is over 70% of the total charge it can contribute to an addition of extra carbon, which has a negative impact on the greenhouse gas effect. It is necessary for steel producers to take phosphorous content into account when they purchase scrap with different qualities. An estimation equation between phosphorous content and scrap's value-in-use price is obtained in the study. It can be used as a reference when purchasing stainless steel scrap and when considering investments of scrap sorting technologies to ensure a competitive production economy.

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