FERRO ALLOY DESIGN, FERRO ALLOY SELECTION AND UTILISATION OPTIMIZATION WITH PARTICULAR FOCUS ON STAINLESS STEEL MATERIALS

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ABSTRACT

The ferro alloy market is characterised by a very long communication distance between the consumer and the producer. This has created a situation where it has been difficult to change ferro alloy properties. In this paper different FeNi and FeCr-compositions are discussed and their merits for stainless steelmakers in different situations are compared using the process models applied at Outokumpus Avesta works and Acerinox's Columbus operation.

1 INTRODUCTION

Raw materials, in particular ferro alloys, are a major cost contributor in stainless steelmaking. This is caused by purchasing costs for the commodity as well as for operating costs caused by it during melting and refining operations. The ferro alloys are also a constant source of production disturbances and unexpected process behaviour. The total cost for purchase and operation is not static but varies greatly between different producers. In fact what is a cheap raw material in one situation may be very expensive in another case.

2 IMPORTANCE OF RAW MATERIALS IN STAINLESS STEELMAKING

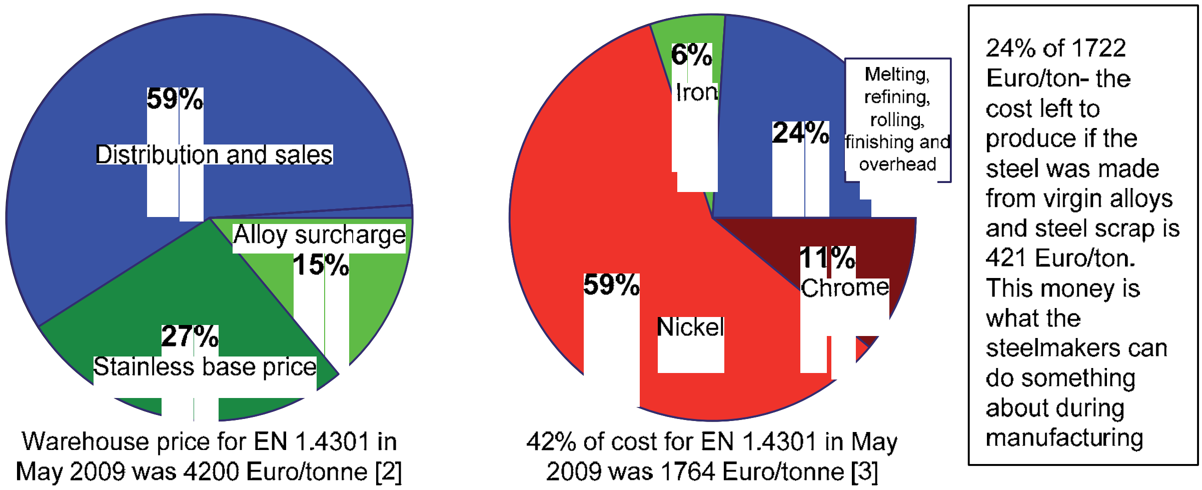
Together with 30-90% (60% average [1]) scrap, alloys are the most important raw material in stainless steelmaking. The cost for purchasing and refining the alloy is a very important component of the stainless steel price, see figure 1. The total cost for the steel producer is a combination of purchasing and operating costs. Hence a good raw material design is also important along with the matching of the correct producer to each product.

During the recent raw material boom, previous to the recession, new materials emerged on the market. This was mainly new types of ferronickel such as the nickel pig-iron but also a drive to process complex ores to complex alloys and reclaim valuables from slag-dumps was noticed. This could be the start of a new generation of alloys entering the market- some of them with combinations of alloys, others with lower alloy concentration than in traditional materials.

The design of such products together with a careful market selection would ensure that a maximum customer value and minimum environmental impact is obtained in this process.

In addition to the value of the purchased element, the steel producer obtains iron and potentially chemical energy in the form of dissolved carbon and silicon. The iron has a substantial value in the aspect that it is well defined and available in a fast melting, lumpy shape- this is seldom true for scrap. The chemical energy also has a potential value; however it can just as well be a problem and a cost.

The raw materials may not only be a source of valuables but it can also contain inclusions, tramp elements and undesired reduction agents such as Ti or Al. These aspects are only discussed briefly in this paper.



Warehouse price for EN 1.4301 in May 2009 was 4200 Euro/tonne [2]

42% of cost for EN 1.4301 in May 2009 was 1764 Euro/tonne [3]

24% of 1722 Euro/ton- the cost left to produce if the steel was made from virgin alloys and steel scrap is 421 Euro/ton. This money is what the steelmakers can do something about during manufacturing

Figure 1: Typical cost structure in stainless steel manufacturing

3 STRUCTURE OF THE FERRO ALLOY MARKET

Direct communication between the consumers and producers of ferro alloys is too rare according to many both producers and consumers. The interaction is done by sales organisations, traders and purchase departments. One reason for the low level of interaction is probably that the producers are relatively spread out over the planet according to where the ore's are mined while the steel works tend to be situated in close vicinity to the main markets which correspond to the main raw material source- scrap. This is also why traders play a vital role in making this market work.

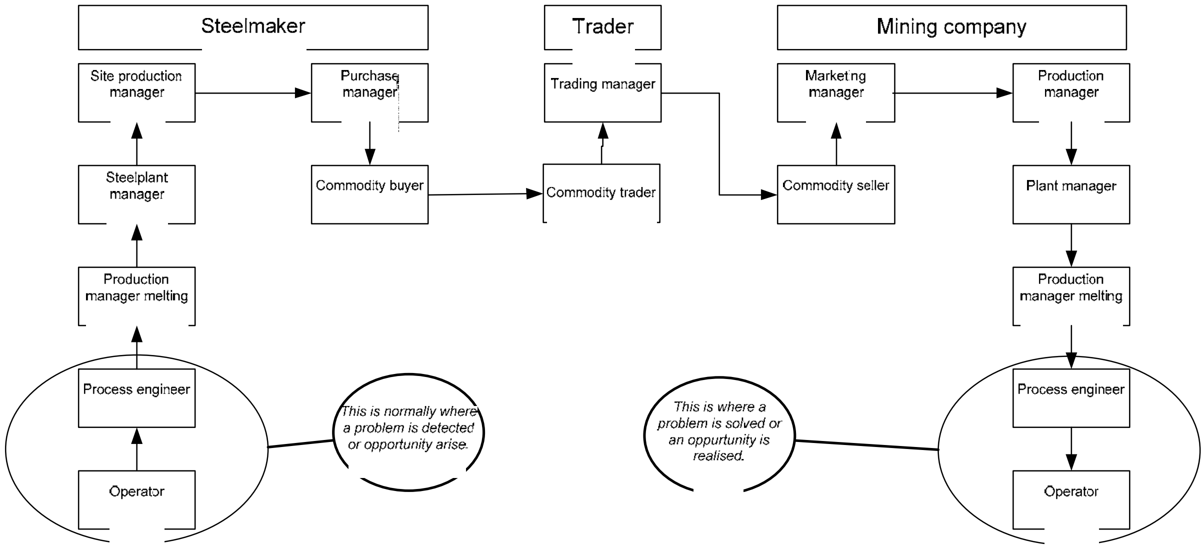


Figure 2: Typical structure of the ferro alloys market

Geographic and cultural differences together with structures within resource and steelmaking groups and market organisation make communication between producers and consumers difficult, see example in figure 2. This means that it is often necessary to manufacture raw materials according to standards even though this in fact will increase the alloy price significantly. In many cases, the steel makercould just as well use a cheaper off standard product.

A shortcoming of this market structure is that it is difficult to trap business opportunities such as demand for low content of one element or with permission for high levels of another element. This may mean possibilities to use cheaper reduction agents or collecting a premium is lost by the desire to meet the entire markets demand instead of looking for a particular customers need.

4 RAW MATERIALS EVALUATED

1.2 General

For the discussions in this paper a number of raw materials was selected. Some of them exists as bulk alloys and some of them are available or have been projected as a consequence of refining or by reduction of complex ores, see table 1. These particular alloys were selected because they cover a wide range of properties.

Table 1: Alloys used for evaluation and discussion

Element	HC FeCr	Ch. Cr	LC FeCr	2Cr22	CrNi	FeNi15	FeNi35	NiPl	Fe Scrap	N. Scrap
C	7	7	0,1	0,02	0,02	0,04	2	0,04	0,1	0,05
Cr	70	50	70	22	11	0	0	0	0	18
Si	2	4	2	0,5	0,5	0,3	2	0,06	0,1	0,5
Ni	0	0	0	0	11	15	35	99,9	0	8
Fe	21	39	27,9	77,5	77,48	84,66	61	0	99,8	73,45

In this table only C, Cr, Si, Ni and Fe are considered. P, S and a number of other elements are also important in applicability and pricing of the materials. In terms of operating costs for the steelmaker these main elements are the most important ones as other elements rather limits if a material can be used at all.

One basic assumption in this paper is that scrap is an equal alternative to the ferro alloy and that key elements have an equal value and price in different raw materials. This is not always the case; the scrap is often not available in a format suitable for bulk handling and may need further treatment for up to 150 euro/ton before it can be added into the converter. On the other hand, the scrap normally comes with a significant element discount compared to the ferro alloys.

1.3 Yield

In terms of yield for value elements in alloys and scrap, there is a significant difference appearing based on where the additions are made in the process-chain, see figure 3. Normally the yield improves the later in the process the addition is made. For Cr the yield may be as low as 90% in an EAF while it is above 99.5% in a ladle while for Ni the yield difference can range between 96-99.9%. This means of course there is always a drive to make additions as late as possible in the process chain without compromising quality of the product and without being forced to use expensive alloys. In this paper no effort was made to model or even to consider this aspect.

1.4 Environmental impact

High levels of carbon combined with high levels of silicon means that surplus reduction power is available during a refining process. This cannot be utilized in most situations and the combination then becomes a mismanagement of precious resources and should be avoided. It generates surplus slag, longer processing time, increased lining wear which all means that an increased environmental footprint is made by the process. In a melting furnace it is different and the high silicon and carbon lowers the melting point and decrease the metal losses to the slag

A particular problem with surplus silicon in the refining is that it does not only increase the slag amount generated by the use of the product but also metal losses. Thus a lower metallurgical yield of the process is a consequence of increased silicon. This effects chromium and manganese more than other elements as small amounts of their oxides normally are lost to the slag. But it also decreases the loss of noble metals such as nickel and molybdenum as metal droplets and spillage also will increase when much slag is handled.

1.5 Value related to information

One of the reasons why having raw materials with a standard specification was so important for steelmakers was that this was a necessary to be able to calculate alloy needs.

Today with the help of computerized alloy optimization it is in fact as easy to handle unique batch information as standard information. In fact most special steel makers have an organizational mind-set for batch operations when it comes to alloying, this means that for them, the final chemistry must become exactly right on each particular tap rather than becoming very good in average.

For a particular batch of material, it would mean that it is evaluated on its own merits rather than on the worst part of the production.

For practical reasons steelmakers want narrow elemental ranges in their purchased alloys but this is more caused by stock-keeping and logistics rather than for any metallurgical reason.

1.6 What about inclusions?

Inclusions that are of importance for stainless steel manufacturers are generally formed late in the process. The inclusions may be oxides, nitrides or carbides alone or in complexes. The effect of the inclusions in the steel is surface errors, corrosion initiation and mechanical insufficiencies.

Some of the inclusions are formed as a consequence of late scrap and alloy additions, see figure 3. What happens in such situations is that an alloy lump with a high melting point compared to the steel becomes a suitable surface for inclusion formation and growth. Inclusion initiation, growth or removal is seldom or never neither a problem nor a possibility in the converter. The turbulence in the converter is simply too great to allow a structured inclusion engineering. This has to be done downstream in a calmer ladle.

Only a very small amount of the alloys used in stainless steel making are added in the ladle station. As a consequence of inclusion engineering awareness the portion, is probably decreasing as well.

5 DIFFERENT MELTSHOP CONFIGURATIONS

In this paragraph a few typical melt shop configurations suitable for stainless steel manufacturing are discussed from a ferro alloy and scrap addition perspective. Focus on the discussion is placed on the secondary metallurgy.

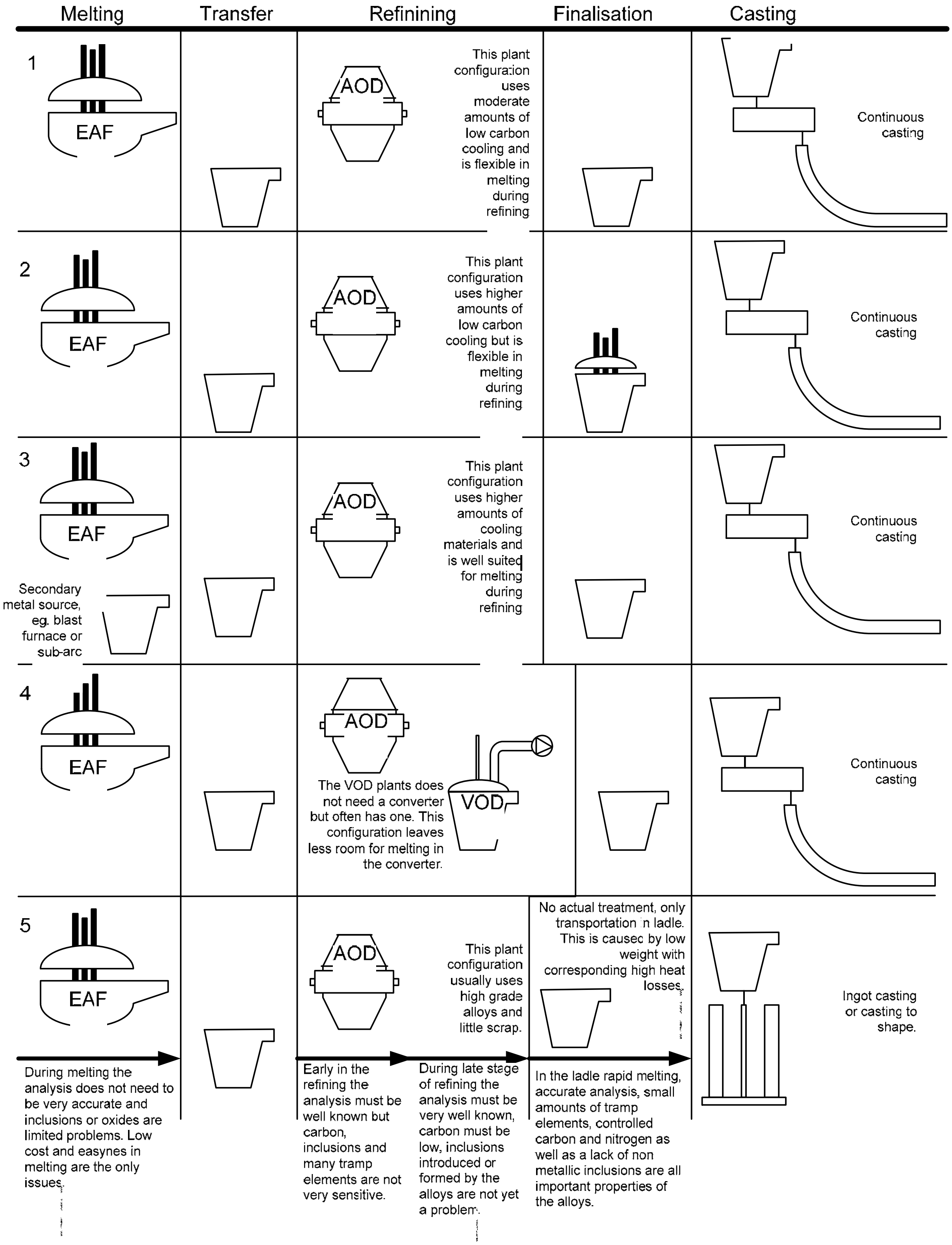
Different melt shop configurations will demand different raw-materials just as different geographical markets will. Some configurations require melting in the converter, some require much cooling while many are designed mainly to handle scrap very efficiently. It is important to understand in which segment a certain melt shop belongs. Some typical configurations are discussed in figure 3.

Line 1 is the most common configuration. This line is used as the base case for the simulations used for evaluation in terms of mass build-up and tapping temperature target.

Line 2 will require more coolants late in the process but is otherwise similar to line 1. This is a common development of line 1.

Line 3 is normally more similar to the high energy cases 10-14 described in table 2 due to the high carbon and silicon content that is normally expected on metal transferred from reduction furnaces.

Line 4 and 5 though very different in actual configuration are likely to be similar to cases 20-24 in table 2 in the sense that they tend to have an energy deficit and less room for mass-build up in the converter.



This plant configuration uses moderate amounts of low carbon cooling and is flexible in melting during refining

This plant configuration uses higher amounts of low carbon cooling but is flexible in melting during refining

This plant configuration uses higher amounts of cooling materials and is well suited for melting during refining

The VOD plants does not need a converter but often has one. This configuration leaves less room for melting in the converter.

This plant configuration usually uses high grade alloys and little scrap.

No actual treatment, only transportation in ladle. This is caused by low weight with corresponding high heat losses.

During melting the analysis does not need to be very accurate and inclusions or oxides are limited problems. Low cost and easynes in melting are the only issues.

Early in the refining the analysis must be well known but carbon, inclusions and many tramp elements are not very sensitive.

During late stage of refining the analysis must be very well known, carbon must be low, inclusions introduced or formed by the alloys are not yet a problem.

In the ladle rapid melting, accurate analysis, small amounts of tramp elements, controlled carbon and nitrogen as well as a lack of non metallic inclusions are all important properties of the alloys.

Figure 3: Line 1 is a duplex scrap based line, line 2 is a duplex scrap based line modified with a ladle furnace, line 3 is a line where iron arrives from a blast furnace, line 4 is a triplex line with a VOD for final decarburisation and the last line is a smaller foundry configuration.

6 PROCESS MODEL USED FOR SIMULATIONS

1.7 General

UTCAS is an advanced computer system specially designed for the converter process management. The system concept includes an effective real-time process control system as well as tools for process design and production evaluation, see figure 4. It is used for stainless steelmaking production process control and for process design in Outokumpus Avesta Works as well as in Acerinox's Columbus Stainless Works.

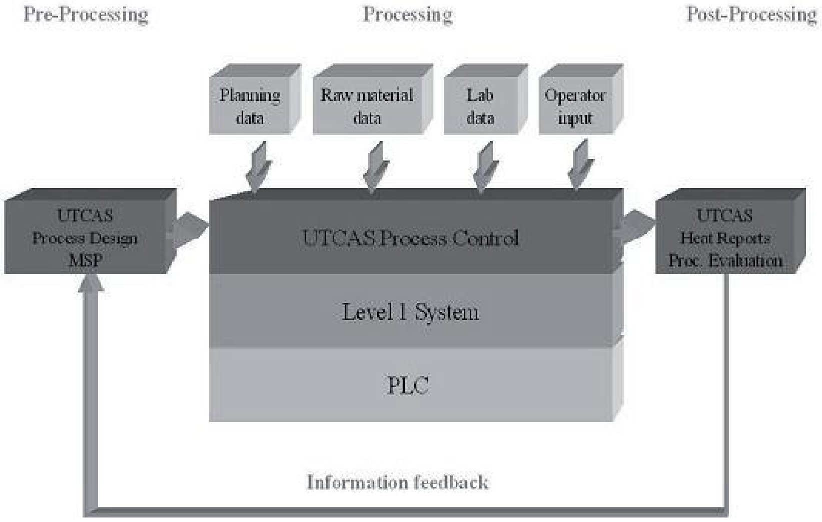


Figure 4: The UTCAS concept for process control and management [4].

1.8 Process models

The UTCAS system includes a set of highly sophisticated metallurgical models capable of determining heat and mass balance and chemical composition continuously during the process. The models are also used to generate a forecast – a prediction – of the final temperature and slag/metal composition based on planned gas blowing and additions. The prediction is used as a valuable tool when designing the process prior to production and also during processing by optimizing and controlling the process in order to meet the final targets. The core of these models is based on Sjöbergs work [5].

In the installations mentioned above, the models have been used in the production of several thousands of heats of various grades. The calculation results are continuously verified by samples and measurements and shows good correlation.

1.9 Simulation

The same models as described under 6.2 can be configured as an off-line simulator providing an environment for analyzing the effects and results of various potential process scenarios such as adding different specific materials at different stages during the process.

Since the models in such a simulation are capable of calculating on all significant consequential effects, such as total gas consumption and the required amounts of reduction agents, slag formers and additional alloys, the total cost for each case can easily be determined.

It is in this configuration that UTCAS has been used in this paper. The results from the simulations are shown in tables 2 and table 3.

7 COST MODEL FOR SCENARIO EVALUATION

To calculate production cost for the different scenarios the following expression is used:

$$Production\ cost = Cost_{Si}^{reduction} + Cost_{slagformes} + Cost_{gases} + Cost_{refractory}$$

The refractory cost is assumed to be a function of inserted oxygen amount where the average oxygen consumption 2056 nm3 gives a refractory cost of 1500 euro for the heat, this figure corresponds to a refractory life of 100 heats for a 150 ton lining. The expression will thus be:

$$Cost_{refractory} = 1500\ x \frac{Amount\ of\ oxygen}{2056} \square \frac{Euro}{ton}$$

This way of estimating the refractory consumption is just one of many ways, there is not one method that is scientifically accepted but among industry people it is accepted that metal/refractory contact time as well as the amount of silica present in the system and operating temperature are important parameters. Both of these figures are closely related to the used oxygen amount.

The unit costs for Si, slagformers and gases are assumed to be as follows including transportation, capital, disposal of residues etc.:

$$Cost_{Si}^{reduction} = 962 \frac{Euro}{ton\ Si}$$

$$Cost_{slagformes} = 150 \frac{Euro}{ton\ Slagformer}$$

$$Cost_{gases} = 0.07 \frac{Euro}{nm^3\ Oxygen} + 0.06 \frac{Euro}{nm^3\ Nitrogen} + 0.5 \frac{Euro}{nm^3\ Nitrogen}$$

The used prices are estimated based on discussions with production engineers and metallurgists or gathered from free information sources on the internet[6] in the case of the ferrosilicon price.

8 SOME SCENARIOS

In this section the merits of the alloys defined previously in table 1 are analyzed using the UTCAS software presented in a previous section. The alloys are compared to each other as well as to scrap of similar composition as the final metal.
All simulated cases generates 100 t of steel with the same final composition and temperature (0.02% C, 0.5% Si, 18.0% Cr , 8.0% Ni , 0.002% S , 1620 °C).

The start conditions for the cases differed slightly (Cases 10-14: 2.5% C , 0.5% Si , 1600 °C; Cases 20-24: 0.7% C , 0.1% Si , 1600 °C; Other cases: 1.5% C , 0.2% Si , 1600 °C). The start mass which is indicated in the tables and composition was adapted to match the desired additions: This means that for cases when Ni was added in the converter less Ni was available in the transfer composition.

Consumption of SiMn and Argon was constant, as was the slag-composition after the treatment.

In table 2, Cases 1-9 illustrates the effect of making scrap additions in different process stages.

Cases 10-14 repeat some of the addition cases but with more available chemical energy (this is a typical situation for a plant where pig iron or liquid ferro alloys are transferred).

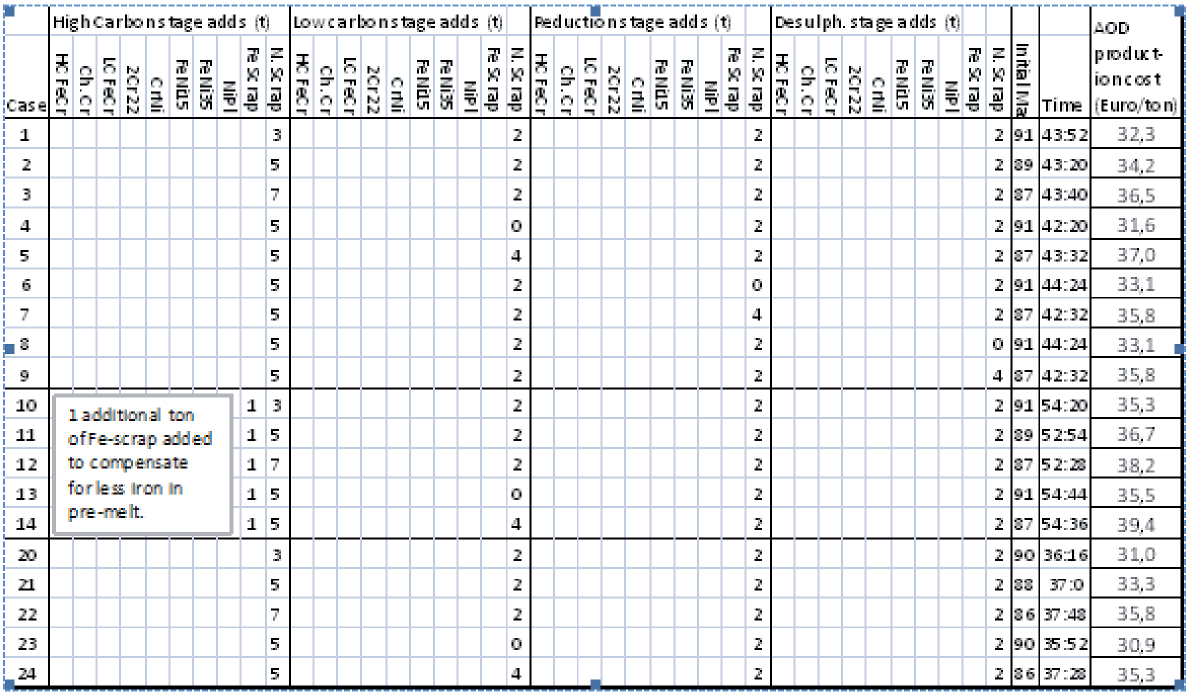
Cases 20-24 repeat some of the addition cases with less available chemical energy (this is a typical situation in a plant with a very high scrap ratio).

From the table 2 scenarios the main conclusions are:

- To refine the steel as fast as possible and to minimize treatment costs, low carbon scrap additions should be maximized late in the process after the decarburisation.
- In cases where much energy is available, scrap additions during decarburization decreases treatment time.
- When little energy is available, scrap additions during decarburization increases treatment time.
- The influence on process time on a 100 t heat by selecting where to put specific additions is in the order of 1 minute per ton of addition.
- With a cost difference of 4-5 Euro/produced ton, the influence on cost per ton of produced unit by selecting where to put an addition is in the order of 1 euro per ton of addition.

Thus, the difference between the best or worst decision on when to make an addition could be up to 10 minutes in process time and 1000 Euros in total cost.

Table 2: 9-13 ton of neutral scrap added in different process situations to demonstrate influence of converter additions and importance of optimizing when to make an addition.



	High Carbon stage adds (t)										Low carbon stage adds (t)										Reduction stage adds (t)										Desulph. stage adds (t)												
Case	HC FeCr	Ch.Cr	LC FeCr	2Cr22	CrNi	FeNi15	FeNi35	NiPl	Fe Scrap	N. Scrap	HC FeCr	Ch.Cr	LC FeCr	2Cr22	CrNi	FeNi15	FeNi35	NiPl	Fe Scrap	N. Scrap	HC FeCr	Ch.Cr	LC FeCr	2Cr22	CrNi	FeNi15	FeNi35	NiPl	Fe Scrap	N. Scrap	HC FeCr	Ch.Cr	LC FeCr	2Cr22	CrNi	FeNi15	FeNi35	NiPl	Fe Scrap	N. Scrap	Initial Ma	Time	AOD product-ion cost (Euro/ton)
1										3										2										2										2	91	43:52	32,3
2										5										2										2										2	89	43:20	34,2
3										7										2										2										2	87	43:40	36,5
4										5										0										2										2	91	42:20	31,6
5										5										4										2										2	87	43:32	37,0
6										5										2										0										2	91	44:24	33,1
7										5										2										4										2	87	42:32	35,8
8										5										2										2										0	91	44:24	33,1
9										5										2										2										4	87	42:32	35,8
10	1 additional ton of Fe-scrap added to compensate for less iron in pre-melt.								1	3										2										2										2	91	54:20	35,3
11									1	5										2										2										2	89	52:54	36,7
12									1	7										2										2										2	87	52:28	38,2
13									1	5										0										2										2	91	54:44	35,5
14									1	5										4										2										2	87	54:36	39,4
20										3										2										2										2	90	36:16	31,0
21										5										2										2										2	88	37:0	33,3
22										7										2										2										2	86	37:48	35,8
23										5										0										2										2	90	35:52	30,9
24										5										4										2										2	86	37:28	35,3

In table 3, simulations were made where two tons of alloys, added at different times, were allowed to substitute the same amount of neutral scrap.From the table 3 scenarios the following conclusions are drawn:

- The influence on process time on 100 t heat by selecting different addition order is in the order of 1 minute per ton of addition.
- Less Si and C clearly give a faster process.
- High C and Si additions give less time influence early in the process and there are restrictions on using them late in the process.
- Cr should be added late in the process and Nickel early when this is possible considering other alloy properties.
- There are restrictions on high carbon raw materials in terms of their use late in the process that makes them less attractive than low carbon alternatives.
- The production cost difference by selecting when to use specific alloy in the process is in the order of 1 euro per ton of addition.
- The production cost difference by selecting what alloying to do in the converter is in the order of 1 euro per ton of addition.

Thus, the difference between the best or worst decision on what kind of 10 t addition to be made in a 100 t heat could be up to 10 minutes in process time and 2000 Euros in total cost.

The combined effect on operating cost and operating time is likely in the magnitude of 20 minutes and 3000 euros by optimizing raw materials usage when refining a 100 t heat. This is not considering the influence of yield and the cost aspects of the different materials in which case the figures would grow further.

Table 3: Effect of substituting two tons of neutral scrap compared to case 2 in table 2 with the different alloys defined in table 1.

	High Carbon stage adds (t)										Low carbon stage adds (t)										Reduction stage adds (t)										Desulph. stage adds (t)												AOD product-ion cost (Euro/ton)
Case	HC FeCr	Ch.Cr	LC FeCr	2Cr22	CrNi	FeNi15	FeNi35	NiPI	FeScrap	N.Scrap	HC FeCr	Ch.Cr	LC FeCr	2Cr22	CrNi	FeNi15	FeNi35	NiPI	FeScrap	N.Scrap	HC FeCr	Ch.Cr	LC FeCr	2Cr22	CrNi	FeNi15	FeNi35	NiPI	FeScrap	N.Scrap	HC FeCr	Ch.Cr	LC FeCr	2Cr22	CrNi	FeNi15	FeNi35	NiPI	FeScrap	N.Scrap	Initial Mas	Time	
30	2									3										2										2										2	89	44:56	34,9
31										5	2																			2										2	89	45:4	35,0
32		2								3										2										2										2	89	45:4	34,3
33										5		2																		2										2	89	45:4	34,4
40			2							3										2										2										2	89	43:36	34,2
41										5			2																	2										2	89	43:36	34,1
42										5										2			2																	2	89	42:32	33,2
43										5										2										2			2								89	42:32	33,2
50				2						3										2										2										2	89	43:24	34,6
51										5				2																2										2	89	43:32	34,6
52										5										2				2																2	89	43:4	34,3
53										5										2										2				2							89	43:4	34,3
60					2					3										2										2										2	89	43:32	34,5
61										5					2															2										2	89	43:28	34,5
62										5										2					2															2	89	43:36	34,5
63										5										2										2					2						89	43:36	34,5
70						2				3										2										2										2	89	43:44	34,6
71										5						2														2										2	89	43:40	34,6
72										5										2						2														2	89	44:20	35,0
73										5										2										2						2					89	44:20	35,0
80							2			3										2										2										2	89	44:8	34,1
81										5							2													2										2	89	43:44	34,0
90								2		3										2										2										2	89	43:4	33,4
91										5								2												2										2	89	43:24	33,6
92										5										2								2												2	89	45:52	34,9
93										5										2										2								2			89	45:52	34,9
100									2	3										2										2										2	89	44:0	34,7
101										5									2											2										2	89	44:4	34,7
102										5										2									2											2	89	44:32	35,2
103										5										2										2									2		89	44:32	35,2

Some other aspects on when and if to use a certain material which is very important is that there are often physical limitations in the number of available alloys around the converter. This means that more versatile alloys, such as low carbon alloys that can be used throughout the process, are more attractive there. This also corresponds to cheap feedable iron units that are very attractive, particularly late in the process when well defined alternatives may be hard to come by.

9 CONCLUSIONS

The know-how threshold in terms of analyzing the need of different stainless steel producers is high and the correct evaluation of particular materials is a difficult and complex task that is often overlooked by consumers and producers alike.

Yield, environmental impact and inclusion management are all important aspects of raw materials used in stainless steelmaking, these parameters are however of a nature that has to be discussed in a greater context than the converter refining alone. Yield and environmental impact of alloying are closely related to the overall management of the steel plant where EAF and AOD must be optimized together.

The inclusion management and the raw materials impact on inclusions is more related to the ladle metallurgy than to the converter where the bulk of materials are used.

By simulating the converter process, it is possible to evaluate the impact of different raw materials and addition strategies on the process both from economical and productivity point of view.

By analyzing the ferroalloy utilization it is possible to optimize the economic as well as environmental value in use for different materials by selecting the right application for them. It is also possible to design or redesign alloys to match specific customer requirements. Computer simulations are valuable in this work as they can determine the actual cost for a certain alloy in different contexts.

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