EFFICIENT SCRAP USAGE WITH AUTOMATED ALLOYING AT OUTOKUMPU'S AVESTA WORKS

Carl-Johan Rick[1], Kristina Beskow[1], Gunnar Lindstrand[2]

[1] Uvån Hagfors Teknologi AB, Kistagången 2, 16440 Kista, Sweden
[2] Outokumpu Avesta Works, Bergsnäsgatan 11, 774 41 Avesta, Sweden

Abstract

In all steel production scrap is generated. In stainless steel making where the raw material cost is much higher than in other steel making the scrap is consequentially a more precious resource. In this paper the use of internally generated stainless steel scrap is discussed.

Internal scrap usage and internal scrap substitution with purchased alloys or purchased scrap is examined in the industrially proven UTCAS® converter automation system. It is found that internal scrap usage in the AOD can reduce costs and time compared to when alternative raw materials are used.

Scrap in stainless steelmaking

Scrap is the main raw material for stainless steel in the world, about 60% of the metallic feedstock for stainless steel is scrap on a worldwide basis [1]. Most of the scrap is melted in the EAF together with alloys. Some further scrap and alloys are added later in the process such as during the AOD or ladle station treatment, see figure 1 [2]. In figure one it is discussed when different types of alloys and scraps can be used in the stainless steelmaking process.

Depending on the source of the scrap it has different properties, see table 1.

Table 1. Some different raw material sources and their usefulness as stainless steel melt stock.

Raw material	Composition	Yield	Recycling time[3]	Price
Internal heavy scrap	Well known	High	<3 months	"free"
Internal light scrap	Well known	Low	<3 months	"free"
External heavy scrap	Good	High	15 years	Inexpensive
External light scrap	Acceptable	Low	15 years	Inexpensive
Alloys	High yield mixture of raw materials			Expensive

Internally generated scrap of known composition such as slab crops and edge trimming or refused material generally has the best value in use for the steel plant as its composition is well known and the material is rarely contaminated with carbon. In many cases this material is used at a very low internal value as it lacks an actual market value. This low value makes the material attractive to use without paying specific attention to its excellent properties.

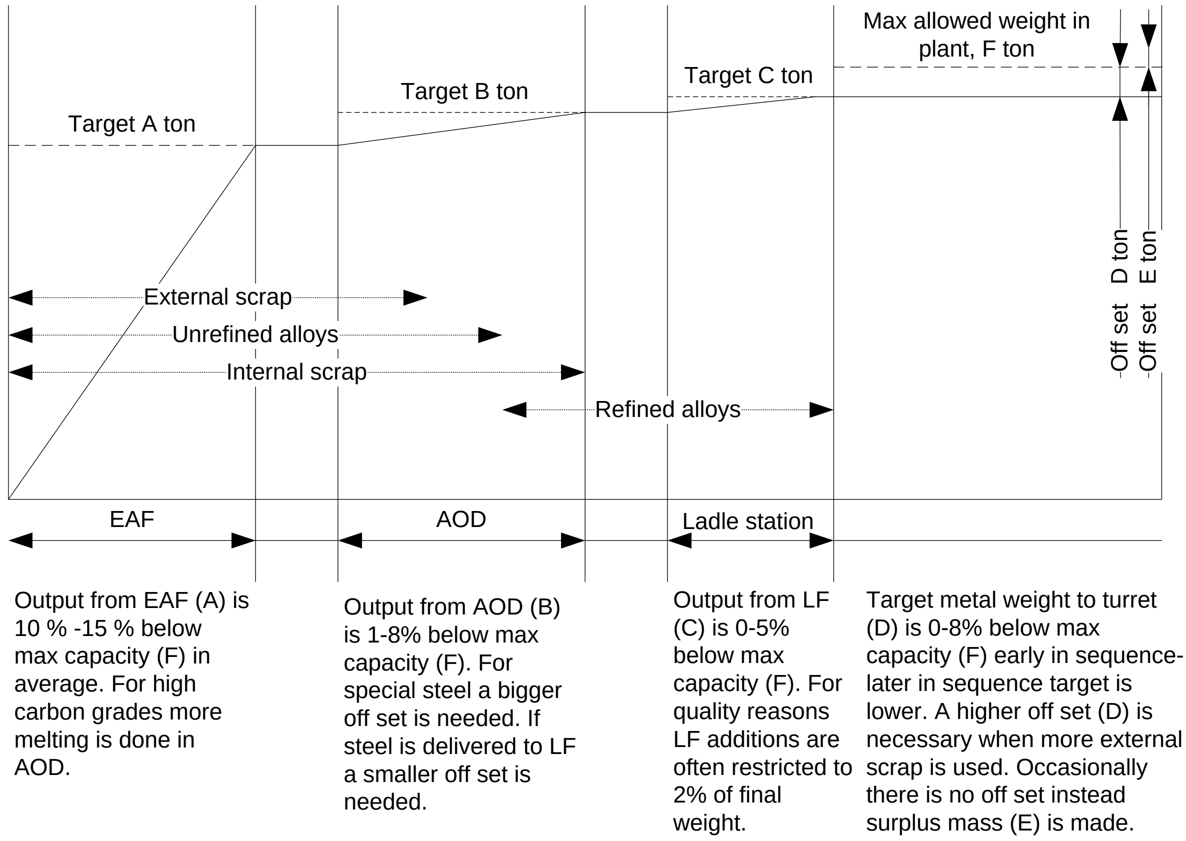

Figure 1. Mass build-up throughout the melt shop.

Externally purchased sorted scrap has an acceptable integrity in terms of composition, it has high average alloy content but due to the abundance of sources where it is collected this material lacks detailed composition integrity. Thus risks are involved in using smaller quantities of this material when the desired analysis span is tight as the actual added scrap pieces may deviate significantly from the average analysis.

When scrap is used it provides a low cost source of alloys compared to virgin raw materials. When a scrap with well known analysis is used it is less likely that refined alloys are needed to compensate for missing elements in the scrap. The general principle for scrap and alloy additions in stainless steel melt shops can be formulated; First external scrap is used, thereafter composition is adjusted with unrefined alloys, then the energy and weight is adjusted with internal scrap and finally the composition is fine-adjusted using refined alloys, see figure 1.

To manage heat in the converter process energy dilution with more mass is often necessary and then well defined internal scrap is favorable as it requires no further treatment and does not add any risk of consequential alloying having to be conducted. There are alternatives to heat dilution such as removal of heat with gases or the use of endothermic processes- these methods are however neglected in this paper.

The alternative to adding scrap is of course to compose neutral mixtures of alloys. In figure 2 it is illustrated how and when different alloys and scrap ranges can be used in a practical way, this addition graph has been discussed in detail in previous papers [4].

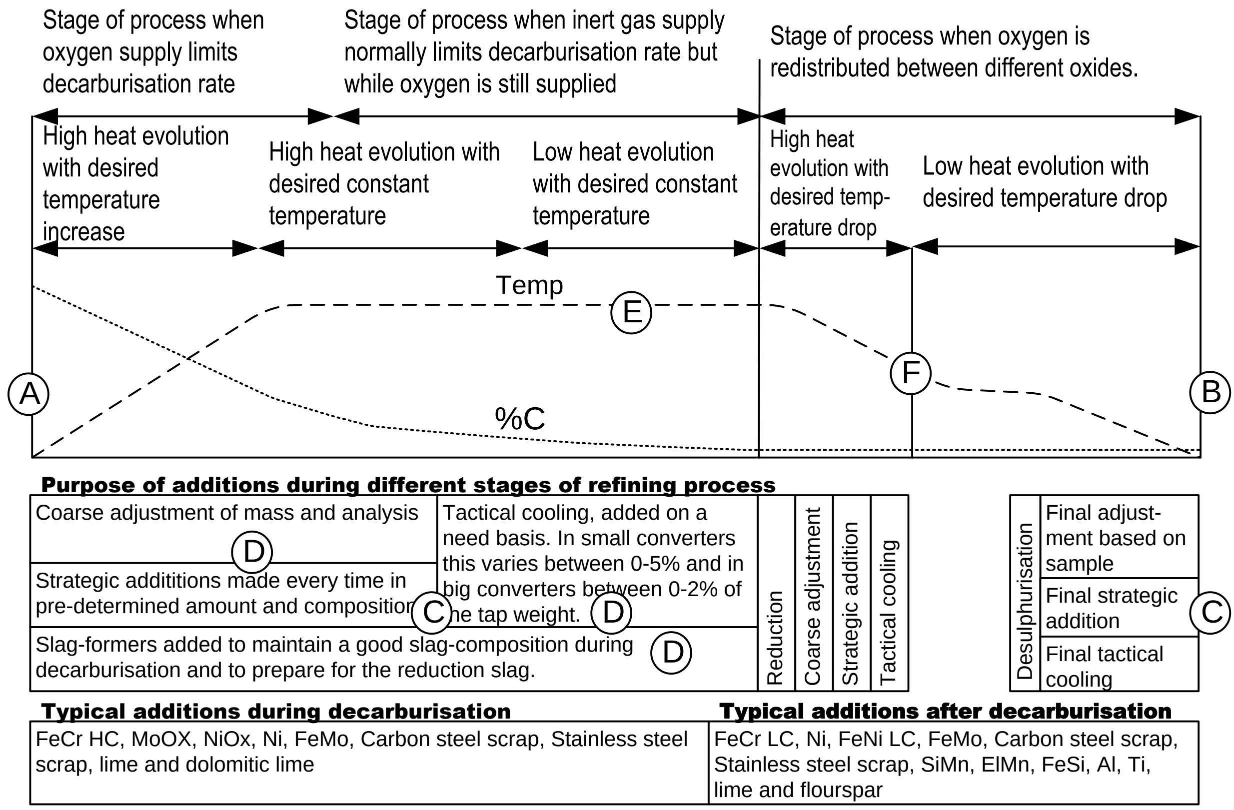

Figure 2. Alloy and scrap additions during the AOD process.

Cost associated with scrap and alloys

Scrap is the raw material of choice mainly because it is cost efficient. If the scrap is added in the AOD after the reduction the process cost for adding it is essentially free and the yield for all elements in clean solid stainless steel scrap is close to 100%.

Earlier in the AOD or in the EAF more process costs will appear on the material addition- these costs are caused by additional treatment to remove undesired elements in the scrap, scrap diluting other elements and making their treatment less efficient but also a lower yield of the scrap. On the other hand if the scrap is added late in the process chain restrictions appear on many elements as there are limited possibilities to remove many of them.

In table 2 some potential mixtures of raw materials that can be used in the AOD-refining is displayed. In addition to these mixtures infinite number of alternative mixtures is available- these mixtures are selected to illustrate the potential cost difference of using scrap or refined raw materials in the AOD. In table 2 a discount on elements Fe, Cr, Ni and Mo is considered in the scrap. The suggested discount fits the current market situation for external stainless steel scrap well but the actual price for different scrap grades are found through negotiations rather than with a formula.

It is possible to break these neutral cooling mixtures, to exchange a component to a high carbon alternative and to add it during the decarburization. This practice also commonly applied and it is well suited for the bulk of converter material additions.

For cooling of the steel late in the process with a material that is not analysis neutral, there is a risk that the available heat or the vessel volume is insufficient. Another risk is that the addition of non analysis neutral material will cause the analysis to change as a consequence of mass uncertainty.

In case that non analysis neutral material was meant to be added to the steel but could not be added due to time constraints, vessel size or insufficient heat the result is that the analysis will not be correct, or in the best case that the analysis can be corrected with expensive refined alloys.

As the yield increase late in the process it is tempting to add more precious alloys such as nickel, low carbon ferrochrome and ferromolybdenum as late as possible while cheap internal scrap is added early. This procedure can create risks for errors and does not consider that the internal scrap, while low in book keeping value, is much cheaper to convert to product than alloys that has to be mixed and measured.

Melting of alloys, particularly chrome, in the EAF can sometimes be difficult and the yield be irregular, this means that chrome alloying in the converter for high chromium containing grades is often substantial even if the intention is not to use the converter as an alloy melting unit. The unpredictable behavior makes chrome melting less attractive in the EAF and it is often tempting to move more alloys to the converter for high alloy steels and to keep the scrap in the EAF.

Table 2: Potential mixtures and costs for scrap and scrap alternatives, prices on raw materials from Asian Metal [5] and LME [6].

Costs in Euro calculated based on Fe delivered freely in alloyed scrap. Ni gets 15% discount, Cr gets 25% discount and Mo gets 15% discount in scrap.								
Component	Alloys for cooling 316 L Necessary mix to make 1000 kg				Alloys for cooling 310 L Necessary mix to make 1000 kg			
Fe-scrap			405	415			60	80
LC FeCr				239		185		360
HC FeCr			255				380	
Nickel		25				147		
FeNi LC		5	282	282			560	560
SiMn		2	20	21				
FeSi								
FeMo		42	43	43				
304 scrap		926				670		
316 scrap	1000							
310 scrap					1000			
Euro/ton	1624	2249	2597	2893	3019	3577	3501	3952

As seen in table 2 it is beneficial to use as much scrap as possible from a raw material cost point of view. The cost difference is substantial when considering only the purchasing prices- actual costs are more complicated to determine as freight costs, further refining, extra time for sampling and increased risks for errors are not considered in this cost table.

Stainless steel making in Outokumpu Avesta works

Outokumpus Avesta melt shop is a ±500.000 t/year operation that concentrates on special steel grades and special formats. The melt shop is a traditional scrap based plant with a duplex process using EAF, AOD, LF and a slab caster. The melt shop is mainly serving internal clients with slabs.

The special steel strategy causes the site to generate more than normal amounts of scrap. But it also causes the plant to require more than normal amounts of good quality scrap in the refining.

This need is caused mainly by two reasons:

1) Special steel grades often have high chrome content and low final carbon requirement- together this means that the necessary cooling is bigger for this production than what is expected for standard stainless steels.
2) The need for big amounts of special steel grades or special formats is less than what is expected for standard grades and standard formats. This means that sequences generally becomes short in this plant- short sequences tend to require more scrap to cool the steel down and to make it castable quickly.

The shorter process is also the main reason why more than normal amounts of scrap is generated- short sequences tend to drop the yield due to increase of steel tied up in tundish skulls and casting crops for instance.

To handle the big amounts of internal scrap efficiently in the AOD with acceptable consumption figures and a good logistic situation the scrap is added to the AOD by two distinctly different routes:

1) Overhead bin system- double shreaded and granulated on grade analysis certified material is added through the overhead bin system.
2) Chute system- heavy scrap and loose unshreaded bundles of high integrity on grade material is added in chutes that are preloaded and made available on operator request.

Alloy and scrap management with UTCAS®

To manage the alloy and scrap additions UTCAS ®- UHT's Converter Automation System is used. In this system the need for cooling, mass build up, alloying and cost control is handled automatically in the background together with the blowing of the heat using sophisticated computer models for decision making. Meanwhile the operator concentrates on practicalities such as ladle logistics, managing maintenance, controlling status of chutes and refractories.

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 3.

A central part of the system in terms of raw material control is the process optimization. The process optimization strategy for UTCAS® was jointly formulated by UHT and Avesta Works personnel already in 1997. The basic idea of the process optimization is that it shall finalize the heat in the converter to the right analysis, temperature and mass as soon as possible by use of as little resources as possible within defined boundary conditions.

To enable the process optimization to take place iterative methods has been used as the AOD-process like many steelmaking processes is not a homogenous system. During the iteration a great number of gradually more likely solutions are tried so that the entire heat can be prepared in one stroke. The optimization of the entire heat is important as it gives the possibility to plan also the finalization of the steelmaking which may differ significantly from one heat to the other, depending on the grade, the slag practice or the heats place in a sequence.

During the system development process it was found that it is necessary to differentiate between:

- Allowed materials to avoid logical problems such as dilution with cupper up to the allowed level in the steel when no suitable iron units are detected by the system.
- Desired materials to differentiate between different attractive materials such as SiMn, FeSi, FeMn that has a similar price structure.
- The order in which materials should be added is necessary to ensure that FeSi, Al and SiMn come below cooling scrap in the charging hopper at reduction.

Furthermore it was found that these rules must coexist with physical models for the internal logistics of the overhead bin system and chute systems, a lowest cost optimization, that the slag must be part of the alloy calculation as it has such a vital importance on the heat balance and that all the rules must be flexible enough to change from one day to another.

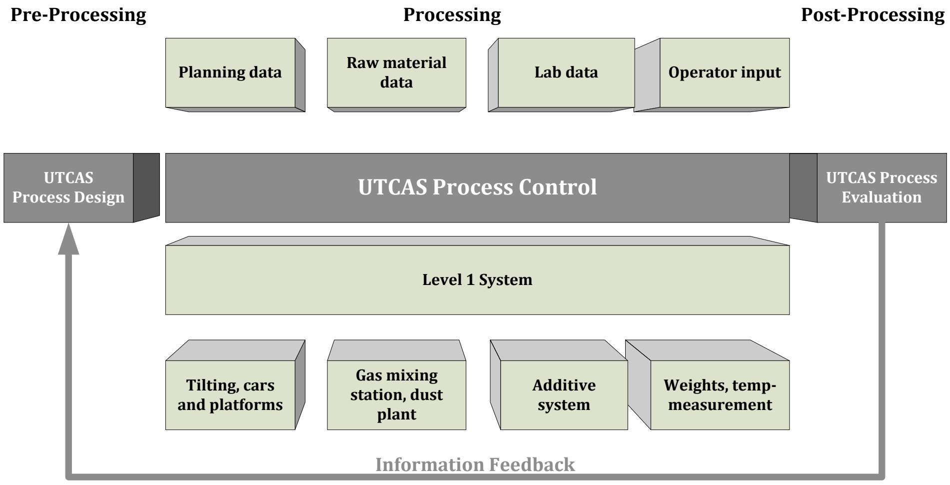

Figure 3. The UTCAS® concept for process control and management.

The flexibility to change rules quickly is a lifeline in the stainless steel melt shop operation as the volatility in the alloy market for stainless steel alloys is notorious. During 2011 the LME cash buyer Ni-price changed numerous times between a high of 29000 USD/ton to a low 17000 USD/ton, during the sharpest change Ni fell 17% in 2 days. Meanwhile mild steel billets started out the year at 550 USD/ ton and ended the year at 550 USD/ton with a peak in August at almost 700 USD/ton.

It is important to understand that the AOD is not only an inhomogeneous system to optimize. It is also a system whose start and end conditions change while the process is being conducted. In figure 2 encircled capital letters (A)-(B) are used to illustrate how the start and end conditions for optimization is changed during the process.

Initially process optimization is done from (A)-(B) but considering strategic coolants (C). Once addition (D) of adjustment alloys, slagformers and coolants have started deviations compared to the initially optimized process will start to appear- in order to still reach the desired conditions at (B) it is necessary to re-optimize the process. Further reasons to re-optimize is that conditions at (B) change, that measurements of carbon or temp deviates from the process plant at (E), that the composition at (F) shows that further alloying is needed.

Simulations for 316L and 310

To illustrate the metallurgical difference of using analysis neutral scrap or alloy mixtures for cooling some UTCAS® simulations are presented.

The 316L is a common stainless steel whose scrap is considerably more valuable when it is used on that grade itself than for alternative grades. Scrap falls after 316L production in similar amounts as for other grades. The need for very good quality scrap is however only moderate in this steel as cooling during decarburization is moderate.

The 310 is a steel grade where alloying is mainly made with Cr and Ni- but it is sensitive for pollution. Furthermore the 310 requires much cooling but also frequent alloying- this means that the scrap demand varies. In addition to scrap demand being irregular, the demand is often higher than the availability, this means alternatives to on grade scrap often has to be used even if the benefit of having on grade scrap is significant late in the process.

Cooling steel with scrap during the decarburization adds a source of melting stock that is well known and that does not make the analysis drift. In case cooling is done with alloys prior to sampling the result will be the same. If however circumstances appear that makes it less attractive to make additions late in the process it is better if only an intended scrap addition has to be omitted than an actual alloying event.

In table 3 below operating costs and raw material costs are illustrated for some simulated scenarios where analysis neutral scrap is used during decarburization, during reduction or if instead an analysis neutral alloy mixture is used.

Table 3. Effect of availability of analysis neutral scrap during AOD processing.

		316			310		
		316 scrap in red	316 scrap in dec	Alloy mix	310 scrap in red	310 scrap in dec	Alloy mix
Cooling after reduction		316 scrap	FeNi	FeNi	310 scrap	Iron	Iron
FeSi	kg	1631	1892	1610	1844	1953	1752
FeNi	kg	6897	6962	11074			
Mild steel scrap	kg	300		200	4990	5000	7127
Nickel Briq's	kg	460	460	62	1617	1612	2680
Charge Chrome	kg	2001	2086	3380	4798	4772	6849
FeMo	kg	752	752	913			
SiMn	kg	362	362	446	89	51	144
Oxygen	Nm3	2330	2497	2455	3116	3152	3256
Argon	Nm3	1791	1928	1956	2491	2621	2646
Nitrogen	Nm3	1030	1148	1170	1614	1618	1699
Time	min	42	45	45	56	57	59
Euro/ton in AOD (RM+OPEX)		499	504	524	461	461	485

The table shows that the metallurgical results are similar but that the heats where internal scrap was used rather than alloys was cheaper to produce in the converter, had shorter process time and were less risky to produce from an analysis accuracy perspective.

Strategically it is possible to allocate a portion of the alloying for the purpose of cooling after reduction. This strategy requires enough volume in vessels, time and heat available in the steel to allow for that alloy late in the process- it also adds an element of risk as there is less room to make corrections should the composition of the alloy added or the mass of the steel be different to what was expected.

Experiences of using UTCAS® to improve scrap management in Avesta

Since the initial implementation of UTCAS® many general benefits have been recognized by Outokumpu[7]:

- 15% less total process time and fewer heats that have a significant deviation from average process time. The renewed process optimization enabled in the real time system has led to the possibility to make adjustments during blowing. Due to this less late corrections are necessary and as a consequence a shorter overall process time is achieved.
- The shorter process time and the fewer adjustments have decreased the average gas consumption by 10%.
- Less use of gas and shorter process time has improved the refractory life by 10%.
- The improved temperature control has permitted a better timing of the additions in relation to the temperature evolution. This has led to a more controlled mass build up of the heat that has improved the control of the final weight. As a consequence the safety margin between aim weight and oversized heats has been decreased (D in figure 1).
- Calculation, blowing and raw material handling by one operator that can administrate the process and all reporting by himself.
- New operators quickly become productive and produce faster and more cost efficient results than many more experienced colleagues.

Such general improvements are essential to motivate the implementation of a new system and help paying off the system once it is installed.

However in everyday production the ability to automatically control the use of scrap and alloys so that late alloying can be avoided is probably more important- and in fact the system's ability to handle the scrap usage efficiently may be part of the general success of the system as it allows operators to make a steel that changes its analysis only marginally in the end of the process even when the EAF's analysis and weight varies significantly.

With the younger generations of operators that are grown up with PC's and internet, the resistance of using more complex computer aid is fading away. This has enabled the implementation of more sophisticated process practices where close operator and system interaction is essential. This generation is able and willing to improve the process through the computer interface and therefore they require tools where they can make use of their skills and good intentions.

Yesterdays strict rules of dedicated materials to specific steel grades has been loosened up and the operator is allowed to find new solutions to process and alloying problems. This makes production more cost efficient and helps leveling out the rapid fluctuations in raw material price and in access to desired scrap and alloys.

References

[1] Reck, B., M. Chambon, S. Hashimoto, & T. E. Graedel.. "Global Stainless Steel Cycle Exemplifies China's Rise to Metal Dominance.." *Environmental Science, & Technology*. 44 (2010)

[2] Beskow K., Rick, C., "Increased Stainless Steel Melt Shop Yield by Improved Converter Tap Weight Management", EOSC 2011, Stockholm.

[4] Rick C., "Strategies for Use of Superheated Steam during Stainless Steel refining in Converters", AISTECH 2010, Pittsburgh.

[3] Teröde, F. "Stainless Steel Recycling- Availability of Scrap", www.worldstainless.org (Uploaded 4/3/2007)

[5] http://www.asianmetal.com (daily news from 2012-02-24)

[6] http://www.LME.com (daily news from 2012-02-24)

[7] Appell A., Internal communication between Outokumpu and UHT, 2011.