

Minimization of Copper Contamination in Steel Scrap



Hyunsoo Jin and Brajendra Mishra

Abstract Copper and tin, as tramp elements in the steel scrap, cause some harmful effects, such as hot shortness caused by a loss of ductility and surface defects. It is also difficult to maintain the quality of the product because the amount of the residual constituents in steel scrap is not consistent. The secondary steel products require consistent copper content and standard due to the limited use of the product for the various applications. Thermodynamically, removing copper from scrap is a viable option, but in reality, the impurities and the included copper in the melt of steel scrap are difficult to remove by conventional methods. Besides, the research of the recycled steel scrap regarding iron and impurities is limited, and it needs to be conducted, in terms of physical and chemical techniques, as the preliminary study to find the efficient separation method.

Keywords Secondary steel · Tramp elements · Steel recycling

Introduction

Issue of Recycling Secondary Used Steel Scrap

The recycling of steel scrap is mainly constrained by its concentration of the ‘tramp element.’ Copper and Tin are two of the most common tramp elements. Those tramp elements not only cause hot shortness in steel product but also limit the range of grades steel shop can produce. Table 1 shows some examples of steel grades with a maximum Cu residuals [1].

H. Jin · B. Mishra (✉)
Worcester Polytechnic Institute, Worcester, USA
e-mail: Bmishra@wpi.edu

H. Jin
e-mail: hjin@wpi.edu

© The Minerals, Metals & Materials Society 2020
X. Chen et al. (Eds.), *Energy Technology 2020: Recycling, Carbon Dioxide Management, and Other Technologies*, The Minerals, Metals & Materials Series,
https://doi.org/10.1007/978-3-030-36830-2_34

Table 1 Maximum tolerable Cu content in common steel grades (wt%)

Interstitial free	Deep drawing quality	Drawing	Commercial	Structural	Fine wire	Rebar
0.03	0.04	0.06	0.1	0.12	0.07	0.4

Theoretical Aspects

Theoretically, controlling the copper impurities to under 0.2 wt% is proven by aspects of thermodynamics. To be specific, Nakajima et al. [2] investigated the distribution of elements between the metal, gas, and slag phases in current steel refining practice. The results provide that the copper and iron are not alloying with each (see Fig. 1). Besides, Zaitesv et al. [3] checked the activities of copper and iron at high temperature and this represents copper and iron are not strongly interacted with each other (see Fig. 2). However, in the field, the problem is these theories did not work in the real field.

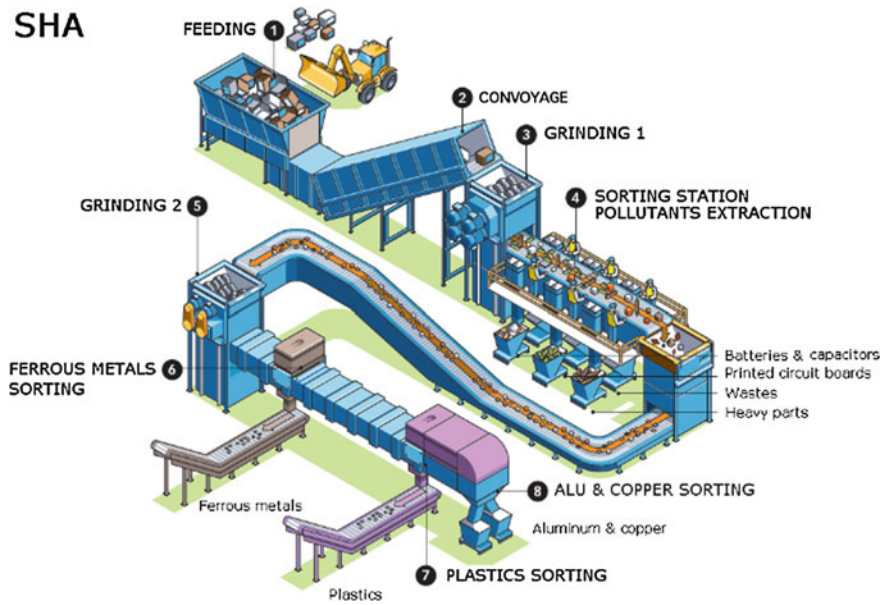


Fig. 1 Traditional recycling process [4]

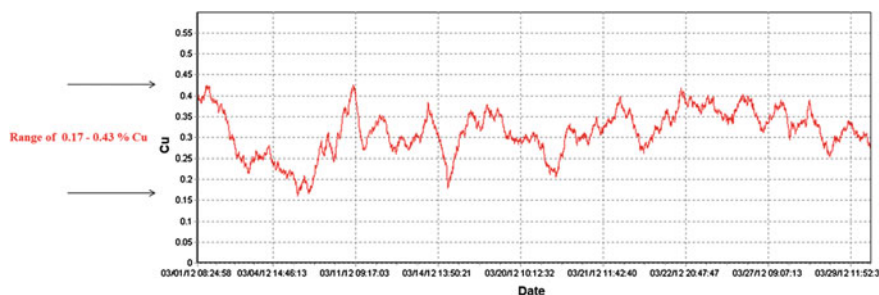


Fig. 2 Cu level in steel scrap that used traditional method

Recycling Process

Traditional Recycling Process

In the steel scrap field, the recycling process depends on the target materials what the company wants to recover or recycle. Although the process is not the same, the steps are almost similar and the difference is the order or some additional process for the target materials.

Figure 1 is the traditional recycling process; the main step is feeding, shredding, sort and extracting pollutants, magnetic separation, and plastic sorting. Specifically, for the separation, magnetic, air, Eddy-current, and sink-float/fluidized bed density are used.

The challenging part of the shredding and sorting process is maintaining the level of content. For example, in tramp elements, it is hard to maintain the impurities level because the contents of these impurities depend on the feeding materials and these feeding materials are not consistency. Figure 2 shows the range of copper that is included in steel scraps. This data is obtained from Company A and this data is based on the conventional method.

Gamma-Ray Process

Company A used a gamma-ray process that is almost similar to the traditional method. It also faced the problem that Cu contaminant is fluctuation and it is too high to use widely (Fig. 2).

Company A developed a new strategy called 'The Cross-Belt Recycled Metal Analyzer.' Briefly, the principle is emitting the radioactive source (Cf 252) and when the scrap nucleus is excited, they emit the gamma-ray than the detector collects the gamma-ray and show the results promptly. When they receive the results, they can

remove the high Cu contaminant part. It makes not only a lower copper contaminant but also maintains the range of copper.

After using this equipment, Fig. 3 is the composition of Cu in steel scrap. This range shows the equipment can improve the process and reduce the tramp elements; however, in the future, if the feedstock Cu contaminant has increased, this solution will be faced on new problems to overcome.

According to Company A, the three key factors of 'Prompt Gamma Neutron Activation Analysis' that makes it uniquely fit for scrap applications are

1. Inbound neutrons and outbound gamma-rays are very penetration in nature so there is interaction with all of the material as it passes through the tunnel
2. The reaction occurs at the speed of light and therefore, it is a real-time analysis
 - Scrap processors or steel mills can use it to control the process/chemistry of shredded scrap
 - The analyzer is capable of handling production rates of over 400tons/hour)
3. The reaction does not activate the material
 - There is no measurable residual radioactivity as the material exits the analyzer

This strategy is efficient and easy to adjust to the existing field. However, these fields need to prepare future high contaminant Cu in waste steel. Several teams try to overcome this problem in the past. Thermodynamically, there are a lot of possible methods [5] existing but most of that is not efficient to use in the field or not work. This research is testing the solvent extracting method and electrochemical method to check the probability and develop efficient ways (Fig. 4) [5].

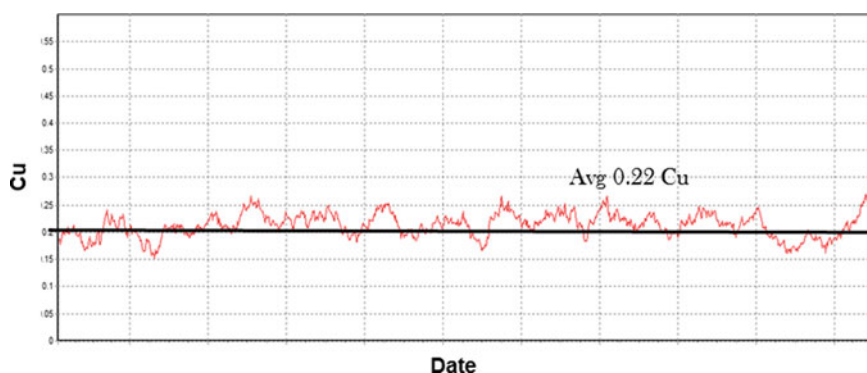


Fig. 3 Cu level in steel scrap that used gamma-ray method

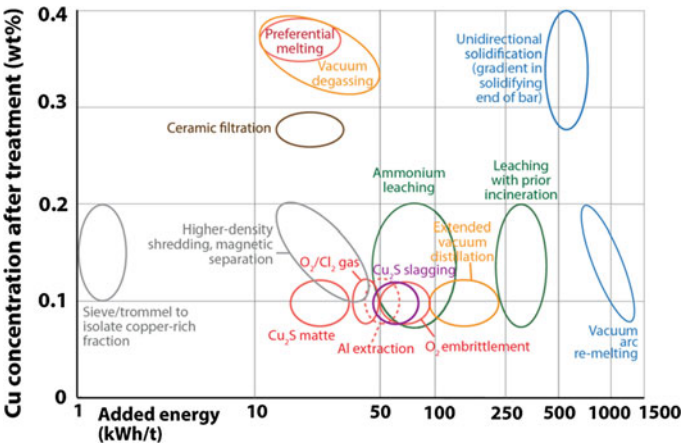


Fig. 4 The energy consumption for reducing the copper concentration [5]

Separating Methods

To separate the tramp elements from the steel scrap, there are several strategies to overcome this problem. Figures 5 and 6 classify the separating methods by the shape of the beginning state [5]. In this project, the solvent extraction method and the slag melt method are conducted for different beginning state and composition. Efficiency and possibility are also one factor to consider.

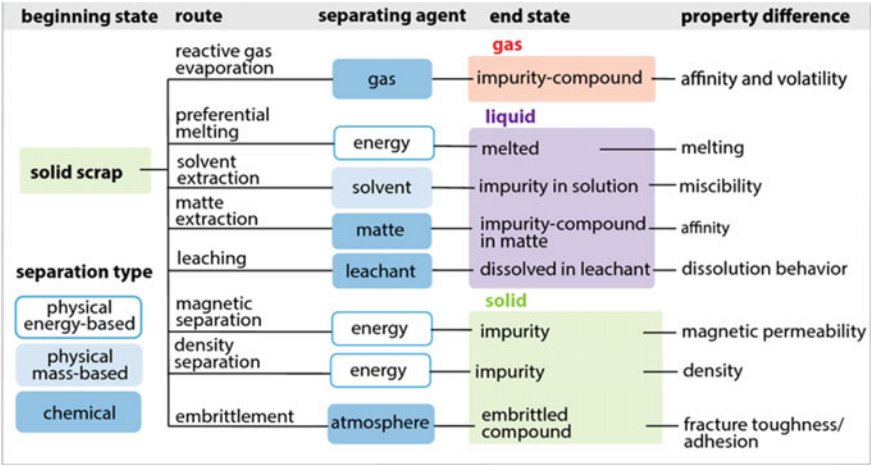


Fig. 5 Methods to separate tramp elements from solid scrap, showing the separating agent applied in each method and the property difference exploited [5]

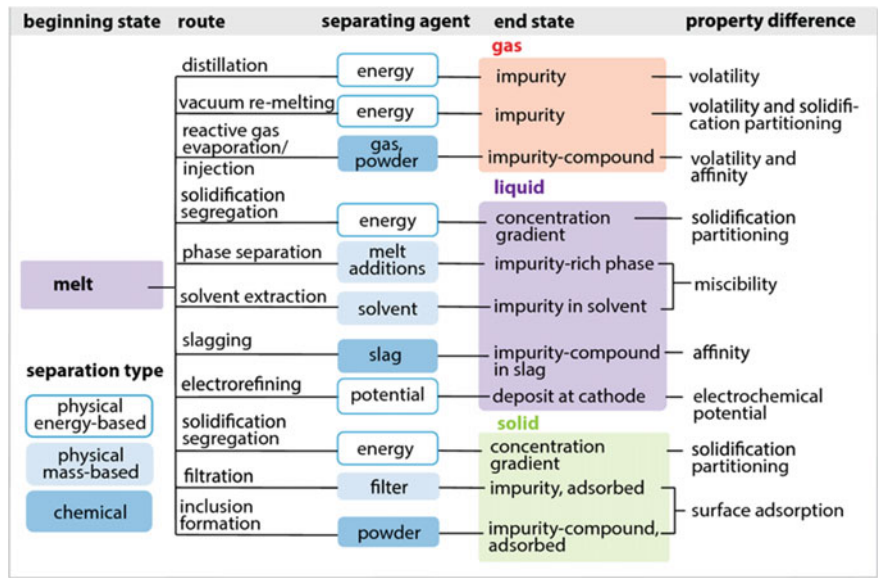


Fig. 6 Methods to separate tramp elements from the melt, showing the separating agent applied in each method and the property difference exploited [5]

Copper Extraction Method

Nonferrous Metal Bath

The basic concept of this method is the different solubility of copper and steel. In the lead or aluminum bath, the copper solubility is higher than steel. According to the literature review, 1000 kg of leads can reduce the copper content in 1t of obsolete from 0.3 to 0.1%. The problem can cause human disease and not environmentally friendly. In contrast, the aluminum bath is attractive and one good possible way to conduct because the amounts of aluminum are unclear and aluminum–copper can bring valuable byproducts that are Al–Cu alloy. According to the reviewed paper, the solubility of copper in the aluminum bath is 65% at 730 °C and it can remove 80% of copper impurity. It needs only 20 min to remove [6, 7].

Slag Melts

This method is using sulphur-containing slag to extract the impurity. The basic concept of this is that copper sulfide is more stable than iron sulfide at above 600 °C.



Table 2 Initial composition of ferrous bulk materials conducted by XRF

	Al	Cr	Ni	Si	Mn	Fe	Cu
1	ND	ND	ND	0.92	0.19	98.52	0.04
2	ND	ND	ND	1.34	0.27	97.82	0.04
3	ND	ND	ND	1.23	0.23	98.23	0.03
4	ND	ND	ND	1.94	0.49	94.19	0.03
Avg.	ND	ND	ND	1.36	0.30	97.19	0.035

According to the papers, 100 kg of slag needs to reduce 1t steel treatment. This method needs fewer amounts of slags than the nonferrous lead bath but it needs high temperature [8–11].

Electrochemical

Electrochemical is based on the difference reduction potential of copper and iron. The required condition for this process is dissolving agents that need to make the elements dissolved into the liquid. If it is dissolved in the liquid, electro-winning is available. Copper and iron can be selectively recovered by using a suitable reduction potential.

Sample Information

The sample was obtained from Company B and randomly selects four samples. To check the initial compositions, XRF analysis was conducted. Table 2 is the results by using XRF. The average of Cu contaminant is 0.035 wt%.

This Cu amount is allowable at the secondary steel field. If it is hard to find a suitable sample, this project will make artificial Cu–Fe samples to see the feasibility.

Conclusion and Future Work

In the secondary steel field, the ultimate goal is to reduce or remove the Cu impurities from steel scraps and previous research suggests several methods based on the thermodynamic aspect. In this study, three routes will be considering that is an electrochemical method, a nonferrous metal bath, and a slag extraction method. The samples accepted at Company A and B recycling fields. Before they send the samples, the samples were conducted basic separation processes in the field. The sample is roughly three, nonferrous Al–Cu samples, bulk steel samples, and bulk wired steel

sample. By XRF and ICP–OES analysis, the initial composition of Cu–Al samples and bulk steel samples are checked.

In the future, the Al bath extraction and slag extraction methods will be conducted and check the possibility and efficiency. For the electrochemical method, sulfuric acid will use as a separation agent and the mole value of sulfuric acid and dissolving time and the surface area will use as a variable.

References

1. Effect of tramp elements in flat and long products (1995) Final report, Contract no. 7210-ZZ/555+ZZ/564, EGKS, Brussels
2. Nakajima K, Takeda O, Miki T, Matsubae K, Nakamura S, Nagasaga T (2010) Thermodynamic analysis of contamination by alloying elements in aluminum recycling. *Environ Sci Technol* 44:5594–5600
3. Zaitsev AI, Shelkova NE, Litivina AD, Shakhpazov EK, Mogutnov BM (2001) An investigation of evaporation of liquid alloys of iron with copper. *High Temp* 39(3):388–394
4. Example of a Process of SHA Treatment at SITA. Available. <http://eco3e.eu/en/base/sha/>
5. Katrin E, Serrenho AC, Allwood J (2019) Finding the most efficient way to remove residual copper from steel scrap. *Metal Mater Trans B* 50(3):1–16
6. Iwase M, Tokinori K, Ohshita H (1993) *Iron Steelmaker* 20(7):61–66
7. Iwase H, Ohshita H (1994) *Steel Res* 65(9):362–367
8. Cohen A, Blander M (1998) *Metall Trans B* 29b(2):493–495
9. Lee J (1997) Kupferproblematik beim Schrottschmelzen. Shaker, Aachen. ISBN 3-8265-2320-2
10. Jimbo I, Sulsky MS, Fruehan RJ (1988) *Iron steelmaker* 15(8):20–23
11. Savov L et al (2003) Copper and tin in steel scrap recycling. *RMZ Mater Geoenvironment* 50(3):627–640