WEEE recycling – metal recycling from complex beneficiation fines

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Abstract

Because of growing mechanization and decreasing life span of technical equipment, the waste production for WEEE (waste of electronical and electric equipment) will rise strongly. Different residual fractions are produced during the beneficiation of WEEE. Some of these fractions contain high contents of valuable metals besides a high amount of organics in form of plastic.

This paper focuses on works with a fine fraction of filter dust with interesting amounts of copper, gold and silver. Pellets are made of this dust in combination with other waste streams as well as slag additives to create an autogenic agglomerate with ideal melting properties. First melting trials with adjustment of a combustion process generates a slag, which is good to handle and metal phase, with high amount of copper. Kinetic investigations provides first results about the behavior of plastic and carbon in context to pellet weight and added slag components.

The full paper will be published soon after the conference in a scientific journal.

Introduction

Waste of electronical and electric equipment (WEEE) is a valuable source for metals because the arising amount and it's high metal content. In 2014 the worldwide accumulation of electronic scrap reached 41.8 million tons (5.9 $\frac{kg}{inh}$) and it is expected to increase 3-5% per year. [1,2] Electronic scrap is a very complex waste stream which consists of many different materials for example metals, glasses, plastics and ceramics. The metal content depends on the type of electronic scrap and consists mainly of copper, iron, aluminium, lead and nickel. But also critical and valuable metals like Gold, Silber and palladium can be found in considerable amounts. [3] Metal recovery from these complex waste streams requires an ambitious recycling process which combines mechanical treatment, hydro-and pyrometallurgical methods.

Processing of electronic scrap

Prior to pyrometallurgical processing, electronic scrap is conditioned via mechanical treatment, which can be seen in *Figure 1*. Examples for generated recyclates are aluminium- and non-ferrous metals-fractions. Next to the recyclates several bypass-fractions like residual waste, fluff fractions and filter dust are remained. Filter dust is generated during each shredding and is collected in a dust extraction. The amount of dust is influenced by many factors, for example type of shredder machine, degree of crushing and incoming material. M. Bigum et al. quantify the amount of filter dust up to 0.3 % and 3,2 % fluff for the pre-treatment of high grad WEEE. [4]

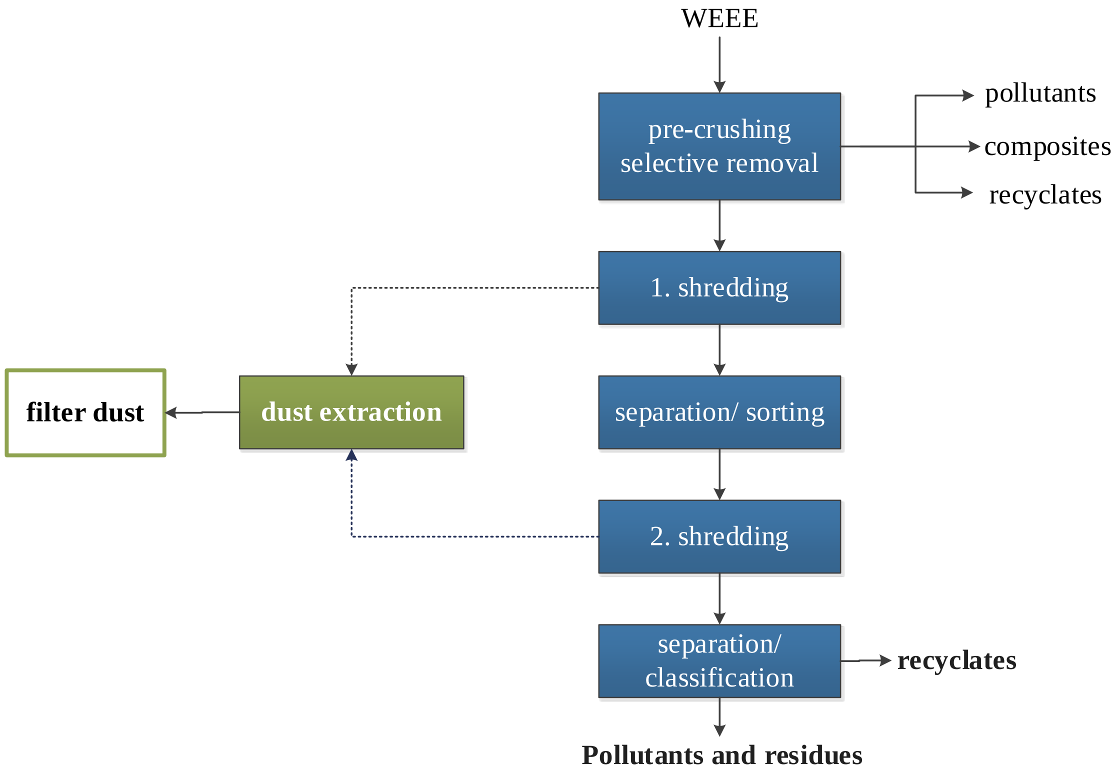

Figure 1 General mechanical treatment of electronic scrap [5,6]

Dissipation in these unintended fractions leads to metal losses especially for precious metals like silver and gold. [7] Gold in electronic scrap can often be found in small components, which are lost in the off-gas due to their light weight. In order to minimize these dissipation and metal losses also these fractioned need to be treated.

Recycling of metals from filter dust

This work focusses on the recycling of metals from a residual fraction arising from the pre-treatment of electronic scrap. In order to generate a usable input material for a pyrometallurgical recycling process this fraction needs to be conditioned and optimized. The aim is to create a pellet made of filter dust with melting properties which enables a nearly autothermic process.

For this challenge the energy content and melting properties like the melting point have to be improved. The used filter dust fraction contains high amounts of carbon in form of plastics, which lead to an exothermic reaction in a combustion process. In order to control this exothermic reaction and use the releasing energy for melting other residue fractions, this fraction with a high amount of energy is combined with fractions of lower energy content. The improvement steps and thermochemical filter dust behavior are simulated with thermochemical software FactSage^{TM}.

The complete developed process for recycling metals from filter dust is shown in *Figure 2*. The conditioning process step contains the components “homogenization and upgrading” and “compaction”. Upgrading means the combination of filter dust with low-energy-scraps and fluxes/ binder. This mixture needs to be homogenized to create a constant input for the compaction. Filter dust and additives are pelletized in order to enable a constant material flow and to minimize material losses during charging. These generated agglomerates contain a defined amount of fluxes, binders and copper containing residues in order to achieve high recovery rates and make use of the energy content in the following melting process under blowing of oxygen.

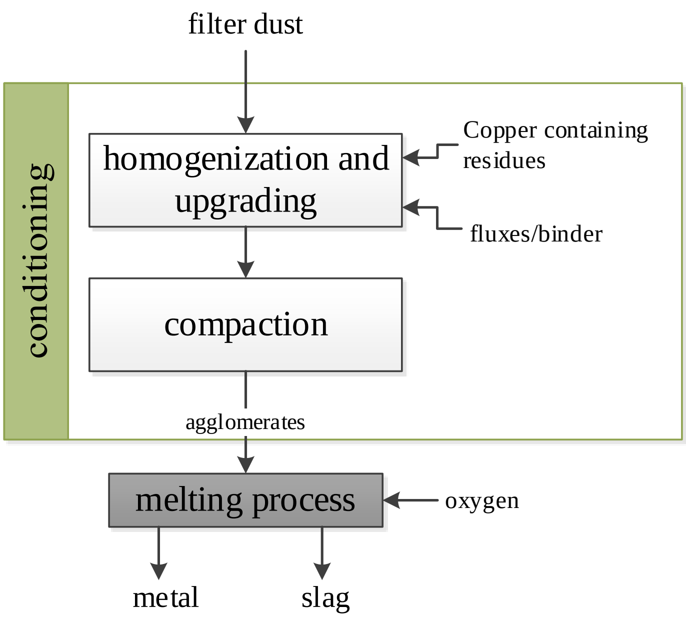

Figure 2: Process for efficient metal-recycling from filter dust

Characterization of filter dust and thermochemical models

The material investigated in this study originates from the pre-treatment of electronic scrap. Nearly all particles (98.5%) are smaller than 125 µm. This material condition points out the importance of compaction in order to minimize material losses in a metallurgical process. The material composition is a complex mixture of oxides, metals and plastic (Figure 3).

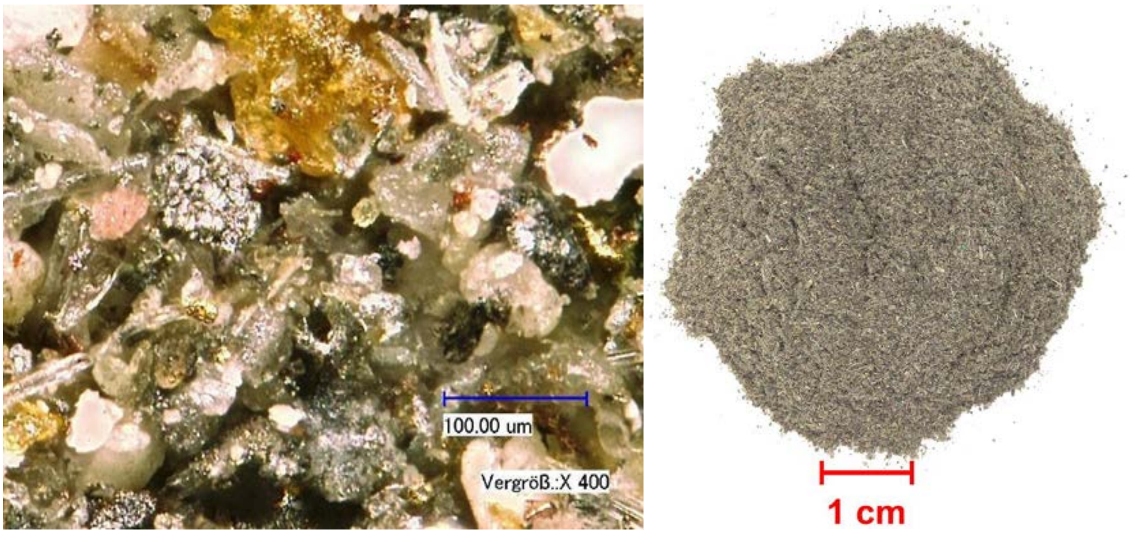

Figure 3: Composition of filter dust under optical microscope 400x magnification (left) and naked eye view (right)

The chemical composition is given in *Table 1*. Due to the varying scraps treated and density separation in the filter dust container the filter dust is chemically heterogeneous. Because of this a range is given for several elements. The ceramic part consists mainly of oxides like Al_2O_3 and SiO_2, the copper amount is given with 6.8-12.0 %. Minor substances are Pb, Sn, Sb and halides like Cl and Br. The high carbon content of approximately 20 % generated a high heat potential. [8]

Table 1: Chemical characterization of filter dust

	Al_2O_3	CaO	SiO_2	MgO	FeO/Fe_2O_3
wt.%	15.0-28.0	4.9-5.5	17.0-19.0	1.1	1.3
	Cu	**Fe**	**Zn**	**Au (ppm)**	**C**
wt.%	6.8-12.0	0.59-2.2	2.8-2.9	311-531	19.2-20.1

The predicted arising slag phase is simulated using the “Phase diagram” module of FactSage 7.0. The phase diagram takes a constant fraction of Fe_2O_3, FeO and MgO into account. The main slag building components that are embedded in the filter dust are SiO_2, CaO and Al_2O_3. Without any optimization of its chemical composition the initial slag composition leads to a liquidus temperature of 1526 °C (phase area mullite). Lowering of the melting point is feasible with defined additions of SiO_2 and CaO. A ratio of SiO_2: CaO = 38: 62 was chosen for further investigation, because liquidus temperature below 1300 °C can be reached. As can be seen, CaO has an important influence on the liquidus temperature and serves also as a hardener for the pelletizing process.

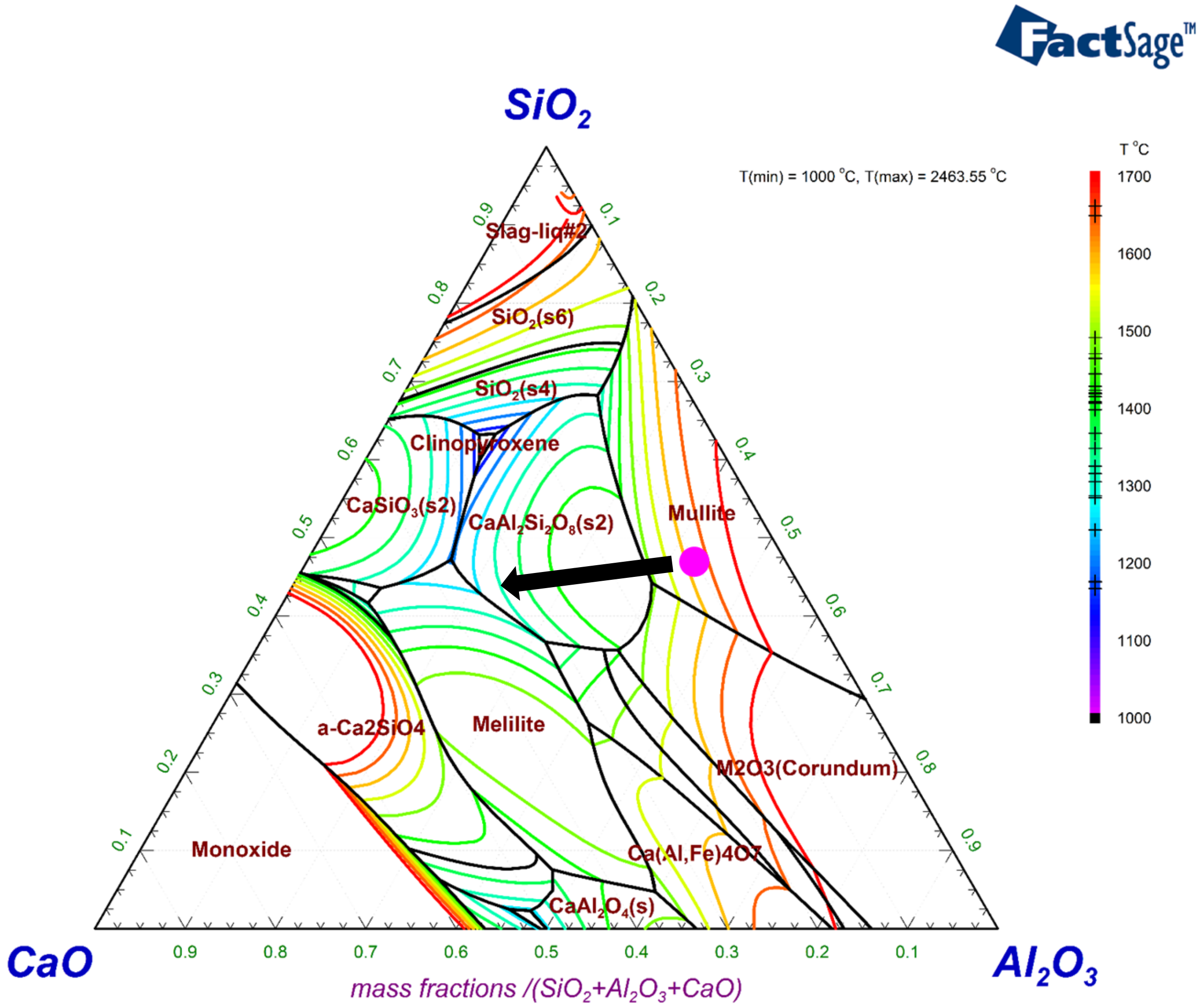

Figure 4: Ternary phase diagram of the three main oxides

Besides the thermochemical modelling of the predicted arising slag phase and required slag additives also the demand of oxygen and copper-rich additives have been calculated.

Experimental work

In order to verify results from thermochemical modelling, smelting behavior of autogenous pellets were investigated. Different pellet-mixtures were tested with variation of additives (fine copper dust), binders (molasses and water). Pellets were build up on a pelletizing disc with an inner diameter of 0.5 m and a spill over height of 11.5 cm. Rotating speeds can be adjusted continuously and 12 rpm showed the best results. Different binders, slag compositions and copper additives were used. Most pellets appeared in the range between 4 and 10 mm in diameter. Before combustion, the pellets were dried at ambient conditions for 24 hours.

The melting process was carried out in a resistance furnace, which was heated up to 800 °C to guarantee the sufficient activation energy for the combustion of the organic compounds (plastic). Oxygen was blown into the crucible by ceramic lance. After combustion, the reaction crucible was hold at 1300 °C-1400 °C for one hour to hold the system at calculated equilibrium conditions. Pellets before the combustion trials and the experimental setup can be seen in *Figure 5*.

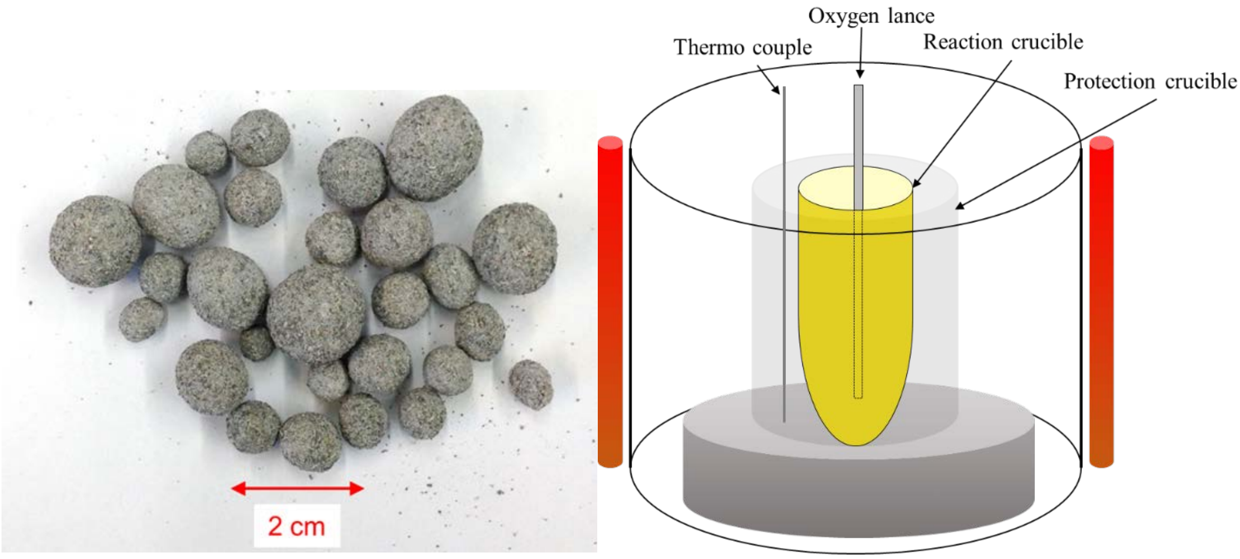

Figure 5: Pellets made of filter dust (left) and experimental setup for combustion trials (right)

Results and conclusion

Charged pellets showed a stable melting behaviour, short time after charging first melt droplet were obtained. Samples of the arising slag and metal phase were analysed by XRF analysis and ICP-OES. In nearly each experiments a metal phase was found on the bottom of the crucible, the metal weight agrees with the simulation. Also, material losses account to about 40 % of the weight share for each experiment due to pellet wearing during combustion and loss of pellets at the charging stage. The averaged compositions of the metal phases is shown in *Figure 6*.

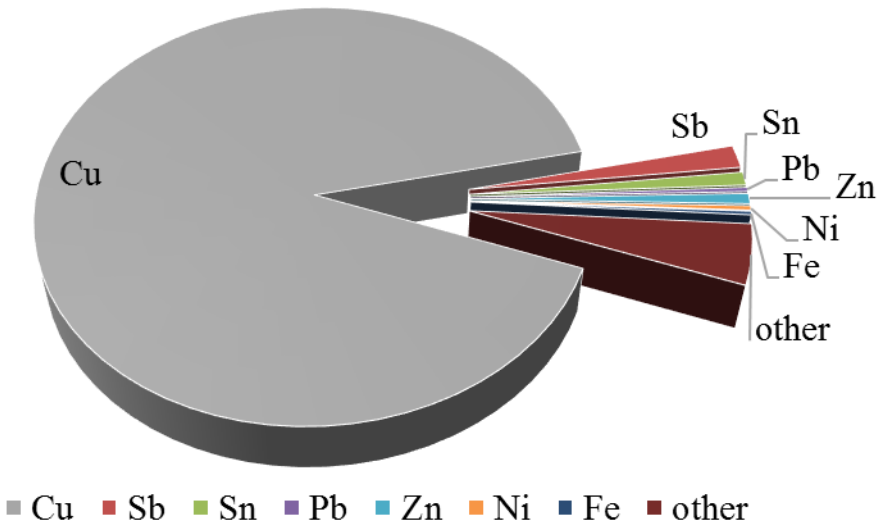

Figure 6: Averaged composition of the metal phases

A mean value of 91,1 wt.-% copper was reached in the metal phases by combusting pellets made of filter dust and additives. This result is in good agreement with the previous modelling with FactSage (estimated value 91.7 wt.-% Cu). Also the estimated values for Fe and Zn match with metal composition, the value for Antimony in the metal phase is much higher than expected.

Depending on the pellet mixture, the content for copper in the slag shows large fluctuations. Adding fine copper dust to the mixture leads to much higher copper content, probably because of metal droplet in the slag. Only 0,03 wt.-% Carbon can be found in the slag, that speaks for a complete combustion of the plastic content in the filter dust. For mixtures without adding copper dust, a copper content smaller than 3 wt.-% could be reached.

To sum up the simulated FactSage models for the metal composition correspond with the metal phases from the trials. Because of high metal content in the slag than expected, the slag need to be optimized to reduce metal losses. Also the experimental setup needs to be optimized, in order to arise a full utilization of oxygen and reduce material losses. More results and investigation about the autothermal behavior of pellets and influence of other slag additives will be published in a scientific journal. On top of that kinetic investigations provides first results about the behavior of plastic and carbon in context to pellet weight and added slag components.

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