

Pre-treatment of beverage can scrap to increase recycling efficiency

Jan Steglich^{1, a}, Regina Dittrich^{2, b}, Marcel Rosefort^{3, c} and Bernd Friedrich^{4, d}

^{1,3}TRIMET Aluminium SE, Aluminiumallee 1, 45356 Essen, Germany

^{2,4}RWTH Aachen, IME Process Metallurgy and Metal Recycling,

Intzestr. 3, 52056 Aachen, Germany

^ajan.steglich@trimet.de, ^brdittrich@ime-aachen.de, ^cmarcel.rosefort@trimet.de, ^dbfriedrich@ime-aachen.de

Keywords: used beverage can, recycling, multi-chamber furnace, dross, de-coating

Abstract

This paper reports the initial results of thermal pre-treatment of used beverage can scrap in an industrial size reverberatory multi-chamber shaft furnace. By investigating the heating conditions in the pre-heating shaft, conclusions about improving de-coating parameters are made. In a second step, the de-coated scrap was re-melted in a new laboratory experiment with focus on dross formation by solid-liquid reactions. These results indicate that de-coating to minimize dross formation is possible in oxygen containing atmosphere of a multi-chamber furnace. By avoiding a maximum temperature above 500 °C in the baled beverage can scrap, oxidation of the material was limited and de-coating maximized under given furnace conditions.

By preventing dross formation during the melting in a reverberatory furnace, the metal recovery is increased. Using the hot furnace off-gas to pre-heat the scrap and post-combusting the thermolysis gases of organic contamination decrease energy consumption. Resource and energy consumption are minimised, making the recycling process more energy efficient at the same time.

Introduction

The global production of aluminium products, as for example beverage cans, has increased steadily during the last years. The used beverage cans (UBC's) are collected, sorted, compacted for transport and finally re-melted to new aluminium alloys. Recycling UBC's in rotary drum furnaces is a state of the art recycling process for aluminium refiners. The rotation of the furnace submerges the melting scrap with already liquid metal, thus protecting the UBC scrap from oxygen and increasing the wetting at the scrap-metal interface. To additionally promote wetting at this interface and enable the coagulation of liquid aluminium drops, salt flux is added. Furthermore, the salt flux protects the metal surface against oxidation and absorbs impurities which are insoluble in aluminium. On the one hand the use of salt flux is beneficial for melt quality, on the other hand it requires additional salt recycling processes, using extra energy and causing additional costs. [1,2]

As an alternative, reverberatory multi-chamber furnaces are increasingly used to recycle organically contaminated UBC scrap. It is a key technical challenge to avoid floating of the low density scrap pieces on the liquid metal surface to prevent oxidation. Given the reason that beverage cans are made of magnesium and manganese rich AlMn1Mg1Cu (EN AW-3104) and AlMg4.5Mn0.4 (EN AW-5182) alloys, floating UBC scrap quickly oxidizes and leads to dross formation and therefore undesirable metal loss. Moreover, high porosity and contamination, as well as poor wetting and low heat conductivity of the UBC scrap, even increase the dross formation mechanisms. [2,3]

To remove organic contamination and pre-heat the charged scrap, multi-chamber furnaces can be equipped with a shaft above the melting chamber. The pre-heating causes decomposition of the organic compounds and carbon reacts with oxygen to form thermolysis gases.

The gaseous products are released and a carbon residue remains on the metal sheets as a result of incomplete organic removal. [3] The decomposition mechanisms are defined as thermolysis processes in this paper, due to the fact that industrial furnace atmospheres contain excess oxygen to completely combust the fuel gas. [2,3] Thermolysis, as an incomplete combustion, has to be distinguished from pyrolysis, which strictly excludes oxygen in the atmosphere. The composition of resulting gases and carbon residues is different in pyrolysis and thermolysis. [4] The removal of organic contamination and can coating from scrap is summarised as thermal pre-treatment in this paper.

Procedure

The experiment procedure is split in two phases consisting of:

1. **Thermal pre-treatment of UBC scrap** in an industry size multi-chamber shaft furnace.
2. **Dross formation and metal recovery** investigation in laboratory scale furnace with pre-treated UBC bale samples.

Separation of these two phases is necessary to exclude additional dross formation by gas-liquid reactions inevitably caused by the thermolysis gases and furnace atmosphere.

Thermal pre-treatment of UBC scrap

An industrial size reverberatory multi-chamber furnace with a capacity of 65 t liquid aluminium was used. The furnace consists of a main holding chamber (1) heated by two regenerative gas-air burners (2) with a maximum power of 6 MW. The melting chamber includes the shaft (3), which is used to pre-heat and de-coat scrap in counter current flow. The melting chamber is separated by a wall (4) with an exchange opening for melt and combustion gases. The melting chamber is separated by a wall (4) with an exchange opening for melt and combustion gases.

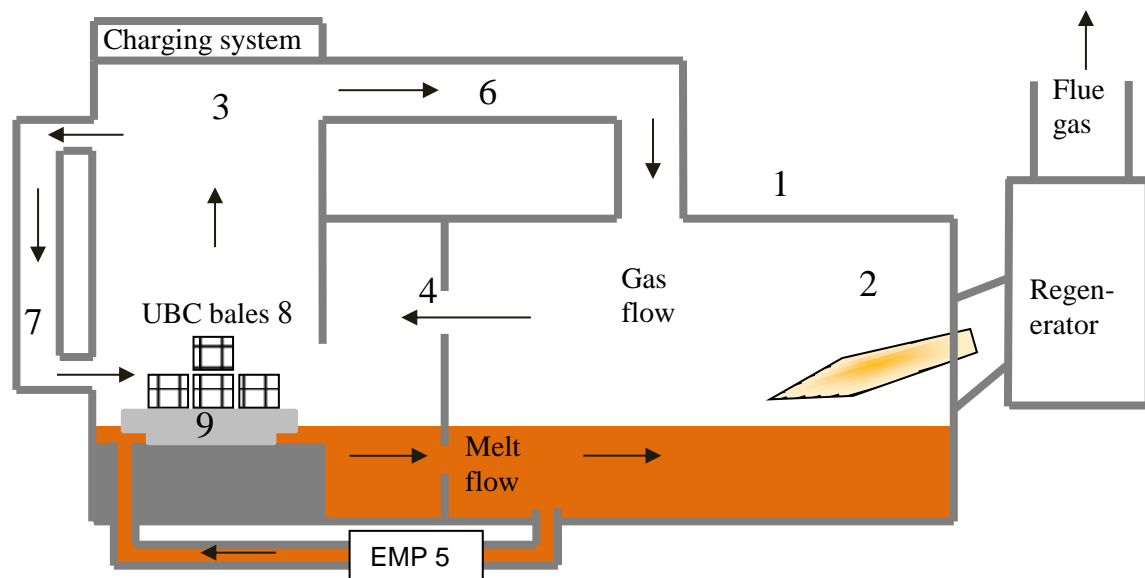


Figure 1: Functional diagram of a reverberatory multi-chamber furnace with pre-heating shaft.

An electro-magnetic pump (EMP) (5) is necessary to circulate metal between the holding chamber and the shaft to promote the heat exchange between melt and scrap at the bottom of the shaft. In addition to the EMP, a ventilation system (6) between the shaft and chamber is used to regulate the temperature in the shaft and melting chamber. The ventilation is also necessary to post-combust thermolysis gas in the holding chamber. Furthermore, the thermolysis atmosphere in the shaft is circulated (7) in counter current flow to increase convective heating between scrap and the hot shaft atmosphere.

Cubical UBC bales (8) with average dimensions of 30 cm by 30 cm by 20 cm were used as scrap material and placed on T-bars (9) for fastening during all experiments. The shaft roof temperature was set to a maximum of 650 °C, resulting in a wall temperature of 550 °C to 600 °C close to UBC bale. Highly compacted bales were used to avoid falling apart of the bales during the thermal pre-treatment and ensure retrieval for sampling after the experiments. Additional furnace parameters and UBC properties are displayed in table 1.

Table 1: Parameters of the 65 t shaft furnace and UBC bales used for the pre-treatment experiments

Furnace parameters		UBC bale properties	
Main chamber roof temperature in °C	1080	Weight in g	16,500
Shaft roof temperature in °C	650	Density in g/cm ³	0.91
Melt temperature max in °C	780	W x D x H in cm	30 x 30 x 20
Gas circulation shaft internal in m ³ /h	8000	Porosity in %	66
Gas circulation shaft-main chamber in m ³ /h	8000	Total metal yield after remelting under salt flux in wt%	76,8
EMP metal circulation in t/min	5-6	Moisture content in wt%	6.8

The scrap in the shaft is heated by thermal convection, radiation and conduction through the scrap. To investigate the influence of the heating rate on thermal pre-treatment of the scrap, one high and one low heating rate were chosen. Both experimental setups are described below:

- Experiment setup 1: convective/radiative heating condition, bale isolated from below
- Experiment setup 2: single bale on hot T-bar

The low heating rate was investigated by fixing a UBC bale onto a heat insulating refractory stone to exclude conductive heating through the scrap. The top bale was placed on a stack of five bales, fastened onto an aluminium T-bar as shown in figure 2 (five additional UBC bales were set directly on a T-bar for another investigation). A second T-bar was used as a security measure to prevent direct contact of the UBC with melt. Even though all bales were stored dry, remaining moisture in the scrap could not be excluded. The top UBC bale was equipped with six thermocouples to measure the temperature at different depth in and around the bale.

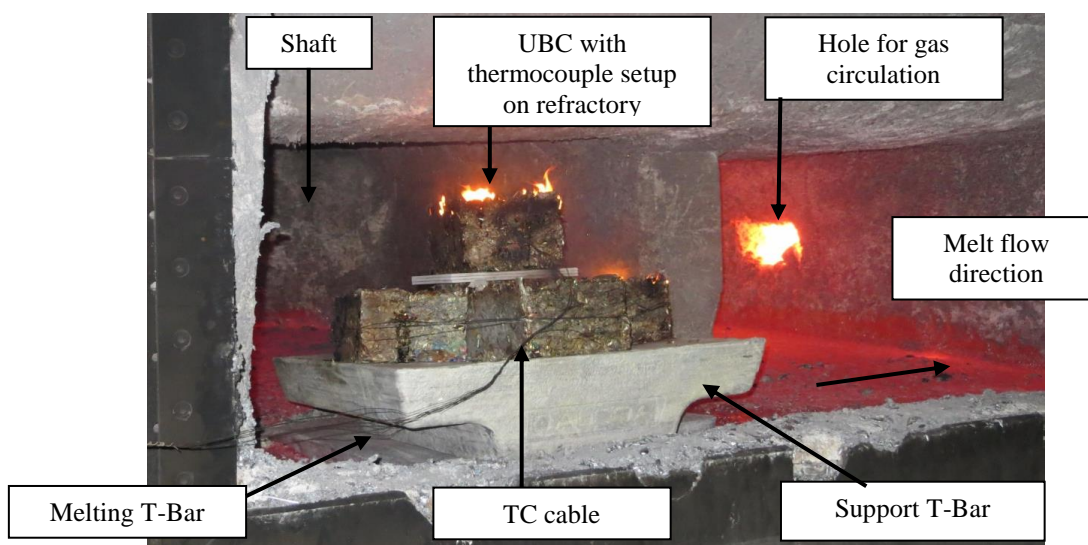


Figure 2: Experiment setup 1 of UBC bales in the melting chamber below the furnace shaft

For the second experiment setup (single bale setup), only one bale was fastened to a T-bar and placed in the shaft. Due to a melt level of about 15 cm height, the melt did not contact the UBC bale

directly, but heated the T-bar prior to melting. The key experiment parameters of experimental setup 1 and 2 are given in table 2.

Table 2: Experiment parameters for the two pre-treatment experiments

Setup	Pre-treatment exp. 1	Pre-treatment exp. 2
Number of bales	6	1
Number of thermocouples used	6	6
Total mass of UBC bales in g	105,289	16,524
Pre-treatment duration in min	40	45
Target shaft temperature in °C	650	650
Average shaft temperature in °C	660	603
Maximum bale core temperature in °C	396	594
Average O ₂ level in the shaft in vol%	14.5	15.6

After completing the thermal pre-treatment experiments, the thermolysed material was analysed for remaining carbon and oxygen content by a glowing loss method and carrier gas method respectively.

Dross formation and metal recovery

As next step, the de-coated material was used in laboratory scale dross formation experiments. For this purpose, a charging system was built to exclude influences of atmosphere on dross formation. An argon atmosphere containing less than 0.01 vol% oxygen was ensured. A functional diagram of the laboratory dross formation experiment setup is shown in figure 3.

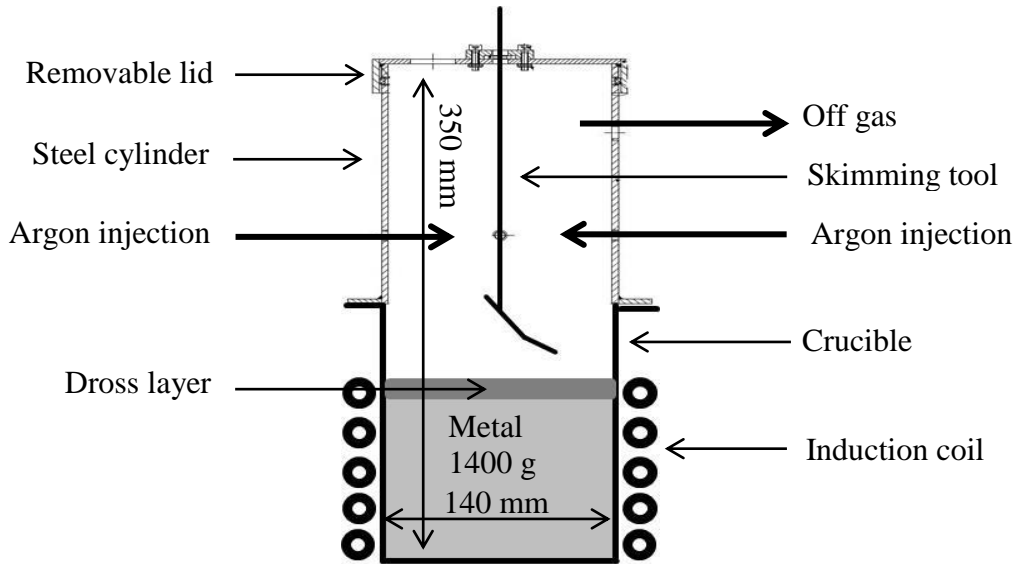


Figure 3: Schematic charging system for laboratory scale dross formation experiments.

The pre-treated UBC bales were cut into pieces of 100 g and dried before melting. After melting can body alloy (EN AW-3104) and skimming the surface, one UBC sample was attached to a sample carrier tool, placed in the crucible and the lid was closed. The setup was flushed with argon for two minutes to replace the atmosphere and the UBC sample was pushed into 750 °C hot metal. After a reaction time of additional 30 minutes, the dross was skimmed with the skimming tool shown in figure 3 and cooled in argon. A scrap/3104-metal ratio of 1/14 was kept constant in all experiments.

Results and discussion

UBC bale scrap was thermally pre-treated with focus on organic removal in relation to bale temperature. Afterwards, the resulting carbon and oxygen content in the material of two experiments is used to quantify the rate of organic removal. Subsequently, metal recovery and dross formation was investigated. The presented results are discussed at the end of each section.

Thermal pre-treatment of UBC scrap

Figure 4 shows the temperature records of the UBC bale in experiment setup 1, plotting the temperature over time. The setup was used to represent a low heating rate of UBC scrap on top of a pile in the shaft. The shaft temperature decreases after 23 minutes in figure 4, because the furnace door was opened for inspection. An average level of 14.5 vol% O₂ in the atmosphere permitted a safe opening of the door. Dark fumes and strong flames were visible above the bale. After 27 minutes, the temperature in the bale centre starts to increase above 100 °C, due to the end of moisture evaporation, indicated by a plateau in the temperature measurement. A following increase of the shaft temperature measured about 10 cm besides the bale indicates post-combustion of thermolysis gases in the oxygen containing atmosphere and correlates with rising bale temperature.

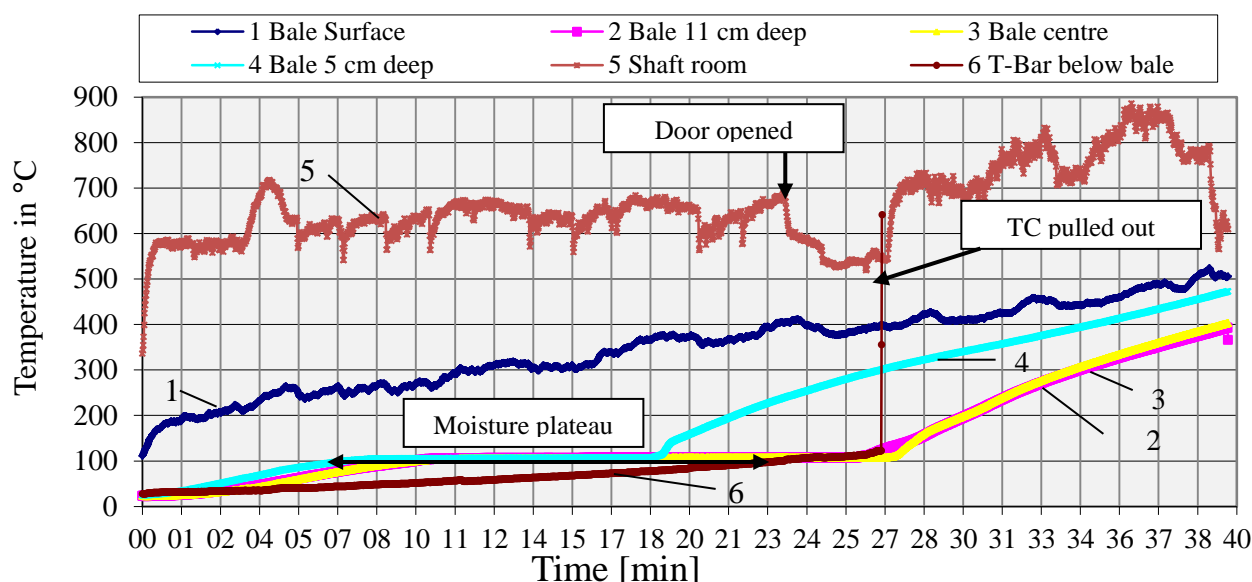


Figure 4: Temperature record of experiment setup 1: low heating rate. Bale insulated from below.

The bale temperature in a depth of 5 cm from the top and the centre increased according to surface temperature, confirming a convective/radiative heating. The highest shaft temperature was measured in this experiment and resulted in a central bale temperature of about 400 °C after 40 minutes, leading to a heating rate of 10 °C/min in the centre of the bale. In the following experiment, the UBC bale was pre-dried to avoid moisture in the bale for security reasons.

Figure 5 shows the temperature records of the single UBC bale in experiment setup 2. This setup was used to represent a high heating rate without direct melt contact. As expected, the bale surface temperature started to rise first. After 40 minutes the bale reached a homogenous temperature of about 580 °C in the centre and resulted in a heating rate of 14.5 °C/min.

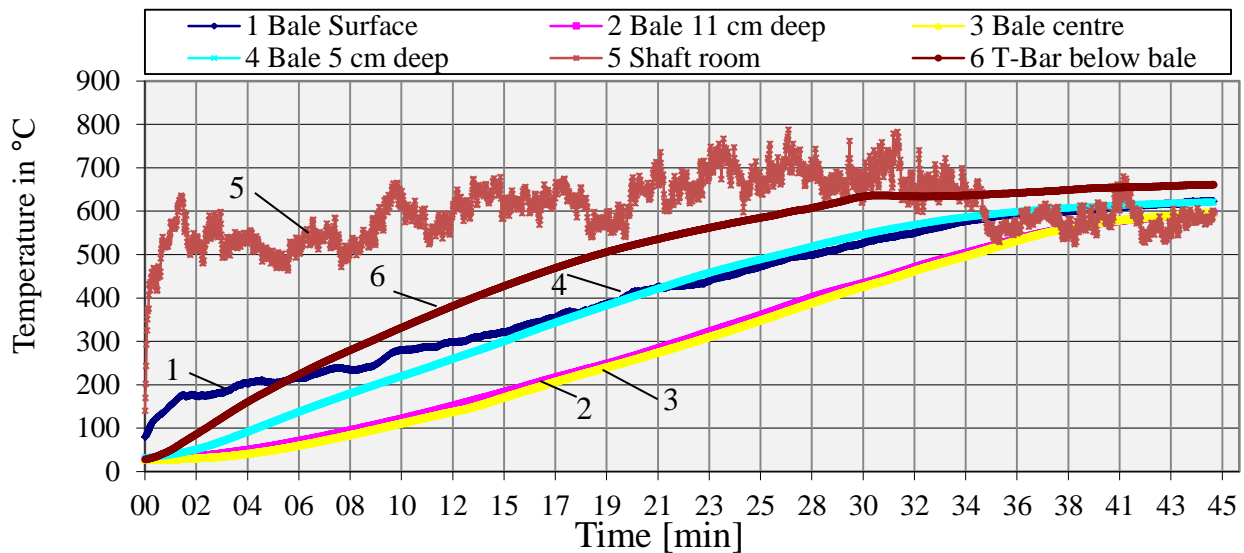


Figure 5: Temperature record of experiment setup 2: high heating rate condition.
One bale mounted onto one T-bar in the shaft.

By comparing the heating rate of experiment setup 1 ($10\text{ }^{\circ}\text{C}/\text{min}$) and 2 ($14.5\text{ }^{\circ}\text{C}/\text{min}$), the convective/radiative heating condition leads to an overall slower, heating of the UBC bale which is due to moisture present in the bale. It has to be noted that the bale surface temperature in exp. setup 1 increased continuously and did not exceed a maximum of $515\text{ }^{\circ}\text{C}$, even in a maximum atmosphere temperature above $800\text{ }^{\circ}\text{C}$. Comparing these observations to the temperatures of the bale in experiment setup 2, it has to be noted that a major part of the bale (surface down to 11 cm depth) spend more than 18 minutes above $500\text{ }^{\circ}\text{C}$ in the oxygen containing atmosphere. It has been shown by Grauer and Schmoker [6] that oxidation of a 1,55 wt% Mg containing alloy leads to an significant increase in weight from a reaction temperature of $350\text{ }^{\circ}\text{C}$ to $500\text{ }^{\circ}\text{C}$ as seen in figure 6.

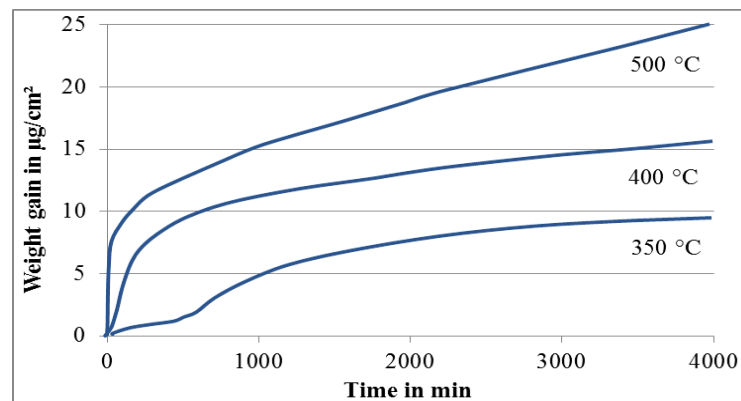


Figure 6: Weight increase over time of an aluminium alloy containing 1.55 wt% Mg at different temperatures in oxygen atmosphere according to [6]

Even if the displayed treatment times are significantly longer than the duration of the experiments, the high surface to weight ratio of the UBC scrap offers a large reaction area for oxidation. It is therefore expected that UBC from exp. setup 2 must have been stronger oxidised than in setup 1.

Organic removal and oxygen content

The efficiency of the thermal pre-treatment is rated comparing the initial oxygen and carbon content of the material with the values after the experiments. Oxidation has to be minimized to avoid metal loss whereas a low glowing loss indicates a high rate of organic removal. Samples were taken as drilling swarf from the top, middle and bottom part of each UBC bale. The total moisture content of the UBC samples was measured by drying in a laboratory furnace at $105\text{ }^{\circ}\text{C}$. The average moisture content was found to be 6.8 wt%.

Afterwards, the samples were glowing at 450 °C in air until no weight loss was detectable. Both procedures were performed on the basis of EN 13039 “*Determination of organic matter content and ash*” [7]. The content of oxygen in the material was analysed using a carrier gas method, by combusting the samples in oxygen free atmosphere at sufficiently high temperatures with carbon substrate to form CO, which can be detected afterwards. The results are displayed in table 3.

Table 3: Glowing loss and O₂ content of UBC before and after thermal pre-treatment.

UBC sample	T core max in C°	Heating time in min	Oxygen in atmosphere in vol%	Level of sampling	Glowing loss in wt%	O ₂ content in wt%
Initial UBC	none	none	none	☼	8.4	3.2
Experiment setup 1	400	40	14,5	Top	0.9	0.22
				Middle	0.7	0.20
				Bot	0.5	n.a.
Experiment setup 2	600	45	15,6	Top	0.7	0.40
				Middle	Sample melted	Sample melted
				Bot		

The results show that the thermal pre-treatment leads to a significant reduction of organic content in the scrap. At the same time, the total oxygen content was decreased, due to the thermolysis of oxygen containing organic compounds and can coating. [8] As expected, the oxygen content of the sample from experiment setup 2 is significantly higher. Furthermore, the resulting glowing loss of the UBC bales from experiment setup 1 and experiment setup 2 show similar values. For this reason, the two high-lighted samples were selected for comparison in the subsequent dross formation experiments.

Dross formation and metal recovery

After thermal pre-treatment, the UBC samples were melted and the generated dross skimmed. The dross samples were additionally re-melted under salt flux to determine the aluminium metal content. The resulting metal distributions are shown in figure 7 as mass fractions of aluminium and non-metallic fraction in dross as well as aluminium in melt. Reference experiment 3104 indicates the dross mass of an EN AW-3104 aluminium ingot with the same mass as the melted UBC scrap.

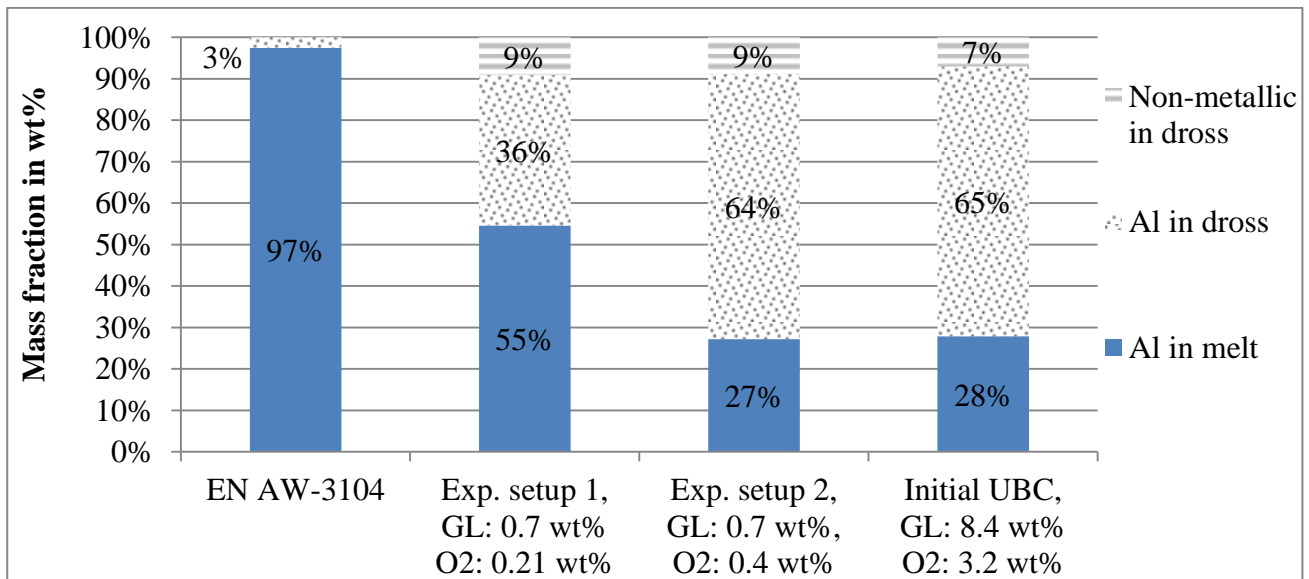


Figure 7: Mass fraction distribution as average values from two melting experiments for each scrap type (GL = glowing loss, Al = aluminium metal) after additionally re-melted under salt flux.

The results of experiment setup 1 with pre-treated UBC show that the dross fraction contains almost 30 wt% less aluminium metal than the dross of initial scrap or the oxidised UBC from experiment setup 2. More metal has been transferred into the aluminium melt. The amount of dross, as combined non-metallic and aluminium metal fraction, is minimal (45 wt%) when oxidation of UBC scrap is prevented during thermal pre-treatment. The non-metallic fraction does not strictly represent the content of aluminium oxide, but may also contain carbon residue, glass or other ceramic particles that are commonly present in inhomogeneous post-consumer scrap.

Oxidised UBC scrap of experiment setup 2 generated a similar amount of dross as melting the initial scrap material. Although the UBC from experimental setup 2 contained significantly less organic contamination, the dross amounts and metal/oxide ratios are comparable. Considering the small amount of organic contamination and oxygen left on the scrap, the influence on dross formation is high. Comparing the results of setup 1 to setup 2, it is indicated that the oxidation of the aluminium can sheets has a much higher impact on dross formation than the measured 0.7 wt% organic contamination. These results confirm the recommended pre-treatment procedure by Giese et al. [9] for UBC scrap. It is reported that a thermal pre-treatment between 450 °C and 550 °C in under-stoichiometric furnace flue gas led to a minimum of dross formation under laboratory conditions. [9] Regarding the aluminium metal in dross and aluminium in the melt as total metal recovery, the three experiments have comparable results between 91 wt% and 93 wt%. Jaroni et al. [3] has shown comparable results by melting UBC with organic content between 1.8 wt% and 3.5 wt%. Thermally pre-treated scrap had a total metal recovery of 97 wt% under laboratory conditions in a similar setup. When regarding only the aluminium transferred in to the melt as recovery, the pre-treated UBC scrap from experimental setup 1 yields the best result with 55 wt% aluminium in melt.

The results show that melting un-treated or oxidized UBC scrap in the described experiment setup led to significant more dross formation with high metal content. Furthermore, it was demonstrated that thermal pre-treatment of highly compacted baled scrap is possible.

Summary and Conclusion

The thermal pre-treatment of highly contaminated and compacted used beverage can (UBC) scrap was investigated. The baled scrap was pre-treated in an industrial multi-chamber furnace with additional pre-heating shaft. Two experiment setups were used to represent different boundary conditions of heat transfer from the furnace shaft into the scrap metal:

- A convective/radiative heating condition represented a bale lying on top of a scrap pile in the shaft. This setup led to a bale temperature of 400 °C in the centre after 40 minutes, even with moisture present in the scrap and resulted in the highest removal of organic contamination and lowest oxygen present on the beverage can scrap.
- A single UBC bale setup was used to represent a high heating rate and led to a homogenous temperature of about 580 °C in the bale, resulting in high removal of organic contamination but highest oxidation of the metal sheets.

Retrieved samples of the convective/radiative and single bale setup were melted in a laboratory setup, in order to investigate the influence of carbon and oxygen content on dross formation. The results were compared to a reference dross formation experiment with a can body alloy ingot (EN AW-3104) and initial UBC bale samples.

This study confirms that the removal of organic contamination by thermal pre-treatment of UBC bales is possible in the shaft of a multi-chamber furnace. Additional conclusions are that effective pre-treatment with highly compacted and contaminated UBC bales is possible by limiting the maximum pre-treatment temperature to 500 °C at the bale surface. A treatment time of 40 minutes was necessary to achieve a temperature of 400 °C in the bale centre under given experimental

conditions. A significant reduction in organic contamination was demonstrated in oxygen containing furnace atmosphere. The suggested pre-treatment parameters have to be confirmed under regular production conditions.

Re-melting of this scrap confirms the effective pre-treatment by decreasing the dross formation from 72 wt% with the initial bale to 45 wt% of the pre-treated bale in a salt flux free re-melting process. Regarding the aluminium metal in dross and aluminium in the melt as total metal recovery, the three experiments have comparable results between 91 wt% and 93 wt%. An increase in maximum pre-treatment temperature leads to higher oxidation of the material and more dross formation. Although a low carbon and oxygen content seems preferable to avoid dross formation, the oxidation of the material seems to have a higher influence on dross formation.

Outlook

This study was conducted not only to investigate the influence of thermal pre-treatment on dross formation but also to generate data for future studies on:

- analysis of the thermolysis gases
- measuring the thermal conductivity of UBC scrap

Results of the generated thermolysis gases have to be evaluated for their energy content and effective post-combustion in the main holding chamber. Schmitz [1] published that a modern closed well furnace with post-combustion of thermolysis gases and regenerative burner can save between 6 - 8 % energy referring to a furnace with 800 kWh/t power. It is reported that substoichiometric atmosphere in a melting chamber is necessary to prevent oxidation of the metal. [1]

Acknowledgements

The research leading to these results has been carried out within the framework of the AMAP (Advanced Metals And Processes) research cluster at RWTH Aachen University, Germany. Furthermore, the cooperation and support of the Real Alloy Recycling GmbH in Stuttgart is gratefully acknowledged.

References

- [1] Schmitz, C., Energieeinsparung beim Umschmelzen von Aluminium-Schrott, Gaswärme international, Issue 4-2014, p. 44-50
- [2] Krone, K., Aluminiumrecycling: Vom Vorstoff bis zur Legierung, Aluminium-Verl., Düsseldorf, 2000
- [3] Jaroni, B., Einfluss von organischen Komponenten auf das Aluminiumrecycling, Diss. RWTH Aachen University, Shaker Verlag, Aachen, 2014
- [4] Rumpel, S., Die autotherme Wirbelschichtpyrolyse zur Erzeugung heizwertreicher Stützbrennstoffe, Universität Karlsruhe (TH), Dissertation, 2000.
- [5] Kvithyls, A., Gaal, S., Kowalewski, P., Engh, T. A., Gases evolved during de-coating of aluminium scrap in inert and oxidizing atmospheres, Light Metals, 2003
- [6] Grauer, R., Schmoker, P., Die Oxidation von Aluminium-Magnesium-Legierungen in Sauerstoff bei erhöhter Temperatur, Werkstoffe und Korrosion, Volume 27, Issue 11, 1976, p. 769–774
- [7] EN 13039:2011, Soil improvers and growing media – Determination of organic matter content and ash, 2012
- [8] Stoye, D., Paints, Coatings and Solvents, VCH Verlagsgesellschaft mbH: Weinheim, 1st edition, 1993
- [9] Giese, A., Rahms, H., Optimierung der thermischen Prozessführung beim Recycling von Aluminiumschrott unter Berücksichtigung des Einflusses organischer Anhaftungen auf den Aluminiumabbrand, Gaswärme-Institut e. V. Essen, 2008