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ALUMINIUM CABLE WASTE MELTING IN MICROWAVE FIELD

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Abstract: *In this paper, the melting of crushed aluminium cable waste in microwave furnace as well as the treatment of gaseous emissions in a microwave thermal filter has been preliminary investigated. Trace PVC sheath content in processed waste is about 3% of the total weight. During the melting, environmental harmful compounds such as: HCl, benzene, toluene, styrene, xylene etc. have been detected in the generated gases. The treatment was carried out by passing the gases through a microwave heated filter. It was observed that the temperature of the filter has a major influence on the neutralization of the harmful compounds, the content being reduced below the legal limits.*

Key words: *aluminium cable waste, microwave furnace, melting, thermal filter.*

1. Introduction

The abundance and the versatility of aluminium in various applications have made it one of the top solutions for lightweight metal strategy in various industries: construction, automotive, energy etc. [8]. In the cable industry, substitute copper with aluminium can considerable reduce the linear weight without degrading too much the electrical properties [5]. To obtain optimal electrical conductivity, aluminium use for cables has purity above 99.7% [4].

The cables are composed of numerous materials: an aluminium core cable, covered with a polymer thick layer. Additional metallic materials are coaxial integrated into the matrix of cables. These cables are manufactured by extruding together all the materials that compose it. Aluminium in cables represents between 30-70% of the total weight. Other metals are mainly steel, lead, copper and zinc. The variety of plastics contained in the sheath are: flexible polyvinyl chloride (PVC), polyethylene (PE), polypropylene, ethylene vinyl acetate, ethylene propylene rubber, silicone and vulcanised rubber etc. [5].

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Although aluminium cables represent about 8% of aluminium products in EU, the inherent purity of aluminium used for cables justify differentiate recycling channels [10].

The traditional recycling of waste cables relies on open burning to separate the metal (aluminium, copper). Because of the polymer insulating sheath contains halogens, the burning process will produce a large amount of toxic gases and dust, causing extreme environmental deterioration and severe damage to human health. In addition, the plastic in cables is wasted and the quality of the reclaimed metal (Al, Cu) is decreased during burning process [7].

A more environmentally friendly metal-plastic separation process relies on mechanical treatment through stripping, crushing and sorting (gravitational, magnetic, electrostatic, flotation etc.). As a mechanical treatment result, metal particles of particular size (1-10 mm) containing 2-5% plastic residue are obtained [7], [9].

Aluminium waste can be melted in different types of furnaces: coreless and channels induction furnaces, crucible and open-hearth reverberatory furnaces fired by natural gas or fuel oil, electric resistance and electric radiation furnaces [2].

Microwave melting is a novel technology which presents a series of major advantages compared to the classical pyrometallurgical processes, such as simultaneous evolution of the heating gradient in the entire volume of material, a much higher heating rates that shorten the melting time by 70-85%, allowing energy savings and higher processing capacities and a superior quality of the obtained materials by reducing the melt impurification through oxidation. Also, this method exhibits a remarkable versatility, as wastes with a wide range of shapes, chemical compositions and structures can be processed in the same installation. Microwave heating also offers the possibility to neutralize the gaseous emissions by passing the gas through a granular MW susceptor material thermal filter [1], [3].

Microwaves (MW) are electromagnetic waves with a frequency between 300 MHz and 300 GHz and wavelengths in the range of 1 mm - 1 m, much larger than the size of the molecules (nm) or the metallic crystalline grains (µm). As a result, part of the energy of the electromagnetic field is transformed into thermal vibration energy and transferred to the molecules of the melted material. This generates a heating effect in the dielectric material which is caused partly by the polarization of the charged particles from the material by the high frequency electric field (hysteresis losses), and partly by the Joule effect due to the conduction of the free loads under the action of the electric field [1], [6].

2. Experimental

In this paper, crushed Al cable waste melting in a MW furnace, as well as the harmful gases treating in a MW heated filter were preliminary investigated.

The waste was purchased from a specialized non-ferrous metals recycling small enterprise and consist of a mixture of Al granules (dimension 1-10 mm) with PVC sheath traces, obtained by crushing the PVC insulated Al cables (2-10 mm diameter) followed by a vibratory sieve separation of the PVC from metal. The weight of the PVC traces was determined by burning through heating the crushed cable samples at 500° C and weighing out the remaining metal. By this method the PVC content in the waste was determined to be about 3 wt.%. The crushed Al cable waste used in the experimental works is shown in Figure 1. The chemical composition of the aluminium in waste is presented in Table 1.

Fig. 1. *Crushed aluminium cable waste*

The chemical composition of the aluminium in waste Table 1

Element	As	Cu	Fe	Mg	Mn	Pb	Sb	Si	Ti	Zn	Al
wt. %	0.01	0.01	0.12	0.01	0.01	0.01	0.01	0.06	0.01	0.02	base

Others elements: Cd, Co, Cr, Mo, Ni, S, Sn, each < 0,005

It can be seen from the data presented in Table 1, that the purity of the aluminium in the processed waste is higher than 99.6 wt.%.

The schematics of the experimental MW equipment for melting nonferrous metals waste is shown in Figure 2. The melting equipment consists of a cylindrical enclosure made of steel (1), in which are five rectangular windows for mounting the microwave magnetrons (6). The axes of the windows are positioned in different horizontal planes, the angle between the axes is 72°, thus radiating different areas of the susceptor material (3). In order to reduce the heat loss, the interior of the enclosure is covered with a thermal insulation layer (2) made of super-alumina ceramic fibres with resistance to temperatures up to 1600 °C. Coaxial, there is placed the melting crucible (4), made of graphite-clay mixture, approx. 1 litter capacity, clothed in a microwave susceptible material (3) made of silicon carbide. The batch heating is performed by five 2.45 GHz microwave generators (6) of 850 W maximum power. The temperature is measured using a ceramic sheath K-type thermocouple (8).

Generated harmful gases and dust are captured through the exhaust pipe (9), fixed in the furnace cover (7), and which is connected with the gas treatment thermal filter (11). The filter consists of a steel cylinder in which windows are cut out for the installation of three 2.45 GHz magnetrons (13) of 850 W power. A microwave transparent quartz cylinder is placed inside the steel cylinder and contains a microwave susceptible material SiC (12) in the form of 5-10 mm diameter granules. The temperature inside the thermal filter is measured with a K-type thermocouple. Gas and dust sampling are carried out through nozzles (10, 14) attached to the exhaust tube (9) just before and after the filter.

The laboratory MW experimental non-ferrous waste melting installation is presented in Figure 3.

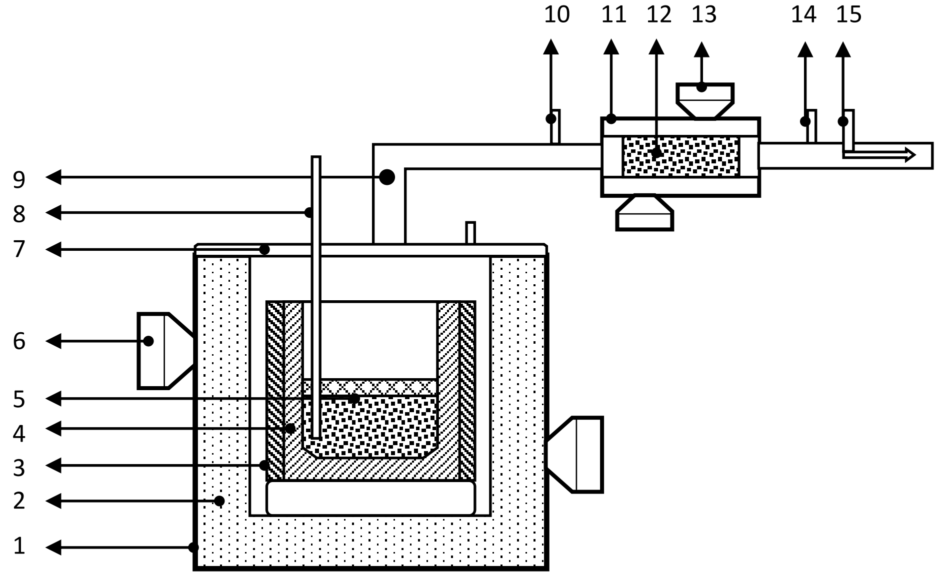

Fig. 2. *Microwave melting furnace and gases thermal filter:*
1 - *Furnace body (steel);* 2 - *Thermal insulating material;* 3 - *MW susceptor material (SiC);* 4 - *Melting graphite crucible;* 5 - *Charge (Al cable waste + cover flux);* 6 - *Furnace MW magnetrons;* 7 - *Furnace cover (steel);* 8 - *Thermocouple (K-type);* 9 - *Flexible exhaust tube (steel);* 10, 14 - *Gas sampling socket pipe;* 11 - *Burning gases thermal filter treating;* 12 - *MW susceptor material (SiC balls);* 13 - *Filter MW magnetrons;* 15 - *Compressed air tube*

Fig. 3. *Laboratory microwave furnace and gases thermal filter installation*

The experimental working conditions are presented in Table 2.

The experimental working conditions Table 2

Charge no.	Melting charge		MW furnace temperature [°C]	Melting time [min]	Thermal filter temperature [°C]
	Al cable waste [g]	Flux [g]			
C 1.	200	10	720 ± 5	30	800 ± 10
C 2.	200	20	720 ± 5	30	800 ± 10
C 3.	200	30	720 ± 5	30	800 ± 10
C 4.	200	40	720 ± 5	30	800 ± 10
C 5.	200	40	720 ± 5	30	800 ± 10
C 6.	200	40	720 ± 5	30	900 ± 15
C 7.	200	40	720 ± 5	30	1000 ± 20

The chemical composition of the cover flux is presented in Table 3.

The chemical composition of the cover flux Table 3

Flux component	NaCl	KCl	CaF_2	Cryolite
wt. %	35	35	15	15

Waste melting generated gases sampling

The schema of the gas sampling equipment is presented in Figure 4.

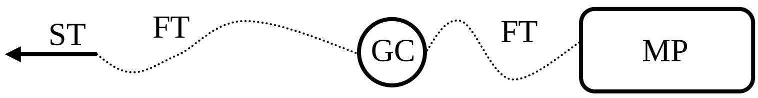

Fig. 4. *Gas sampling equipment:*
ST - gas sampling tube (stainless steel, OD = 10 mm, L = 1000 mm), GC - gas collector, MP - air mechanical pump, FT - flexible tube (silicon rubber)

Volatile Organic Compounds (VOC) were captured on CSC Anasorb cartridges according to standard SR EN 13649:2002. The OVCs were desorbed on dichloromethane and analysed by gas chromatography.

HCl was captured with on an absorbent solution - distilled water (50 mL/sampling) according to standard SR EN 1911:2011

Apparatus

The chemical composition of the Al cable waste as well as Al ingot were analysed by ICP-OES - AAS Zenit 700, Analytic Jena AG.

The physical parameters (temperature, pressure, speed, debit) of the exhaust gases were determined with portable Maxiλyzer NG apparatus.

Gas chromatograph with mass spectrometer GC-MS QP 2010 PLUS NCI apparatus, coupled with Autosampler AOC 20i device, was used for VOC determination.

The HCl content was determined by spectrophotometry with Specord 30 apparatus.

3. Results and Discussion

The experimental results of the crushed aluminium cable waste MW melting are presented in Table 4.

The experimental results of the crushed aluminium cable waste MW melting Table 4

Charge no.	IN		OUT		Metal recovery efficiency [%]
	Al cable waste [g]	Fluxes [g] / [wt.%]	Al metal [g]	Slag [g]	
C 1.	200	10 / 5	165	42	85
C 2.	200	20 / 10	176	43	91
C 3.	200	30 / 15	184	43	95
C 4.	200	40 / 20	190	47	98
C 5.	200	40 / 20	188	46	97
C 6.	200	40 / 20	190	48	98
C 7.	200	40 / 20	189	45	98

From the experimental data, it could be observed that the Al recovery efficiency increases with the increasing the cover flux quantity. Due to the high surface area of the Al granules, the oxidation process during melting is very intensive; increasing the flux quantity up to 20 wt%, it forms a continuous layer on the melted Al surface thus preventing further oxidation. The chemical compositions of recovered aluminium, in wt.%, are presented in Table 5.

The chemical compositions of recovered aluminium, in wt.% Table 5

Charge no.	Cu	Fe	Mg	Pb	S	Sb	Si	Zn	Others	Al
C 1.	0.01	0.13	0.01	0.16	0.01	0.01	0.06	0.02	< 0.1	base
C 4.	0.01	0.12	0.01	1.42	0.015	0.01	0.02	0.07	< 0.1	base

Others: As, Cd, Co, Cr, Mn, Mo, Ni, Sn, Ti, V, each < 0.01

The increased quantity of Fe, Pb and Zn in the recovered Al could be due to the contamination of crushed Al with these metals (from the metallic shields of the cable) as well as to the presence in the cable structure of the heavy metal stearates, as these compounds are used in the extrusion cable process as lubricants.

The efficiency of aluminium recovery vs. cover flux quantity used at MW melting of waste is presented in Figure 5.

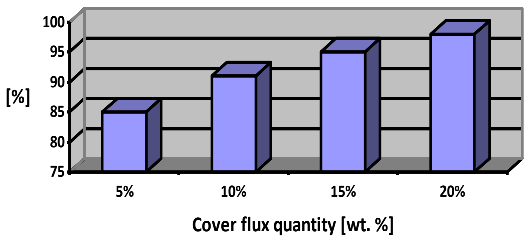

Fig. 5. *Aluminium recovery efficiency vs. cover flux quantity*

The chemical composition of the generated gases during the melting of aluminium cables waste and after passing the thermal filter heated at different temperature (batch code: C 5, C 6 and C 7 respectively) are presented in Table 6.

The quantity evolution of some harmful compounds in the generated gases out of the MW melting furnace and after passing through MW thermal filter heated at different temperature is shown in Figure 6.

Table 6

The chemical composition of the generated gases during the melting of aluminium cables waste and after passing the thermal filter heated at different temperature

		OUT MW furnace	OUT of thermal filter			Legal limits*
			Thermal filter temperature [°C]			
			800 ± 10	900 ± 10	1000 ± 10	
Gas temperature	°C	88	96	128	134	
Gas speed	m/s	2.6	2.5	2.6	2.8	
Debit	m^3/s	0.9	0.9	1.1	0.9	
Pressure	kPa	93.5	92.3	96.7	96.9	
Gas components:						
Acetone	mg/Nm^3	1.70	0.84	0.81	0.67	150
2-Butanona	mg/Nm^3	1.65	-	-	-	150
Benzene	mg/Nm^3	143.57	34.30	15.65	4.23	5
Toluene	mg/Nm^3	22.97	4.35	3.64	2.16	100
2-Hexanona	mg/Nm^3	3.02	0.46	0.34	0.27	100
Chlorobenzene	mg/Nm^3	0.74	0.64	0.53	0.37	100
Ethylbenzene	mg/Nm^3	5.41	0.99	0.72	0.53	100
Xylene	mg/Nm^3	10.30	2.89	2.16	1.58	100
Styrene	mg/Nm^3	1.52	0.80	0.65	0.44	100
Propyl-benzene	mg/Nm^3	0.79	0.53	0.51	0.35	-
1,2,4-trimetil-benzene	mg/Nm^3	0.28	-	-	-	100
Butyl-benzene	mg/Nm^3	0.26	-	-	-	100
Naphthalin	mg/Nm^3	1.73	-	-	-	100
HCl	mg/Nm^3	21.94	4.33	4.05	3.28	5

*) Regulation no. 462/July 1, 1993

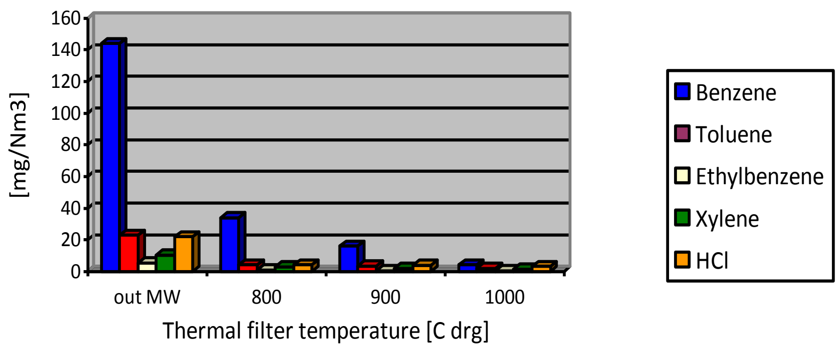

Fig. 6. *The quantity of some harmful compounds in the gases after MW filter treating*

At a filter temperature of 800 °C and 900 °C, only benzene, overpass the limits, heating the filter up to 1000 °C, all the harmful compounds analysed being below the legal limits.

4. Conclusion

The melting experiments of crushed Al cable waste in MW field furnace have shown that the method is feasible, ecological and economically efficient, with very high metal recovery yields.

Increasing the cover flux quantity in the melting process has as result a better molten Al bath protection against oxidation with favourable consequence on recovery efficiency.

Due to the thermal decomposition of the trace PVC sheath in the Al cable waste, harmful compounds such as benzene, toluene, ethylbenzene, xylene, HCl etc. have been determined in the effluent gases.

The treatment of the gaseous emissions in a MW heated filter reduced their concentration below the legal limits. It was observed that the temperature of the filter has a major influence on the neutralization of the toxic compounds (benzene, HCl).

Acknowledgements

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