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ECOLOGICAL AND EFFICIENT METHOD FOR THE RECOVERY OF NONFERROUS METALS FROM INDUSTRIAL WASTES BY PROCESSING IN MICROWAVE FIELD

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Abstract: The present paper presents an innovative ecological and efficient method to recover the useful metals from various types of industrial wastes by processing in a microwave field. Compared to the classical methods, microwave melting presents a series of major advantages, such as: i. simultaneous evolution of the heating gradient in the entire volume of material; ii. much higher heating rates that shorten the melting time by 70-85%, thus leading to energy savings and higher processing capacities; iii. superior quality of the obtained materials by reducing the melt impurification through oxidation; iv. remarkable versatility, as wastes with a wide range of shapes, chemical compositions and structures can be processed in the same installation; v. the possibility to neutralize the gaseous emissions also in microwave field. In the present work two types of wastes from the obtaining of aluminum-silicon and respectively antifriction antimony-tin-lead alloys, were melted in a microwave furnace. The values of the metal recovery efficiencies were of approximately 90%. Also, the treatment of the gaseous emissions in microwave field lead to the reduction of the hazardous substances' contents to values under the legal limits.
Keywords: novel materials and environmentally friendly technologies, microwave field, recycling, sustainable development

INTRODUCTION

The recycling of nonferrous metal wastes has a significant impact on the environment through the reduction of energy consumptions and of the emissions, thus contributing to the preservation of the natural resources and the sustainable development of human society.

In the European Union, the recovery of nonferrous metals is essential for the rentability of the metallurgical industry. The reintroduction of metallic materials in the economic circuit reduces the EU's dependence on the import of raw materials. Also, the production of metals using secondary sources requires a much lower amount of energy compared to the extraction of same metals from ores [1].

Pyrometallurgical processes are the most common methods used for processing nonferrous wastes. Current processing manages to convert the waste into metal or other raw materials (oxides, salts, etc.) which can be used in various industrial applications. 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% and allow 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 melting also offers the possibility to neutralize the gaseous emissions in microwave field.

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 of 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 [2-11].

In the present work two types of wastes from the obtaining of aluminum-silicon and respectively antifriction antimony-tin-lead alloys, were melted in a microwave furnace.

EXPERIMENTAL PART

The wastes come from the casting of Al-Si alloy parts and components and the production of antifriction Sb-Sn-Pb materials. The materials were milled and homogenized in a disc mill at a sized of maximum 3 mm. The 350 g charges were melted at temperatures up to 1000°C in graphite and silicon carbide (SiC) crucibles.

The influence of the crucible composition on the metal extraction yield from the molten waste was investigated. Table 1 shows the composition of the melting-protection flux used in the experimental work. The flux quantity used was of 5% of the charge mass.

Table 1. Chemical composition of the melting-protection flux [% wt]

Compound	NaCl	KCl	CaF_2
% gr.	35	35	5
Compound	NaF	Na_3AlF_6	$Na_2B_4O_7$
% gr.	5	10	10

The schematics of the experimental equipment for melting non-ferrous metal waste using microwaves is shown in Figure 1. 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 susceptible 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 fibers with resistance to temperatures up to 1600°C. Coaxial, the melting crucible (4), made of graphite-clay mixture, approx. 2 litters, clothed in a microwave susceptible material (3) made of silicon carbide.
The batch heating is performed by five microwave generators (6) of 850 W maximum each. An inert atmosphere (N_2, Ar) at a pressure of about 0.5 bar can be made inside the furnace through a nozzle mounted on the furnace cover (7). The temperature is measured using a Pt / Pt-Rh thermocouple (8).
Melting gases and vapors are captured through the exhaust pipe (9), mounted on an adjustable speed blower. On this tube is placed the gas treatment filter (11). It consists of a steel cylinder in which windows are cut out for the installation of three magnetrons (13) of 850 W each.
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 of the thermal filter is measured with a Pt / Pt-Rh thermocouple. Gas sampling is carried out through nozzles attached to the exhaust tube (9).

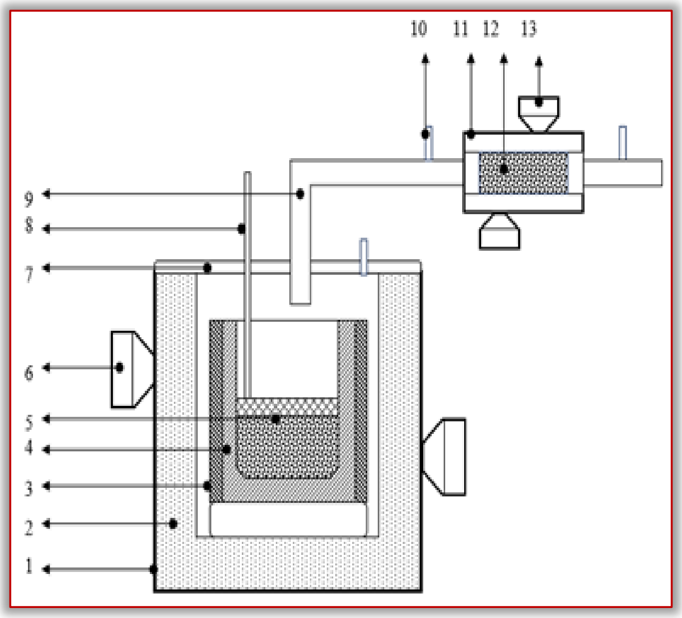

Figure 1. The experimental installation for the recovery of non-ferrous metals by melting in microwave field and resulting gas treatment: 1.Furnace body (steel); 2. Thermal insulation material; 3. microwave susceptible material (SiC); 4. Graphite/SiC crucible; 5. Charge; 6. Magnetron; 7. Furnace cover (steel); 8. Thermocouple (Pt / Pt-Rh type); 9. Outlet gas tube (steel); 10. Gas nozzle; 11. The resultant gas treatment heat exchanger; 12. Microwave susceptible material (SiC granules); 13. Magnetron.

The technological flow-chart of the metal-containing waste melting in microwave field is shown in Figure 2.

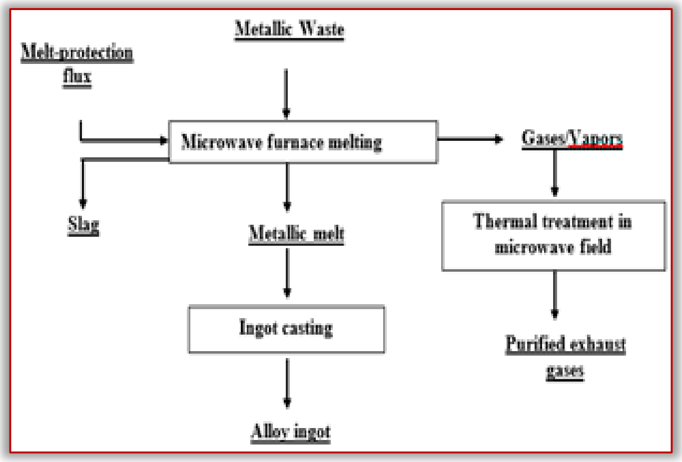

Figure 2. Technological flow-chart of the melting process and the microwave field treatment of resulted gases

At the end of the melting process, the crucible was removed from the furnace, the formed slag was removed, and the molten metal was poured into a metal shell.

RESULTS AND DISCUSSION

After complete cooling the obtained ingots were weighed for the determination of the metal recovery efficiencies and samples were taken for the chemical characterization of the resulting alloys. The chemical compositions are given in tables 2 and 3. Table IV presents the efficiencies of the recovery process, with very high values. For the antifriction alloy the efficiency was over 90%; for the aluminum alloy a maximum value of 82.3% was attained.

Table 2. Chemical composition of aluminum alloys

Element	Al	Si	Mg	Fe	Mn	Other* (sum)
wt%	base	12,35	2,82	0,48	0,82	< 1

*) Other: Cu, Zn, Ca, Na, Cr, Ni

Table 3. Chemical composition of antifriction alloys

Element	Sn	Pb	Sb	Cu
wt%	58,80	2,86	10,85	6,5

Table 4. Metal recovery efficiency

Waste	Crucible	Metal recovery efficiency
Antifriction alloy	Graphite	95.33
Antifriction alloy	SiC	87.66
Aluminum alloy	Graphite	82.3
Aluminum alloy	SiC	67

From the data presented in Table 4, it can be observed that the values of the recovery efficiency obtained when using the graphite crucible are higher than the ones determined in the case of melting in the silicon carbide crucible. These differences may be caused by the different values of the thermal conductivity for the two materials (120 W/mK for SiC, 8.7 W/mK for graphite) [12,13]. This characteristic may influence the capacity of the materials for maintaining the working temperature in order to provide the latent heat for melting.

Also, the heating rate is faster for the graphite crucible because this material exhibits a stronger microwave susceptor character compared to SiC. Thus, for identical durations of the melting process, the use of a graphite crucible leads to the attaining of the melting temperature in a shorter time and its maintaining for a longer period.

Gas analyses have shown the presence in the melting gases of some particles/vapours of metals and HCl vapours (as a result of chlorine decomposition in the flux). Table 5 shows the content of HCl measured in the gases resulted from the waste melting.

Table 5. HCl content in gases resulted from melting

Temperature range, [°C]	50-400	700-750	Maximum legal limit
Contained HCl, [mg/Nm3]	5.5	1.5	5

The thermal treatment of the gases in a microwave heat filter lead to a significant reduction of their content, below the legal permissible limits.

CONCLUSIONS

The microwave field melting experiments for waste containing non-ferrous metals have shown that the method is feasible, ecological and economically efficient, with very high metal recovery yields. Two types of wastes from the obtaining of aluminum-silicon and respectively antifriction antimony-tin-lead alloys were processed, with recovery efficiencies of approximately 90%. The treatment of the gaseous emissions in the microwave heat filter reduced their concentration below the legal limits.

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