HEALTH, ENVIRONMENT, DEVELOPMENT

X-RAY FLUORESCENCE ANALYSIS OF WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT

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Summary
The aim of this paper is x-ray fluorescence analysis of waste electrical and electronic equipment. The paper evaluates the composition of waste electrical and electronic equipment most often used by today's society. For the five electronic devices (mobile phone, computer mouse, keyboard, web-camera, and computer monitor), the components have been identified and elemental composition has been measured using x-ray fluorescence analysis. As expected, most of the devices weight accounts for plastic (since the casing is mostly made from plastic). Cables also have a significant weight. In the devices analysed, 28 chemical elements were found during the study: the greatest diversity were found in monitor. The largest weight corresponds to "heavy" elements forming metal parts of the devices. Among the valuable components, copper and zinc are the most common. It is worth noting the high content of titanium in all the devices.
Keywords: elemental composition, electronic device, waste electrical and electronic equipment, metal, x-ray fluorescence analysis

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1. Introduction

Mankind is currently at the stage of regulation and adjustment of waste management. In recent years, the policy of developed countries focused on the circular economy, including resources extraction from waste. When assessing the resource value, waste electrical and electronic equipment (WEEE) is very important. Today, WEEE is collected along with other household waste in most countries. As a result, WEEE is either landfilled or incinerated, i.e. resources are lost.

Besides, WEEE may be dangerous to the environment because it contains toxic components, such as heavy metals or organic compounds in plastic *(Ishchenko, 2019)*. Poor waste management results in soil or groundwater pollution by hazardous compounds.

Electronic waste has many components. They include accumulators, batteries, mercury lamps, cathode ray tubes, liquid crystal and plasma panels and other parts consisting of various alloys, plastic, glass and other mixtures.

There are many studies dedicated to WEEE composition *(Morf,2007, Musson, 2006, Dimitrakakis, 2009, Chancerel, 2009, Hlavatska, 2021)*, which cover different countries and different types of WEEE. The diversity of WEEE and regular changes of technologies cause a need for new research. A number of researchers *(Salhofer, 2011, Oguchi, 2013, Nnorom, 2009, Lincoln, 2007, Ernst, 2000)* have analysed the content of hazardous substances in WEEE. Bigum et al. *(Bigum, 2013)* have found lead, cadmium, mercury, brominated retardants (BFRs), polyvinyl chloride and other toxic compounds in WEEE. Dimitrakakis et al. *(Dimitrakakis, 2009)* have found that some heavy metals (cadmium, lead) are over the limits in the plastic of electronic waste.

Taking into account the abovementioned and permanent changes of WEEE due to technological progress, there is a need for chemical analysis of WEEE. Such an analysis is necessary for further resource value assessment of WEEE and identification of relevant environmental risks.

2. Methods and materials

The most common electronic devices were selected for the study: mobile phone, computer mouse, keyboard, web-camera, and computer monitor. These devices were disassembled into components (by functional purposes) and weighed. Afterwards, the content of chemical elements was measured by X-ray fluorescence analyser “Expert-3L” (INAM, Ukraine). This analyser can be used for chemical analysis of high accuracy (hundredths of a percent). Currently, x-ray fluorescence analysis is often used in environmental research since it allows quick measurement of many elements simultaneously. Therefore, this method was chosen to study WEEE containing a wide variety of chemical elements.

3. Results and discussion

Mobile phone

The main components of the mobile phone under investigation are as follows: cable, toggle switch, capacitor, winding, screen backing, membrane, screen sensor, plastic case, metal part of the case, printed circuit board. The total weight of the phone is 109.88 g, including: plastic – 15.45 g, metals – 33.11 g, battery – 22.46 g, printed circuit board (PCB) – 15.09 g, touch screen – 14.06 g, other small components – 9.71 g. The weight fractions of each chemical element were determined by x-ray fluorescence analysis (Table 1).

As one can see from the Table 1, iron, copper and strontium are the most represented in the mobile phone.

Chemical composition of computer mouse is also diverse though this is simple device. The computer mouse was defined to consist of the following components: plastic case – 44.55 g, cables – 22.45 g, PCB – 11.15 g, screws – 0.26 g. Table 2 shows the chemical composition of the computer mouse components. Calcium is of the highest concentration, a significant part belongs to titanium, chlorine, copper, bromine, zinc and tin. Rest of the chemical elements are found in small quantities. This distribution is explained by 57% of plastic content in the device.

Table 1

Chemical composition of mobile phone, weight fraction, %

Component	Cl	Ca	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Br	Sr	Zr	Mo	Ag	Sn
cable	-	-	-	-	-	-	-	-	-	98.2	-	-	-	-	-	-	1.8
toggle switch	-	8.3	-	-	-	-	-	-	-	76.3	-	-	-	-	-	-	15.4
capacitor	97.3	-	1.6	-	-	-	0.2	-	-	0.1	0.2	-	0.1	-	-	-	0.5
winding № 1	-	-	-	-	-	-	-	-	-	100	-	-	-	-	-	-	-
winding № 2	-	-	-	-	-	-	-	-	-	97.6	-	-	-	-	-	2.4	-
screen backing	-	-	-	-	-	-	-	-	-	-	18.8	-	81.2	-	-	-	-
membrane	-	-	-	-	18.3	1.1	71.6	0.4	8.0	0.4	-	-	-	-	0.2	-	-
plastic case	-	27.5	65.3	1.2	-	-	4.2	-	-	-	-	-	1.5	0.3	-	-	-
screen sensor (inn.)	-	-	-	-	-	-	-	-	-	-	-	-	97.8	2.2	-	-	-
screen sensor (out.)	-	-	-	-	-	-	-	-	-	-	-	0.4	98.3	1.3			-
metal part of the case	-	-	-	-	18.3	1.1	71.6	0.4	8.0	0.4	-	-	-	-	0.2	-	-
PCB	-	-	-	-	-	-	-	-	18.5	62.5	19.0	-	-	-	-	-	-

Table 2

Chemical composition of computer mouse, weight fraction, %

Component	Cl	Ca	Ti	Fe	Co	Cu	Zn	Br	Rb	Sr	Sn	Sb
plastic case	-	49.1	45.8	-	-	5.1	-	-	-	-	-	-
PCB	-	6.2	-	0.2	41.7	-	24.0	0.3	-	27.6	-	-
cables	53.6	44.3	0.6	-	0.1	0.5	-	-	0.1	-	0.8	-

Chemical analysis of the keyboard has identified many elements (Table 3). As in the previous device, the main component of the keyboard is a plastic case, consequently calcium is among the most represented elements. Also, 1.362 g of lead was detected in the keyboard cable.

Table 3

Chemical composition of keyboard, weight fraction, %

Compo-nent	Cl	Ca	Ti	Fe	Co	Ni	Cu	Zn	Br	Br	Sr	Y	Zr	Rh	Ag	Sn	I	Ba	Hg	Pb	Bi
keys	-	-	98.6	-	-	-	-	-	-	-	-	-	0.6	0.8	-	-	-	-	-	-	-
case	-	22.4	58.8	3.8	-	-	-	6.6	8.4	-	-	-	-	-	-	-	-	-	-	-	-
cable	55.5	39.6	-	-	-	-	-	-	-	-	0.1	0.1	-	-	-	-	-	-	-	4.7	-
capacitor	89.6	4.7	5.4	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-	-	-
diode	-	-	-	35.7	-	25.0	2.0	-	30.9	-	-	-	-	-	6.4	-	-	-	-	-	-
resistor	-	20.7	17.4	22.2	-	-	3.0	0.2	-	0.1	0.1	-	0.1	-	-	1.2	-	34.9	-	-	0.1
PCB	-	-	9.4	2.0	0.6	4.4	8.8	-	0.4	-	0.9	0.6	9.4	-	1.6	55.8	4.5	-	1.6	-	-
backing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-	-	-	-

Web-camera was at the peak of sales in the 2000s. Nowadays, most PC monitors and laptops have a built-in camera. That reduces the need for a separate device. The composition of a typical web-camera is as follows: lens, optical filter, charge matrix, digitization unit, video compression unit, CPU, RAM and flash memory, network interface. The weight of the web-camera analysed is 139.24 g: cable – 32.67 g, plastic – 65.8 g, metals – 36.3 g, PCB – 2.51 g,

speaker – 0.33 g, lens – 1.63 g. Table 4 shows the weight fractions of chemical elements detected in web-camera by x-ray fluorescence analyser. The chemical elements of the plastic case prevail: chlorine, calcium, bromine. Also, there is dangerous lead in the amount of 0.23 g.

Table 4

Chemical composition of web-camera, weight fraction, %

Component	Cl	Ca	Ti	V	Fe	Ni	Cu	Zn	Br	Rb	Sr	Mo	Sb	Pb
rubber base	53.1	43.6	1.0	-	0.2	-	0.2	0.3	0.1	0.01	0.03	0.01	0.3	1.15
case	-	34.5	11.5	-	2.2	-	-	1.0	43.4	0.6	0.4	-	6.4	-
cable	57.8	41.3	-	-	0.1	-	0.5	0.2	-	-	0.1	-	-	-
PCB	-	-	7.8	1.6	-	-	80.9		8.8	0.3	0.6	-	-	-

According to the results, PC monitor consists of 22 chemical elements, including precious and toxic metals. The total weight of the monitor is 3.175 kg. Mainly, the weight is made up of metal parts of the case and the screen. Table 5 presents the weight fractions of chemical elements detected in the analysis. The key elements of the PC monitor: titanium, iron, strontium, calcium, copper, bromine, tin, zinc, chlorine, zirconium, silver and antimony. The weight of rest elements is less than 1 g. Such a content is due to the predominance of plastic and metal parts.

Table 5

Chemical composition of PC monitor, weight fraction, %

Component	Cl	Ca	Ti	Cr	Mn	Fe	Ni	Cu	Zn	Ga	As	Br	Rb	Sr	Y	Zr	Mo	Ag	Sn	Sb	Ba	Pb
frame			95.0			5.0																
case		21.1	50.0			14.0			2.6			12.4										
binding					0.2	58.5			41.3													
back cover						99.3													0.7			
inner layer of screen		99.7												0.3								
outer layer of screen												99.2	0.8									
strontium layer of screen		13.8							1.8		4.0	0.3		78.4		1.7						
cable								98.2											1.8			
resistor			1.1	1.6	1.1	9.7		2.7	0.2					0.1	0.1	0.1			0.5		82.8	
electrolytic capacitor	98.0		1.4			0.3		0.05	0.05	0.05		0.05						0.05	0.05			
transformer		16.6				0.3		82.8						0.3								
ceramic capacitor			9.0				2.9	9.4				49.7	1.2			9.0			4.8	14.0		
transistor							0.5	96.5										0.6	2.4			
PCB № 1			1.6					97.8				0.5	0.1									
PCB № 2			8.6				1.1	44.6			0.8	22.2	0.4	0.3				3.1	12.1			6.8
PCB № 3			9.2					24.1				31.4	0.5	0.2				1.2	33.0			
PCB № 4		5.9						48.4				6.3	0.1					1.6	37.7			

When averaging the data from the Tables 1–5, we obtain the following average content of chemical elements (Fig. 1): more than half of the weight accounts for iron and titanium (form the metal part of the devices) followed by calcium (due to high plastic content) and strontium. Copper, bromine, zinc, tin and chlorine have a low weight, while other elements are found in very small quantities.

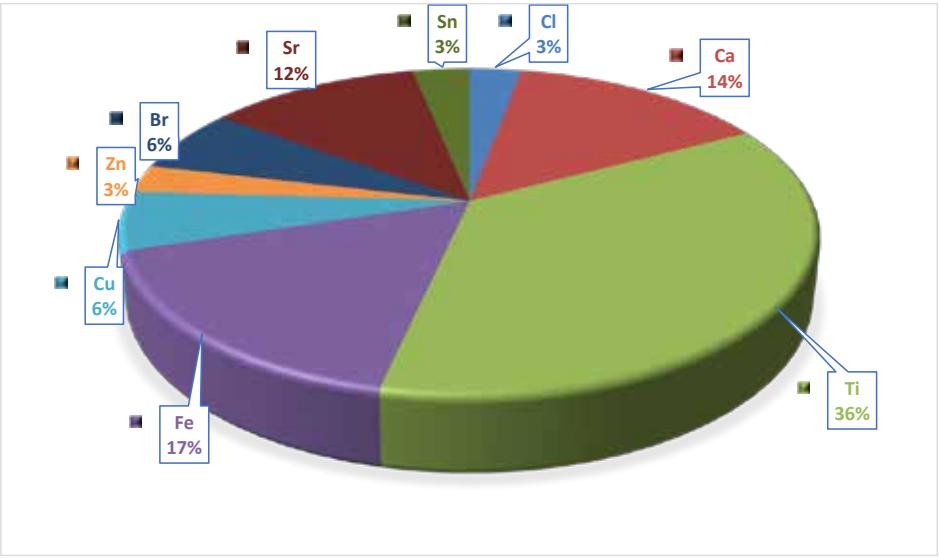

Figure 1. Average chemical composition of electronic devices analysed

4. Conclusions

A study of the most common electronic devices (mobile phone, computer mouse, keyboard, web-camera and PC monitor) has showed a very diverse chemical composition of these devices. As expected, the largest weight corresponds to "heavy" elements (titanium and iron) forming metal parts of the devices. Among the valuable components, copper and zinc are the most common. The distribution of elements by devices is as follows: mobile phone mostly consists of iron, copper and strontium; computer mouse includes the highest calcium concentration while significant part belongs to titanium, chlorine, copper, bromine, zinc and tin; keyboard mainly consists of titanium and calcium; in web-camera, chemical elements of the plastic case dominate: chlorine, calcium, bromine; PC monitor mostly consists of titanium, iron, strontium, calcium, and copper. These results will allow to estimate the resource potential of electronic waste with greater accuracy.

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