Using E-waste in asphalt mixtures – a laboratory investigation

M L Dragomir1*, R D Cadar1 and R M Boitor1
1 Transport Systems Research Group, Technical University of Cluj-Napoca, Romania

* mihai.dragomir@cfdp.utcluj.ro

Abstract. Incorporating electronic waste (E-waste) in a new asphalt mixture is a subjected connected to the recycling process of PCB (Printed Circuit Boards), in which PCB waste is turned into a powder. The aim of the paper is to present the performance of the new asphalt pavement obtained by using PCB waste to substitute lime filler in a share of 100%. First, laboratory analyses are performed to determine the composition of PCB. Then, the feasibility of using PCB waste in the asphalt pavement industry is analysed in a series of laboratory investigations conducted on asphalt concrete BA16 rul 50/70 (AC16) that is a standard asphalt mixture in Romania. The following tests are performed on the new material: cyclic compression-dynamic flow, rutting test, and Marshall Stability and flow. The conclusion after the first experimental stage of this research is that the mixture containing PCB is softer than the control/witness mixture containing lime filler. Further investigations regarding the use of E-waste in road asphalt pavements will be conducted to find a way to reduce the use of new raw materials in the road construction industry.

1. Introduction
Road safety and road maintenance are a permanent concern for road administrations and finding alternatives to reduce the use of new raw materials in the road construction industry has led to creating and testing new pavements that incorporate different type of waste.

The idea of incorporating waste as a substitute for filler is not a new one. Various types of materials that have a mineral origin, such as brick dust, fly ash, hydrated lime dust, recycled concrete waste, aggregate dust and stone dust were used to substitute lime filler in asphalt mixtures so far [1].

Others deal with the recovery of metals and non-metals from electronic waste by the physical and chemical recycling process, used the so-called E-Waste [2].

The new material that is used to substitute filler in a share of 100% in the asphalt mixture in the research presented in the paper is a powder obtained by recycling electronic waste - Printed Circuit Boards. This raw material is used to support and electrically connect electronic components that have attached Cu sheets glued over a non-conductive support.

According to [3], PCB assemblies contain a green/yellow board and ECs (i.e. resistors, relays, capacitors and integrated circuits (chips) attached to it. PCBs are a mixture of phenolic/cellulose paper (yellow and low grade) or epoxy (green and high grade) resins, woven glass fiber and multiple kinds of metals (Cu, Sn, Pb etc.). The basic structure of the PCBs is the Cu-clad laminate consisting of fiber glass-reinforced epoxy resin and a number of metallic materials including precious metals. The concentration of precious metals especially Au, Ag, Pd and Pt is much higher than their respective primary resources, making waste PCBs an economically attractive material.
Additionally, PCBs also contain different hazardous elements including heavy metals (Cr, Hg, Cd etc.) rare earth elements (Ta, Ga etc.) and flame-retardants (Br and Cl) that pose grave danger to the ecosystem during conventional waste treatment such as land filling and incineration.

PCB composition investigated previously by [4] is presented in table 1.

| Table 1. PCB material composition. |
|------------------------------------|
| **Metals** | **Ceramics** | **Plastics** |
| **About 40%** | **About 30%** | **About 30%** |
| Cu | SiO₂ | PE |
| Fe | Al₂O₃ | PP |
| Al | Alkaliearthoxides | PS |
| Sn | Titanates-micas | Epoxy |
| Pb | | PVC |
| Ni | | PTPE |
| Zn | | Nylon |
| Sb | | |
| Au(ppm) | 250-2050 | |
| Ag(ppm) | 110-4500 | |
| Pd(ppm) | 50-4000 | |
| Pt(ppm) | 5-30 | |
| Co(ppm) | 1-4000 | |

Other research papers [5-7] consider the use of the brake pad waste in new road pavements due to the waste composition including metal powder, graphite, rubber and fibers. Furthermore, [8] highlights the advantages in using fibers in asphalt concrete.

There are more waste materials that can also be reused to reduce the consumption of raw natural resources, providing opportunities to make new progresses in the building materials industry such as steel slag, rubber particles, graphite powder, PET and so on [9-13].

The research presented in the paper focuses on substituting the lime filler in a standard asphalt mixture used in Romania with PCB in a share of 100%.

The results of the laboratory investigation conducted on the new asphalt mixture shows that further investigations are needed in order to obtain a more proper asphalt mixture for road pavements. Different percentages of PCB will be used to obtain and to test a new material that can be used with great success considering the standards and regulations in Romania. In this way, by reusing PCB waste a great help will be given to reducing the use of new raw materials in the road construction industry.

The sections of the paper are Introduction, Experimental study, Results and discussion, Conclusion.

2. Experimental study

2.1. PCB waste description

The first step in analysing the waste is to use X-ray diffraction to show the composition of PCB (see Figure 1). X-ray radiography shows that the waste looks like the PCB described by [4] or in a different manner. The average for the three specters is shown in table 2.
Figure 1. X-ray radiography of the PCB sample:
(a) Electron image; (b) Spectrum 1; (c) Spectrum 2; (d) Spectrum 3.

According to the results of the laboratory test, the sample of PCB waste contains a large amount of non-metals. This leads to the simple conclusion that there are different types of PCBs made from different materials. In this case, the results of the analyses show that Carbon represents up to 72.7% from the waste mass.

Table 2. PCB material composition.

| Element | Non-metals About 93.40% | Metals About 6.60% |
|---------|-------------------------|---------------------|
| C       | 44.72.7                 | Ca 1.6-6.7          |
| O       | 19.2-35.6               | Al 1.4-3.1          |
| Si      | 4.5-8.2                 | Mg 0.2-0.3          |
| Br      | 0.4-2.2                 | Fe 0.00             |
| S       | 0.1                     |                     |

The granularity of the W-waste is compared with the lime filler one (see table 3). Therefore, the research question is whether PCB can substitute the filler in the asphalt mixture in a share of 100%.

2.2. Asphalt mixture design
The asphalt mixture design was made according to European standards (EN), SR EN 12697 [16] and to the Romanian standard AND 605-2016 [17]. A mixture for the final course layer – top layer – that is the most exposed to traffic and climatic changes from all road structures interlayers was prepared.

The name of the layer according to AND 605-2016 is BA 16 rul 50/70.
Table 3. PCB physical characteristics versus lime filler.

| Laboratory tests | PCB | Filler | Standards               |
|------------------|-----|--------|-------------------------|
| Granularity [mm] | %   | %      | SR EN 933-10:2009 [14]  |
| 1                | 99.3| 100    |                         |
| 0.63             | 90  | 100    |                         |
| 0.25             | 62.7| 99.8   |                         |
| 0.125            | 53.2| 93.9   |                         |
| 0.063            | 44.1| 79.9   |                         |
| 0.02             | 17.2| 18.9   |                         |
| Humidity         |     |        |                         |
| Max. 2%          | 1.44| 0.12   | STAS 539/79 [15]        |
| Apparent density | 0.48| 0.54   |                         |
| 0.5-0.8 g/cm³    |     |        |                         |
| Hydrophilicity   |     |        |                         |
| coefficient      | 0.78| 0.28   | STAS 539/79             |
| Max. 1 cm³       |     |        |                         |
| Voids content    |     |        |                         |
| range 0.3-0.5%   | 0.82| 0.41   | STAS 539/79             |

BA 16 rul 50/70 means: the maximum size of the aggregates is 16mm, rul- came from the wearing layer (the final one) and 50/70 is the binder/bitumen type. Bitumen 50/70 is the most common asphalt binder used in Romania.

First tested hypothesis is that PCB substitutes Filler in a share of 100%. The goal was to make an eco-mixture that can respond well to all the laboratory tests and can be successfully used in the road construction industry for roads or highways. The new eco-mixture results from using this waste instead of classical lime filler are presented below.

The mixture recipe is described in table 4. The results of testing the mixtures with PBC and with filler are presented in table 5.

Table 4. BA16 rul 50/70 recipe.

| Material-granular and binder | %   |
|------------------------------|-----|
| 0-4mm                        | 42.48|
| 4-8mm                        | 23.6 |
| 8-16mm                       | 19.82|
| Lime filler – PCB            | 8.50 |
| Bitumen                      | 5.60 |

Table 5. Primary results of laboratory tests.

| Lab. test       | BA16 Rul50/70 | BA16 Rul50/70 | Standards               |
|-----------------|---------------|---------------|-------------------------|
| Marshall Stability | 10.7          | 11.3          | SR EN 12697-34:2012     |
| Flow            | 8.7           | 3.3           | SR EN 12697-34:2012     |
| Density         | 2129          | 2399          | SR EN 12697-6:2012      |
| Water absorption | 7.3           | 2.4           | AND605:2016              |
| Void content    | 8.5           | 2.7           | SR EN 12697-5:2012      |
| Void content    | 8.5           | 2.7           | SR EN 12697-5:2012      |
2.3. Dynamic results

The first laboratory investigations regard the behaviour of both asphalt mixtures. The standard one using filler and the new one that has instead of filler the PCB waste. According to the Romania Standard AND 605:2016 [17], for the asphalt mixture design is very important that all bituminous mixtures respond to dynamic actions too: dynamic flow-cyclic compression and rutting.

BA16 rul 50/70 filler samples have the following characteristics: 101.1 mm diameter, 63.2 mm high. The cyclic load was set up at 300 kPa, temperature 50°C, frequency 3 Hz, lateral pressing 150 kPa and 10,000 pulses.

BA16 rul 50/70 PCB samples have the following characteristics: 100.2 mm diameter, 63.6 mm high. The cyclic load is set up at 300 kPa, temperature 50°C, frequency 3 Hz, lateral pressing 150 kPa and 10,000 pulses.

The results were compiled to describe the mixtures:
- BA16 rul 50/70 with Filler in Table 6 and Figure 2.
- BA16 rul 50/70 with PCB in Table 7 and Figure 3.

### Table 6. Dynamic flow-Cyclic compression for BA16 rul 50/70 with Filler.

| Determination                      | MU       | Result  | Standard method                  |
|-----------------------------------|----------|---------|----------------------------------|
| 1 Deformation speed at 50°C at 10000 pulses μm/m/cycle | 0.30     | SR EN 12697-25:2016               |
| 2 Deformation at 50°C at 10000 pulses μm/m  | 17602    | SR EN 12697-25:2016               |

### Table 7. Dynamic flow-Cyclic compression for BA16 rul 50/70 with PCB.

| Determination                      | MU       | Result  | Standard method                  |
|-----------------------------------|----------|---------|----------------------------------|
| 1 Deformation speed at 50°C at 10000 pulses μm/m/cycle | 0.51     | SR EN 12697-25:2016               |
| 2 Deformation at 50°C at 10000 pulses μm/m  | 55718    | SR EN 12697-25:2016               |

Rutting behaviour was tested according to SR EN 12697:22, B procedure, at temperature 60°C, 40 mm thickness of the slab, number of vehicles over 6000.
Figure 3. Dynamic flow-Cyclic compression for BA16 rul 50/70 with PCB.

The results of the rutting behaviour tests for the two asphalt mixtures are presented in table 8 for BA16 rul 50/70 with Filler and in table 9 for BA16 rul 50/70 with PCB.

Table 8. Rutting behaviour for BA16 rul 50/70 with Filler.

| Test                                      | m.u      | Result | Standard-method                  |
|-------------------------------------------|----------|--------|----------------------------------|
| Deformation speed WTS\(_{AIR}\) mm/10\(^3\)cycles | 0.16     |        | SR EN 12697-22+A1:2007          |
| Proportional Rut depth PRD\(_{AIR}\) %    |          | 4.6    | SR EN 12697-22+A1:2007          |
| Rut depth RD\(_{AIR}\) mm                  |          | 1.82   | SR EN 12697-22+A1:2007          |

Table 9. Rutting behaviour for BA16 rul 50/70 with PCB.

| Test                                      | m.u      | Result | Standard-method                  |
|-------------------------------------------|----------|--------|----------------------------------|
| Deformation speed WTS\(_{AIR}\) mm/10\(^3\)cycles | 0.35     |        | SR EN 12697-22+A1:2007          |
| Proportional Rut depth PRD\(_{AIR}\) %    |          | 14.1   | SR EN 12697-22+A1:2007          |
| Rut depth RD\(_{AIR}\) mm                  |          | 5.63   | SR EN 12697-22+A1:2007          |

3. Results and discussion
As a result of testing the new road asphalt mixture with 100% PCB E-waste replacing the lime filler some conclusions can be drawn.

The basic experimental set of tests that were conducted, namely Marshall flow and stability, density, water absorption and void content, show that both asphalt mixture possess good properties.

Not the same thing can be said about the results of the dynamic tests, where the differences between the two asphalt mixtures are significant.

The difference for the dynamic flow is: 17602 \(\mu\)m/m for the mixture containing filler compared to 55718 \(\mu\)m/m for the mixture containing PCB. Therefore, the dynamic flow modulus is 3.16 times higher for the mixture containing PCB which cannot be admitted in practice.

In terms of rutting, the difference between the two asphalt mixtures is similar to that of the dynamic flow. Rut depth is 3.09 higher for the mixture containing PCB.

4. Conclusions
The results of the first experimental stage, show that according to the Romanian Standard AND 605:2016, the eco-mixture using PCB E-waste to replace the filler in a share of 100% cannot be used as
an asphalt pavement for the final course layer – top layer - to successfully support vehicle traffic because the deformations are significant.

Therefore, the new eco-mixture is not proper to use as asphalt pavement on roads.

However, it is proper to use on pedestrian or bicycle dedicated areas, where the asphalt mixture has a different role.

Exploring the good interaction between carbon and asphalt binder, a second step of the research will be carried out considering different ways to use this waste.

It is of great importance to continue this research to find some ways to help the road construction industry to face the great challenges concerning the diminishing of the raw material deposits and increasing costs with materials, as well as to help the environmental protection dealing with the increasing waste generation and reduced recycling rate.

E-waste recycling is one step further to a cleaner environment. PCB waste can be used in road materials but more hypotheses will be tested in order to find the proper usage in the asphalt pavement for the final course layer – top layer - to successfully support vehicle traffic.

Acknowledgments
In memory of PhD Eng. Andrei Boboc, who has inspired the research in this paper.

Authors wish to acknowledge: Technical University of Cluj-Napoca for the financial and logistic support in obtaining these results, Physics National Institute of Cluj-Napoca for the PCB X-ray examination and TPA Cluj-Napoca for the laboratory testing and results. TPA is a private society for innovation and quality on laboratory examination, member of Strabag group.

References
[1] Kuity A, Jayaprakasan S and Das A 2014 Laboratory investigation on volume proportioning scheme of mineral fillers in asphalt mixture Constr Build Mater. 68 637-43
[2] Kaya M 2016 Recovery of metals and nonmetals from electronic waste by physical and chemical recycling processes Waste manage. 57 64-90
[3] Li J, Shrivastava P, Gao Z and Zhang HC 2004 Printed circuit board recycling: a state-of-the-art survey IEEE Trans. Electron. Packag. Manuf. 27 33-42
[4] Duan H, Hou K, Li J and Zhu X 2011 Examining the technology acceptance for dismantling of waste printed circuit boards in light of recycling and environmental concerns J. Environ. Manage. 92 392-9
[5] Hu X, Wang N, Pan P and Bai T 2017 Performance evaluation of asphalt mixture using brake pad waste as mineral filler Constr Build Mater. 138 410-7
[6] Pan P, Wu S, Xiao Y, Wang P and Liu X 2014 Influence of graphite on the thermal characteristics and anti-aging properties of asphalt binder Constr Build Mater. 68 220-6
[7] Sugozi I, Can I, Oner C and Bagirov H 2015 Friction behavior of granite powder added brake pads Mater. Test. 57 685-9
[8] Wang H, Yang J, Liao H and Chen X 2016 Electrical and mechanical properties of asphalt concrete containing conductive fibers and fillers Constr Build Mater. 122 184-90
[9] Răcănel C and Burlacu A Int. Multidisciplinary Sci. GeoConf.: SGEM „Surveying Geology & Mining Ecology Management (SGEM) 2016 Sofia” vol 2 pp 33-40
[10] Popescu D, Burlacu A and Răcănel C Int. Multidisciplinary Sci. GeoConf.: SGEM „Surveying Geology & Mining Ecology Management (SGEM) 2016 Sofia” vol 3 pp 585-591
[11] Răcănel C and Burlacu A Int. Multidisciplinary Sci. GeoConf.: SGEM „Surveying Geology & Mining Ecology Management (SGEM) 2015 Sofia” vol 1 pp 795-802
[12] Răcănel C and Burlacu A Proc. of the 3rd Int. Conf. on Road and Rail Infrastructure - CETRA, Road and Rail Infrastructure III „University of Zagreb 2014 Spilt Dalmatia” pp 395-400
[13] Popescu D and Burlacu A 2017 Considerations on the benefits of using recyclable materials for road construction Rom. J. Transp. Infrastruct. 6 43-53
[14] SR EN 933-10:2009 Încercări pentru determinarea caracteristicilor geometrice ale agregatelor.
Partea 10: Evaluarea părților fine. Determinarea granulozității filerului (cernere în curent de aer) (Romania: Technical standard)

[15] STAS 539/79 Filer de calcar, filer de cretă și filer de var stins în pulbere (Romania: Technical standard)

[16] SR EN 12697-5:2012 Mixturi asfaltice. Metode de încercare. Partea 5: Determinarea densității maxime (Romania: Technical standard)

[17] AND 605-2016 2016 Normativ privind mixturile asfaltice executate la cald. Conditii tehnice de proiectare, preparare si punere in opera a mixturilor asfaltice (Romania: Technical standard)