Use of Non-Metallic Powder Reclaimed from Waste Printed Circuit Boards in Rigid Concrete Pavement

K Kakria¹ and S Priya¹,*

¹School of Civil Engineering, Vellore Institute of Technology, Vellore, India
*Corresponding author: shanmugapriya.t@vit.ac.in

Abstract. Treating E-Waste is the need of the hour, about 2 million tons of E-Waste with a 5% share of PCB (Printed Circuit Boards) is generated by India out of which only few is treated, majority of which is disposed in water bodies and landfills. The disposal of e-waste is a worldwide concern and to deal with the same we propose to use the e-waste in rigid concrete pavement. India with 43,20,000 km of roads, gives a wide possibility of using e-waste in this industry. This research mainly focuses on the conversion of Non-Metallic Powder (NMP) waste recycled from PCBs into acceptable construction material. The objective of this study is to investigate the effect of e-waste as a filler replacement, on the strength parameters of concrete (M40 grade) and used as rigid pavement. NMP from waste PCB is mixed with 0%, 3%, 6%, 9% and 12% as an additive and based on Compressive Strength, Split Tensile Strength, Flexural Strength test and Impact Resistance test, the most suitable dosage of the additive is then to be calculated. It is observed that there is definite increase in compressive strength, split tensile strength and flexural strength with increase in percentage of NMP up to 9%. Here an attempt is made to use the PCB waste products in rigid road construction, which affect the environment and are difficult to process. The study concludes that 9% of e-waste can be used as filler material in bituminous mixes.

1. Introduction
The electronic and electrical waste (e-waste) is one of the fastest flourishing waste streams in the world. The increase of “market penetration” in developing countries, “replacement market” in developed countries and “high obsolescence rate” makes e-waste one of the fastest flourishing waste streams. Environmental issues and trade linked with e-waste at local, cross border and International level has led many countries to intervene [1]. In accordance with the National Environmental Policy (NEP) and to address sustainable development concerns, there is a need to facilitate the recovery, reuse and recycling of useful materials from waste generated by electronics by different processes thereby reducing the wastes for final disposal to safeguard the environment. The NEP also gives legal recognition and strengthening of the informal sector systems for the collection and recycling of unused or disposed materials. Considering the high recycling ability of e-waste such wastes should be subjected to recycling in an environmental friendly way [2].

India is ranked as the second largest mobile phone user and fifth largest e-waste producer in the world. Overall it produces 18.5 lakh tons of e-waste every year, which increases with the increment in the usage of electronic devices. The devices, which are sold in the beginning of the year, will end up in 25% of e-waste at the end [3]. Computer wastes account to virtually 70%, the contributions from telecom industry is around 12%, medical instruments being 8% and electrical instruments being 7% of the total annual e-waste accumulation in our country [3]. Several studies have been done on using the waste material in concrete as aggregate or filler. It is not only a solution to reduce the environmental
and ecological problems but overall it improves the microstructure and hence increases its strength [4, 5, 6].

The printed circuit boards (PCB) are recycled by physical processing and hydrometallurgical treatment. The chemical analysis showed that PCB contains metals like Cu, Zn, Pb and Sn and some precious metals [7]. The boards are shredded at required size which can be used as a substitute for aggregate in construction. The chemical components are mostly toxic and it may cause adverse effects to the environment. Therefore the recycling should be done in such a way that it should not cause any harm to the surroundings and should reduce the demand of natural materials [8].

In this study PCB waste (NMP) is used as an additive in concrete used as rigid pavement and to determine the optimum percentage of PCB Board waste for M40 grade concrete based on compressive strength, three-point load test strength, split tensile strength and to test with different dosages (0%, 3%, 6%, 9% and 12%) of the additive and hence evaluate the potential of the PCB waste to be used in rigid pavement constructions.

2. Material and methods

2.1. Materials

2.1.1 Cement
Ordinary Portland cement (OPC 53) conforming to IS:12269-1987 [9] has been used in this research. The cement was free from lumps and had a grey with a light greenish shade. Table 1 gives the physical properties of the cement.

2.1.2 Non-metallic powder
Printed circuit boards were collected from discarded electrical appliances and gadgets, which were treated to remove the metallic component to obtain the non-metallic component. The non-metallic component was then shredded into fine particles of size less than 150 μm. The non-metallic processed powder (Figure 1) was obtained from Victory Recovery and Recycle Technologies India Pvt Ltd. The physical properties of NMP is discussed in Table 1.

![Figure 1. Non-metallic powder (NMP)]
Table 1. Physical properties

|                  | Blaine fineness (cm²/g) | Soundness Autoclave (%) | Specific Gravity | Setting time in minutes |
|------------------|-------------------------|--------------------------|------------------|-------------------------|
| Cement           | 2280                    | 0.85                     | 3.15             | 94                      |
| E-waste          | 5210                    | 0.72                     | 2.3              | 115                     |

Figure 2 shows the SEM images of the non-metallic powder. The non-metallic powder exists in small cylindrical solids with some content of irregular solids of thermo-setting resins.

2.1.3 Fine aggregates
Clean river sand sieved through 4.75 mm IS sieve was used in this research. It had a specific gravity of 2.62. The sand was confirmed to Zone II and the tests were carried as per the specification laid by IS 383:1970 [10].

2.1.4 Coarse aggregates
These are the strongest and least porous component of the mix. Various aspects where taken care while selecting the aggregates like, low porosity, high crushing strength and interlocking textures. Coarse aggregates of 20 mm IS Sieve size was selected which had a specific gravity of 2.74.

2.2 Methods

2.2.1 Mix design
A concrete mix was prepared with help of the above-mentioned materials, following the guidelines given in IS 10262- 2009 [11]. For 0%, 3%, 6%, 9% and 12% addition of NMP the mix ratio chosen was 1:1.6:2.98 (Cement:Fine Aggregate:Coarse Aggregate) and 2.842 litres of water was added with 0.0392 kg of admixture. However, for 3% addition of NMP 0.1959 kg of additive was added, 0.3918 kg was used for 6% addition of NMP, 0.5877 kg for 9% addition of NMP and 0.7836 kg for 12% addition on NMP.
2.2.2 Preparation of cube specimens
To determine the compressive strength of the mix, five mixes M1-0% addition of NMP, M2-3% addition of NMP, M3-6% addition of NMP, M4-9% addition of NMP and M5-12% addition of NMP were prepared. 30 cube moulds of 100mm×100mm×100mm, 15 beam specimens of 500mm×100mm×100mm and 15 cylinders of 100mm diameter and 200mm height were used to cast the specimens.

3. Testing

3.1 Compressive strength test
The compressive strength test was performed on concrete with varying non-metallic powder contents as per IS 4031-6 (1988) [12]. The wet cubes were placed with the cast faces directly in contact with the testing machine plates as shown in Figure 3. The machine plates is to be cleaned first and the dimensions is to be taken to nearest 0.2 m. The cubes were then tested after a curing of 7 and 28 days in a Digital Compression testing machine having a capacity of 20,000 kN.

The load was applied uniformly starting from zero at the rate of 2.5 kN/sec till the specimen failed. Three specimens of each percentage of additive was tested and the average of compressive strength was found.

![Figure 3. Compressive strength test of cube](image)

3.2 Split tensile strength test
Concrete is very weak to direct shear stress and often develop cracks due to its brittle nature. Thus, it is necessary to determine the tensile strength of the concrete to determine the point of failure of concrete. The test cylinders of size 100 mm diameter were casted using different amounts of non-metallic powder and tested after 7 days curing. A uniform load of 2.5 kN/sec was applied starting from zero till the specimen failed (Figure 4).
3.3 Three-point loading test of beam
During flexure test the tensile stress is produced in the convex side of the specimen whereas the compression stress is produced in the concave side. This creates a shear stress area along the midline. The Flexural test is used to measure the force required to bend a beam by a Three-point loading system. This test data is used to select materials for components that will support loads without bending and flexing. Flexural modulus is an indicator of a material’s stiffness when flexed. The flexural test was performed as per ASTM C348-14 [13] (Figure 5).

![3-point Flexure test](image)

**Figure 5.** Three-point loading test of beam

3.4 Impact resistance test
Concrete structures are often prone to high force or shock applied for a short time period (impact loads) such as machine vibrations, vehicle impact, earthquake etc. Impact resistance energy for the specimen was measured by drop hammer test as recommended by ACI committee 544.2R-89 [14]. A concrete specimen of 150 mm and a height of 64 mm was subjected to drop hammer test. A hammer of weight 45 N was used and dropped from a height of 457mm to test the ultimate failure of the specimen. Ultimate failure is the number of blows to open the crack in the specimen, when the fractured piece touches three or four lugs on the base plate. The impact energy absorbed for complete failure was calculated by multiplying the number of blows required for ultimate failure and the impact energy (Figure 6).
4. Results and discussion

4.1. Compressive strength test

The compressive strength of concrete with different amount of non-metallic powder after 7 and 28 days of curing was found. Figure 7 shows the variation of compressive strength with additive percentage.

The compressive strength of cube with 0%, 3%, 6%, 9% and 12% additive after a curing of 7 as 34.51, 35.67, 36.63, 45.22 and 32.52 N/mm² and 28 days as 52.67, 54.52, 58.51, 63.57 and 56.32 N/mm² respectively. The compressive strength is seen to increase with addition of non-metallic powder, 9%(M4) being the largest. There is seen a 3.39% increase in compressive strength with the addition of 3% NMP when compared to 0% addition of NMP. The compressive strength is maximum on 9% addition of non-metallic powder but decreases on further addition of non-metallic powder. The compressive strength is seen to increase on addition of e-waste as due to the small size of particles they fill up the voids.
4.2 Tensile strength test
The tensile strength of specimen was found after 28 days of curing in water tank. Figure 8 shows the variation of tensile strength with additive percentage.

![Tensile strength graph](image)

**Figure 8.** Tensile strength of cylinder for different percentage replacement

It is seen that the best result was shown on addition of 9% (M4) of non-metallic powder. The tensile strength of concrete increases on addition of non-metallic powder. Addition of non-metallic powder does not have major effect on compressive strength but increases the tensile strength of concrete. Non-metallic powder act as a fiber for concrete and decreases the permeability of pavement.

4.3 Flexural test
The flexural test was performed on 15 beams of size 500mm×100mm×100mm after 28 days of curing as per ASTM C348-14. Figure 9 shows the variation of flexural strength with additive percentage.

![Flexural strength graph](image)

**Figure 9.** Flexural strength for different percentage replacement
The flexural strength of the mix for different percentage replacement (0%, 3%, 6%, 9% and 12%) was found to be in the range of 5.12 to 6.62, 6.62 N/mm$^2$ being the highest at 9% (M4) addition of NMP.

### 4.4 Impact resistance test

The impact resistance of the specimens were found with a hammer of weight 45kN. Fig 6 shows the test specimens after performing the drop hammer test. Table 2 shows the variation of impact energy with additive percentage.

| Mix | Impact resistance or energy absorbed for complete failure (Nm) |
|-----|-------------------------------------------------------------|
|     | 28 days | 90 days |
| M1  | 110     | 128     |
| M2  | 122     | 135     |
| M3  | 135     | 142     |
| M4  | 140     | 156     |
| M5  | 132     | 120     |

The Impact resistance or energy absorbed for complete failure of the specimen with different mixes 0%, 3%, 6%, 9% and 12% was found to be in the range of 110 to 152, 156 Nm being the highest at 9%(M4) addition of NMP at the age of 90days.

This concrete can be used in rigid pavements for highway and airfield and for repair of existing pavement. NMP additive concrete helps in reducing the pavement thickness and increases the resistance to impact. It provides a smooth riding surface and increases the transverse and longitudinal joint spacing.

### 5. Conclusion

According to the test results the following conclusions can be drawn:

- There is no major effect on compressive strength of the concrete when the percentage of the additive increases and shows maximum compressive strength on 3% (M4) addition of non-metallic powder.
- The tensile strength increases as the percentage of PCB waste increases. The same characteristic is observed when the fibre is added to the concrete. So we can conclude that the PCB waste can be used as a fibre to increase the tensile strength of the concrete pavement.
- The flexural modulus increases with percentage addition of NMP and mix M4 (9% addition of NMP) shows the highest value of 6.62.
- The mix M4 shows best results for drop hammer test with a value of 156 Nm.
- The addition of fibre (in the form of PCB waste) decreases the permeability of the concrete pavement, not allowing water to seep inside and destroy the subgrade, hence increasing the life of concrete pavement.

### Acknowledgments

The research work was carried in the Structural Research Laboratory, School of Civil Engineering, VIT, Vellore, India. The authors would like to thank the technical staff of the laboratory for their support and guidance.
References

[1] Duan H, Hu J, Yuan W, Wang Y, Yu D, Song Q and Li J 2016 Characterizing the environmental implications of the recycling of non-metallic fractions from waste printed circuit boards *Journal of Cleaner Production* 546-554

[2] Ministry of Environment and Forests 2008 Guidelines for Environmentally Sound Management of E-Waste, *Ministry of Environment and Forests Letter* No. 23-23/2007-HSMD Central Pollution Control Board Delhi.

[3] Muthukumar S, Bavithran OKC, Nandhagopal AR and Snehasree T 2017 Stability Study on Eco-Friendly Flexible Pavement Using E-Waste and Hips *International Journal of Civil Engineering and Technology (IJCET)* 956–965

[4] Tavakoli D, Hashempour M and Heidari A 2018 Use of Waste Materials in Concrete: A review, *Pertanika J. Sci. & Technol.* 26 (2): 499 - 522

[5] Rui Silva JDB 2015 Use of waste materials in the production of concrete *Key Engineering Materials* 634:85-96

[6] Batayneh M, Marie I and Asi I 2006 Use of selected waste materials in concrete mixes *Waste Management* 27 (2007) 1870–1876

[7] Bizzo WA, Figueiredo RA and Andrade VFD 2014 Characterization of Printed Circuit Boards for Metal and Energy Recovery after Milling and Mechanical Separation *Materials* 7, 4555-4566

[8] Kadari R, Velchuri R, Malathi M, Vithal M and Munirathnam NR 2017 Degradation of organic pollutants by Ag, Cu and Sn doped waste non-metallic printed circuit boards *Waste Management* 60 629–635

[9] Ordinary Portland Cement 53 Grade-Specifications 2013 *Bureau of Indian Standards* 12269-1987

[10] Specification for Coarse and Fine Aggregates from Natural Sources for Concrete 2002 *Bureau of Indian Standards* 383:1970

[11] Concrete Mix Proportioning-Guidelines 2009 *Bureau of Indian Standards* 10262

[12] Methods of Physical Tests for Hydraulic Cement 2005 *Bureau of Indian Standards* 4031-6

[13] Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars *ASTM* C348-14.

[14] Measurement of Properties of Fiber Reinforced Concrete (Reapproved 2009) 2009 *American Concrete Institute*