PROPERTIES OF ALTERNATIVE CONCRETE MIXED WITH NON-METALLIC POWDER FROM RECYCLED PRINTED CIRCUIT BOARDS

[1]PONGSATORN SAENGPAENG, [2]PREMRUDEE KANCHANAPIYA, [3]CHAKRAPAN TUAKTA

[1]Advanced and Sustainable Environmental Engineering Faculty of Engineering, [3]Department of Civil Engineering, Faculty of Engineering, Kasetsart University, Bangkok 10900, Thailand,[3]Department of Material Technology for Environment Laboratory, National Metal and Materials Technology Center (MTEC), NSTDA, Pathum Thani 12120, Thailand
E-mail; [1]kengkab_kk@hotmail.com, [2]premrudk@mtec.or.th,[3]fengcptu@ku.ac.th

Abstract - The objective of this study is to investigate the effects of using non-metallic power (NMP) as an alternative constituent on properties of concrete. The NMP was obtained during a recycling process of printed circuit board waste in a recycling plant in Thailand. Coarse-grained NMP was mixed in concrete mixture as fine aggregate (sand) replacement ranging from 0 to 50% by weight with specified water/cement ratio of 0.62. Compressive, splitting tensile, and slump tests were conducted in accordance with corresponding ASTM Standards. Test results have shown that both compressive and splitting tensile strengths gradually decreased as percentage of replacement increased. The slump of freshly mixed concrete with NMP was highest at 8 cm for 10 and 20% NMP replacements, while marked reduction was observed for concrete mixes with higher NMP replacements. On the other hand, concrete with 50% NMP replacement had lowest bulk density of 2,216 kg/m^3 as expected. Considering strengths and workability attained from different mixes, this preliminary study has suggested that use of NMP in concrete is limited to no more than 20% replacement. With further development, the resulting concrete can be sustainable in a wide range of building applications, offering an alternative way for electronic waste management.

Index Terms - Concrete, Compressive strength, Non-metallic Powder, Recycled printed circuit boards

I. INTRODUCTION

Currently, technology is very important in human life. The rapid development and use of new technology, especially electrical and electronic equipment, result in increase of electronic waste. This can cause pollution and other environmental issues, if waste from such equipment is not properly managed, for example, by waste incineration. This encourages research and innovation in utilization of printed circuit boards (PCBs) from recycled electronic waste. Recycling of PCB is an environmentally-friendly process because it employs a closed system by circulating and recycling water in the system and using cooling spray to prevent dust and gas that are formed during the grinding process [1]-[2]. One recycling strategy is to introduce non-metallic powder as an ingredient for making concrete more sustainable, while limiting negative effects on concrete properties, such as strength, durability, permeable, etc., so that it will not cause pollution or contamination into the environment during the recycled process. In addition, it ensures an environmentally-friendly product (Green-Product) and contributes to the economy as value-added construction material.

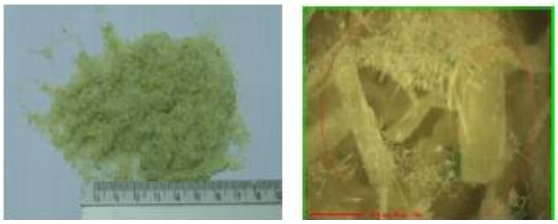
The reclamation of PCB powder employs the milling crusher currently in use by a recycling plant in Thailand, in which waste PCBs are crushed, compressed, and sheared into fine powder. Then, the process separates the metallic and non-metallic components apart by splitting them with water. The metallic parts such as copper, gold and silver that settle in the water can be sold [3]. However, the remainder of the recycling process is the non-metallic powder that is a mixture of about 30-35% of thermosetting polymers and 65-70% fiberglass [4]. Although there has been a number of researches on the use of NMP from waste PCBs, these studies mainly investigated properties of mortar containing NMP [5]. The solidification or stabilization method for this waste has been investigated by studying the properties and effects of non-metallic powder on mortar, so that the resulting mortar satisfied many standards and can be made into recycled products. Therefore, the utilization of NMP in concrete products is an encouraging alternative recycling technique and further development is required. Therefore, the main objective of this research is study the properties of concrete with mixing ratio that incorporates NMP from PCB recycling process. Tests were conducted to determine the properties of concrete in accordance with recycled NMP.

II. EXPERIMENTAL DETAILS

A. Materials

This research used NMP from recycled PCB waste as fine aggregate replacement with varying NMP percentages of 10, 20, 30, 40 and 50% in concrete mix. Ordinary Portland Cement (OPC) type I with specific gravity of 3.15 was used in all concrete mixtures [6]. River sand with specific gravity 2.44 was used as fine

aggregate with maximum grain size of 4.75 mm. NMP with specific gravity of 2.0481 was used as fine aggregate (sand) replacement as showed in Fig 1. Crushed limestone with maximum size of 19 mm was used as coarse aggregate with specific gravity of 2.02. Water for mixing in all concrete mixtures was available in laboratory. The water-cement ratio (w/c) was 0.62 and all mixes were also compared with the controlled mix (0% NMP).



(a) (b)

Fig 1. (a) NMP waste and (b) Micro EXRF analysis of NMP sample at magnification of 70x.

B. Mixing and molding procedures

The controlled mix design was designed to have the compressive strength of 24 MPa with water/cement ratio of 0.62 and mix proportion was kept at 1:2:4 (cement : fine aggregate : coarse aggregate) by weight for all mixtures. For mixing methods, cement, fine aggregate (sand) and coarse aggregate were mixed first for 1-2 minutes, then NMP were added to mix together with those components and the mixing had done for 3 minutes. After that water was added and further mixed for 5 minutes then the mixing procedure was finished. In the casting and molding procedures, freshly concrete for compressive and splitting tensile test specimens were prepared with 15 cm x 30 cm cylindrical molds in accordance with ASTM C- 31. The specimens of bulk density were molded with 15 cm x 30 cm cylindrical molds in accordance with ASTM C- 31 [7]. In the final step, all specimens were covered with damped cloth and moist-cured in a standard room temperature at 25°C. After 24 hours, the specimens were demolded and cured in a curing bath of saturated-limewater for 28 days before testing.

C. Test Procedures

Workability or slump of fresh concrete was determined by slump test in accordance with ASTM C- 143 [8]. Freshly mixed concrete was placed in a slump cone (frustum cone) with equally three layers of cone (one-third of the volume of the slump mold fills it to a depth of 67 mm [25 /8 in.]; two-thirds of the volume fills it to a depth of 155 mm [61 /8 in.]). Concrete was then compacted by rodding in a mold with 25 times per each layer. The mold is then raised, and the concrete allowed to subside within 2-1/2 minutes elapsed time, then the vertical distance between the original and displaced position at the center of the top surface of the concrete was measured and reported as the slump of fresh concrete (Fig 2).



Fig 2. Slump test of NMP concrete.

Compressive strength of controlled NMP concrete was tested according to ASTM C- 31 and C- 39 [9]. This test method consisted of applying a compressive axial load to cylinders at a rate which is within a prescribed range until failure occurred using a universal testing machine (Fig 3). In this case, the displacement of test machine crosshead was controlled at the rate of 1 mm/min. The compressive strength of the specimen was calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimens.

Calculate the compressive strength of the specimen as follows:

$$f'_c = \frac{P}{A} \qquad (1)$$

where f'_c is the 28-day compressive strength (MPa); P is the maximum force (N); A is the area of force P is applied (mm^2)

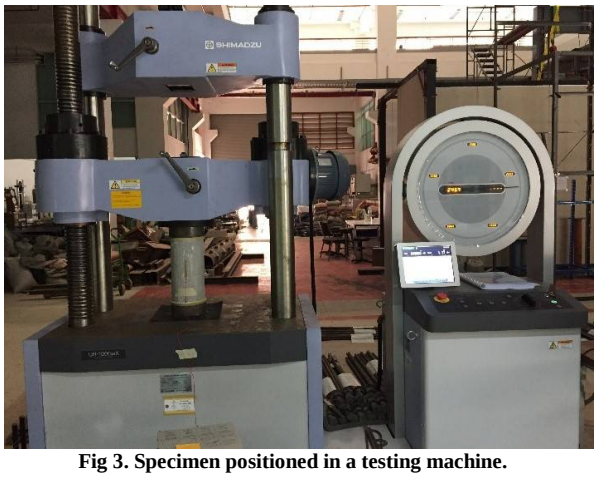


Fig 3. Specimen positioned in a testing machine.

Splitting tensile strength of controlled and NMP concrete was tested according to ASTM C- 496/C-496M [10]. Splitting tensile strength was used in the design of structural lightweight concrete members to evaluate the shear resistance provided by concrete and to determine the development length of reinforcement. The test procedure was to apply a diametrical compressive force along the line of cylindrical

concrete specimen at a rate that was within a prescribed range until the failure occurred (Fig 4).Calculate the splitting tensile strength of the specimen as follows:

$$T = \frac{2P}{\pi ld} \quad (2)$$

where T is the splitting tensile strength (MPa); P is the maximum applied load indicated by the testing machine (N); l is the specimen length (mm); d is the specimen diameter (mm).



Fig 4. Tensile splitting specimen positioned in a testing machine.

Bulk density of cylindrical specimen was determined by method in accordance with ASTM C- 39 and C-642 [11]. This test method was used to determine mass loss of hardened concrete specimen at normal room temperature of the 28-day specimens. The test procedure was to weight the controlled and NMP concrete specimens then calculated the bulk density by dividing the specimen weight with volume of cylindrical specimen in air.

Calculate the bulk density of the specimen as follows:

$$Density = \frac{W}{V} \quad (3)$$

where W is mass of specimen (kg); V is the volume of specimen computed from average diameter and average length or from weighing the cylindrical in air and submerged (m^3).

III. RESULTS AND DISCUSSION

1. Workability or Slump

The slump of freshly mixed NMP concrete was compared with controlled mix of 0% NMP. The test results in Fig. 5 showed that the slump of concrete mixed with NMP gradually decreased with increasing amount of NMP in concrete. For the expected value of 5 to 10 cm conforming to the slump standard, there are three mixes that passed the standard, namely 10, 20 and 30% NMP with slump values of 8.0, 7.0 and 5.5 cm, respectively. Slump of fresh concrete is a significant indicator of construction workability related to time of hardening, ability to cast in framework and also timing for setting in any type of construction or concrete product manufacturing.

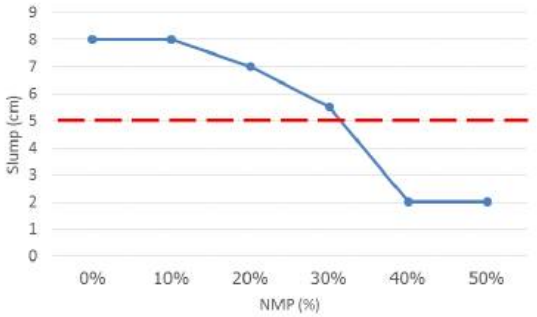


Fig 5. Slump of NMP concrete compared with controlled mix, w/c 0.62 (Red dashed line is a minimum range of slump standard i.e. 5-10 cm).

2. Compressive Strength

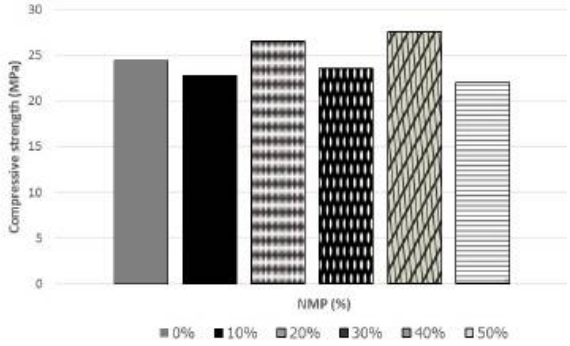


Fig 6. Compressive strength of controlled and NMP concrete (w/c 0.62).



Fig 7. Failure of specimen in compressive strength test.

Compression test of NMP concrete has shown that strength of each mix was slightly different from the controlled mix as shown in Fig 6. Concrete mixed with 20% and 40% NMP has higher strength than controlled mix, while compressive strength decreased with increasing of NMP fraction in concrete mix. This may be distributed to the weak bonding between cement paste and NMP (thermosetting plastic

aggregate) in concrete mixture. Type of concrete failure was vertical cracking by conical failure as expected (Fig 7). The compressive strengths of all NMP concrete were in the range of 21-35 MPa as required for structural-lightweight aggregate concrete in accordance with ACI 213R-03 [12].

3. Splitting tensile strength

The splitting tensile strength of NMP concrete has shown gradual decrease with increasing fractions of NMP in concrete (Fig 8). However, the result suggested that the limit of adding NMP in mixture is no more than 30% NMP with highest splitting tensile strength of 4.48 MPa. The decreasing of splitting tensile strength of NMP concrete may also be related to the weak boding between cement paste and NMP as the compressive strength. The failure of concrete was in the middle of specimen as a marked diametrical line (Fig 9).

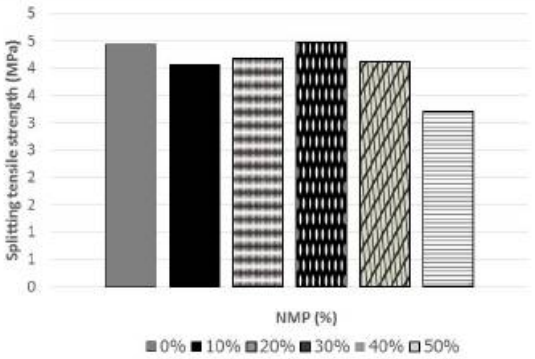


Fig 8. Splitting tensile strength of controlled and NMP concrete (w/c 0.62).



Fig 9. Failure of specimen in splitting tensile strength test.

4. Bulk density

The result of bulk density of NMP concrete at the age of 28 days is shown in Fig 10. The increase of NMP in concrete mix reduced the bulk density of concrete. The bulk density of concrete with 10, 20, 30, 40 and 50% NMP is 2370.75, 2323.90, 2306.92, 2258.49 and 2236.16 kg/m^3, respectively. The reduction of weight has reduced up to 7.46 % for 50% NMP concrete as in Table I. This can be attributed to the fact that the density of NMP is lower than that of natural fine aggregate (sand). This reduction in dead weight of a building or the lower weight of structure could help reduce the risk of earthquake damage [13]. The lower weight concrete is also now trend in building materials to reduce the costs of construction and transportation.

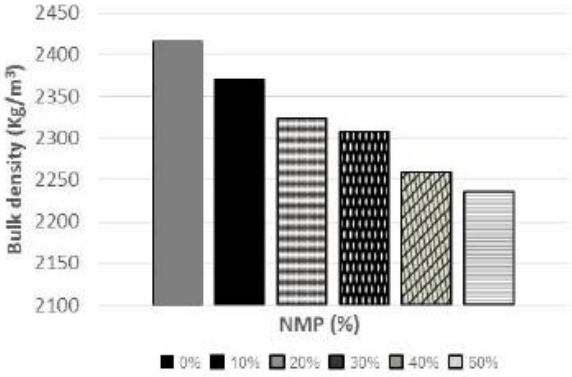


Fig 10. Bulk density of controlled and NMP concrete (w/c 0.62)

NMP (%)	Bulk density (kg/m^3)	Weight reduction (%)
0%	2416.35	-
10%	2370.75	1.89
20%	2323.90	3.83
30%	2306.92	4.53
40%	2258.49	6.53
50%	2236.16	7.46

Table I. Bulk density of NMP concrete and weight reduction in percentage.

CONCLUSION

The physical and mechanical properties of concrete mixed with non-metallic powder of water/cement ratio 0.62 were studied and major conclusions are as follows:

1. Workability of freshly NMP concrete has reduced as more fraction of NMP were added to the concrete mix. Concrete with 10, 20 and 30% NMP satisfied standard in term of slump.

2. Compressive strength and splitting tensile strength of NMP concrete has gradually decreased when more fraction of NMP were added in concrete mix, except at 40% NMP, the strength has increased higher than others mix but not significantly considered to be the appropriate mix due to workability results not in line with the minimum of slump standard.

3. Bulk density of NMP concrete has gradually decreased because NMP has lower specific gravity than natural fine aggregate (sand).

4. The satisfied appropriate fractions of NMP for using in concrete mix, considering strength and workability, are 10 and 20%.

5. The NMP concrete can be sustainable in a wide range of building applications, offering an alternative way for electronic waste management.

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