Utilization of Recycled Concrete Aggregate for High Performance alkali Activated Concrete: Towards a Sustainable Building Solution

C L Hwang\textsuperscript{1}, M D Yehualaw\textsuperscript{1,2} and D H Vo\textsuperscript{1,3}

\textsuperscript{1}Department of Civil and Construction Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan
\textsuperscript{2}Faculty of Civil and Water Resource Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia
\textsuperscript{3}Faculty of Civil Engineering, University of Technology and Education, the University of Danang, Danang, Vietnam

Email: mtkdmt2007@gmail.com

Abstract. The purpose of this study is to prepare environmentally friendly and highly sustainable concrete for an ever-increasing demand of concrete in the construction industry. In the study both natural course and fine aggregates were partially replaced by recycled concrete aggregate from construction and demolition wastes. High performance alkali activated concrete was prepared by utilizing pozzolanic industrial wastes as a binder which fully replaced cement powder. High volume of fly ash with 30\%, 40\% and 50\% replacement of slag was used as a main binder. NaOH and Na_2SiO_3 with an alkali modulus of 0.6 were used as an alkali activator solution. The findings of this research revealed that alkali activated recycled aggregate concrete have competitive engineering properties with respect to cement concrete with natural aggregate. The UPV and thermal conductivity test results were found to be 4302 m/s and 1.425 W·m⁻¹·K⁻¹ respectively. The results of this study will pave the way towards the better practice of sustainable concrete construction by replacing the cement and natural aggregate in one concrete mix.

1. Introduction

Nowadays, with accelerated industrialization and urbanization increases the rate of industrialization and urbanization has made the use of concrete as the most non-sustainable material. It uses approximately 20 billion tons of raw materials (coarse aggregate) each year. However, it was forecasted that the global consumption of aggregate used in construction may exceed 26 billion tons by 2012. With this increase in rate of consumption, it is expected that the demand of aggregates will be doubled in the next two to three decades [1,2].

Thus, the concrete industry consumes a large amount of natural resources that cause substantial environmental, energy and economic losses as it exploits 50\% raw material, 40\% of total energy, as well as generates 50\% of total waste [2]. So, minimizing the environmental impact, energy consumption and the increase in CO2 intensity for the concrete to be used for construction have become more evident for construction industry which can lead towards sustainable development. On the other hand, Portland cement (PC) manufacturing for concrete work is an energy-intensive process that requires high temperatures (1450-1550 °C), consumes natural resources (mainly limestone and clay) and generates vast greenhouse gas emissions to the atmosphere (approximately 1 ton of CO2 per
ton of produced cement. As reported by Torgal et al [3], it is one of the primary causes of global warming, and accounts for 7% of worldwide CO2 emissions.

To alleviate the problem, researchers draw two solutions. The first one is recycling Construction and Demolition Wastes (CDW) as an aggregate for new concrete production. Ajdukiewicz and Kliszczewicz [4] studied the effects of the incorporation of fine and coarse recycled aggregates (RFA and RCA) from demolished concrete with medium/high strength (35-70 MPa) on the performance of concrete. The results showed that using RFA and RCA decreases the compressive strength of concrete from 5-20%. Different researchers improved the performance of Recycle Aggregate Concrete (RAC) by applying chemical admixtures and pozzolanic materials. The second solution is using Alkali activated binder to replace cement. This system pozzolanic materials as a binding material and uses different alkaline solutions such as NaOH and Na2SiO3 as activators. As pointed out by Behera et al [5], the alkali-activation of pozzolanic materials helps to minimize the exploitation of non-renewable raw materials, and to reduce pollution, energy consumption and the areas employed to dispose waste, all of which help mitigate global warming. Alkali activated mortars made by commercial water glass reduce CO2 emissions by 13% compared to PC mortars.

This paper is dedicated to study sustainable and high-performance concrete with utilization of CDW as both RFA and RCA to replace Natural Coarse and Fine Aggregate (NCA, NFA). Cement is fully replaced by slag and fly ash with the application of NaOH and Na2SiO3 as alkaline activators.

2. Material characterization and nature of the concrete mixes
For this study there are two groups of concrete mixes. The first group is the control group, which is made from natural fine and coarse aggregate whereby cement is used as a binder material with w/c ratio of 0.42.

The second group is made from a combination of natural and recycled CDW. The coarse aggregate is composed of 60% NCA and 40% RCA while the fine aggregate is made from 30% RFA and 70% NFA. Recycling CDW replaced 40% and 30% by volume of NCA and NFA respectively. For this group alkali activated fly ash and slag paste is used as a binder with a w/b of 0.38. Three concrete mixes were prepared (F30, F40, & F50) with varying in content of fly ash and slag. The slag was replaced by 30%, 40% and 50% fly ash and the effect on fresh and harden properties of concrete are studied. NaOH and Na2SiO3 are used as alkali activator solutions with M+ and AM value of 4% and 0.6 respectively.

3. Results and discussion
3.1. Workability
The workability of fresh concrete was studied by conducting slump test according to ASTM C 143. The test result is portrayed on Figure 1. It can be understood that the workability of concrete increases with an increase in fly ash and a decrease in slag content. This can be explained that the spherical and glassy nature of fly ash decreases friction [6]. The control mix has higher workability than F30 and lower than F40 & F50. To illustrate figuratively, F30 and F50 concrete mixes showed the least and the highest slump value of 220 and 195mm respectively while the control mix and F40 showed similar slump value of 210mm. All concrete mixes have very good workability with very close figure with a range of 25mm.
3.2. Compressive strength

The compressive strength results of concrete mixes were tested on 3, 7- and 28-days age according to ASTM C 109 and the results are summarized on Figure 2. It can easily understand that the compressive strength of concrete mixes with recycled coarse and fine aggregate is lower than the concrete mix with natural aggregate. This is due to the adhered mortar on the surface of recycled course and fine aggregate hinder to make strong bond between aggregate and alkali activated paste. This explanation agreed with previous research works [7]. The compressive strength of recycled aggregate concrete mixes was improved with an increase in content of slag. This is actually due to high reactivity nature of slag as can be seen on Figure 1. The control concrete mix showed the highest strength at 28 day with 60MPa while F30, F40 & F50 showed 51, 46 & 40MPa respectively.

Figure 1. Workability of concrete mixes

Figure 2. Compressive strength of concrete mixes
3.3. Ultrasonic Pulse Velocity (UPV)

Different researchers have demonstrated UPV test to measure the durability of concrete such as porosity and permeability value to assess the compressive strength and durability of properties of concrete [8]. The UPV test results of control and alkali activated concrete mixes is displayed on table 1. It can be understood that UPV results drops with in increase in fly ash content. The UPV results of control and alkali activated concrete mixes corresponds to their respective compressive strength results. This is also supported by research result of different researchers [9]. The control mix revealed UPV value of 4525m/s at 28 days age while F50 displayed 4265m/s. All alkali activated recycled aggregate concrete group mixes showed lower results than the control mixes due to the low density of RFA and RCA. According to the suggested UPV ratings of Malhotra et al. [10], all concrete samples are considered to be good quality concretes, because all UPV results are in the range of 3660–4575 m/s

| Mix | UPV (m/s) | Thermal Conductivity (W/m*k) |
|-----|-----------|-------------------------------|
| C   | 4525      | 1.455                         |
| F3  | 4302      | 1.425                         |
| F4  | 4294      | 1.335                         |
| F5  | 4265      | 1.29                          |

3.4. Thermal conductivity

The ability of the concrete to absorb heat is measured by applying thermal conductivity test. The result of thermal conductivity test on 28th date is summarized on Table 1. It was found that the thermal conductivity of concrete made from alkali activated recycled aggregate is lower than the control concrete with natural aggregate. This is basically due to the high porosity of RFA and RCA. Since the conductivity of air is very low therefore, conductivity of Recycled Aggregate Concrete (RAC) varies with the variation in aggregate density or porosity [11]. Moreover, since cement has higher thermal conductivity than fly ash and slag thermal conductivity of control concrete mix is higher than Alkali activated RAC. However, the thermal conductivity of alkali activated RAC improved with an increase in slag content due to its very amorphous nature it produces more alkali activated paste and makes the concrete micro structure of concrete to be denser [12,13].

4. Conclusion

From the results of the study the following points can be concluded:
• Recycled CDW can be simultaneously used as coarse and fine aggregate for the development of RAC for a high-performance concrete
• The compressive strength of alkali activated RAC is lower than the control concrete. F50% has 33% lower strength than the control mix.
• UPV and thermal conductivity show similar trends with the compressive strength of concrete mixes. They improve with an increase in compressive strength of concrete.
• Alkali activation system is the best alternative to make sustainable concrete by replacing the environmentally unfriendly, costly and energy intensive ordinary Portland cement.
5. References

[1] Sonawane T, Pimplikar S., Use of recycled aggregate in concrete. Int J Eng Res Technol ;2(1):1–9. 2013.

[2] Oikonomou N., Recycled concrete aggregates. Cem Concr Compos; 27:315–8 2005.

[3] Torgal P., Labrincha J, Leonelli C., Palomo A., Chindaprasit P., Handbook of Alkali-Activated Cements, Mortars and Concretes 1st edition, Woodhead Publishing, United Kingdom, 2014.

[4] Ajdukiewicz A., Kliszczewicz A., Influence of recycled aggregates on mechanical properties of HS/HPC. Cem. Concr. Compos 24 (2), 269-279, 2002.

[5] Behera M., Bhattacharyya S. Minocha A, Deoliya R, Maiti S, Recycled aggregate from C & D waste & its use in concrete - A breakthrough towards sustainability in construction sector: a review, Constr. Build. Mater. 68 501–516 2014.

[6] Hwang C, Yehualaw M, Vo H, Huynh P, development of high strength alkali activated paste containing high volume of waste brick and ceramic powders, construction and building materials, 218 (2019) 519-529.

[7] Pedro D, Brito D, Evangelista L, Structural concrete with simultaneous incorporation of fine and coarse recycled concrete aggregates: Mechanical, durability and long-term properties, Construction and Building Materials, 154 294-309 2017.

[8] Lafhaj Z, Goueygou M, Djerbi A, Kaczmarek M, Correlation between porosity, permeability and ultrasonic parameters of mortar with variable water/cement ratio and water content. Cem. Concr. Res., 36(4), 625–633 2006.

[9] Hwang C, Tran V, Engineering and Durability Properties of Self-Consolidating Concrete Incorporating Foamed Lightweight Aggregate, J. Mater. Civ. Eng., 28(9) 2016.

[10] Malhotra V, Testing Hardened Concrete: Nondestructive Methods American Concrete Institute Monograph No. 9, Detroit, Michigan, 1976.

[11] Chung S, Han T, Kim S, Kim J, Youm K, Lim J, Evaluation of effect of glass beads on thermal conductivity of insulating concrete using micro CT images and probability functions, Cem. Concr. Compos. 65 150–162 2016.

[12] Demirboğa R., Influence of mineral admixtures on thermal conductivity and compressive strength of mortar, Energy Build. 35 (2) 189–192 2003.

[13] Bentz D, Peltz, Duran M, Valdez A., Juárez P, Thermal properties of high-volume fly ash mortars and concretes, J. Build. Phys. 34 (3) 263–275 2011.