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RECYCLED CONCRETE AGGREGATE AND ITS PROSPECTS IN STRUCTURAL CONCRETE

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ABSTRACT

A review carried out has shown that recycled aggregate is suitable for the production of concrete for structural applications. Recycled aggregate is majorly used for secondary purpose due to the adhering mortar which renders it inferior compared to its companion natural aggregate. Efforts have been made by previous researchers to overcome the negative impacts of the attached mortar through thermal and chemical processes, but these techniques have disadvantageous effects. An ongoing research at Coventry University, United Kingdom, proposes a composite material consisting of recycled aggregate and steel fibres in the production of steel fibre-reinforced recycled aggregate concrete. In the study, a mix proportioning technique dubbed "Equivalent Mortar Volume" method, which treats recycled aggregate as a heterogeneous material, is adopted.

1 INTRODUCTION

Concrete is used all over the world and its annual consumption is reportedly increasing. Over 20 billion tonnes of crushed stones are required by concrete industry every year, and twice this figure is expected in the next two to three decades (Behera et al. 2014, Oikonomou 2005). This is because aggregates account for ¾ of concrete volume (Tu et al. 2006). The excessive use of natural aggregate has become worrisome due to associated negative environmental impact and control measures are required for posterity. Not only are the natural resources depleted, Wang et al. (2017) pointed out that sooner or later, most concrete structures would be demolished resulting in large quantity of construction and demolition waste (CDW). The common practice is to dump the CDW in landfills for disposal, thus causing shortage of land and environmental degradation. Thinking of measures to the associated negative environmental impacts of concrete production and waste management, intense studies have been going on in the past few decades and recycling of concrete debris for use in wide variety of civil engineering works has emerged. Also, the inclusion of steel fibres (SF) in concrete for strength compensation is remarkable for improving crack resistance and ductility. Thus, a concrete composite made of recycled aggregate (RA) and SF would serve as a relief to incessant consumption of landfills and exploitation of limited natural resources.

2 STATE – OF THE – ART

Fundamentally, RA is obtained from processed wastes which originally comprised of mixed materials of wood, reinforcements, concrete, soil, polymers, etc. Returned fresh concrete from ready-mix, production waste at a pre-cast production facilities and, CDW are the sources of RA (Silva et al. 2017, WBCSD 2012, BRE Digest 433 1998). As a result, its production is a recycling process involving series of steps and requires a special technology. Despite the studious investigations by researchers, greater usage of RA is limited to non-structural applications for pavement base and backfill for retaining walls (Ignjatović et al. 2013). Information available have shown that the properties of RA from variety of sources are inferior compared to those of its equivalent natural aggregate (NA). This inferiority is mostly due to the residual mortar from the original concrete attached to the RA, which is highly porous. Previously, different techniques have been employed to address the overwhelming influence of the residual mortar. One method is described as a thermal process (Mulder et al. 2007) and the other a chemical process (Wang et al. 2017, Ismail and Ramli 2013). Whereas the former requires high amount of thermal energy and accompanied by Carbon (IV) Oxide emission, the latter introduces Chloride and Sulphate ions that are detrimental to the aggregates and also can be harmful to workers. Another technique is to alter the water – cement ratios of the concrete mix to improve the compressive strength of recycled aggregate concrete (RAC) (Topcu and Sengel 2004, Dhir et al. 1999).

Until year 2009, conventional mix proportioning method has been used to prepare RAC and that has never produced elastic modulus of equal or greater value than its related parent concrete that produced the RA. A milestone was reached, as a new mix design approach which specializes in making the compisition of RA akin to that of NA, was developed (Fathifazl et al. 2009). Literature revealed that quality of parent concrete (Silva et al. 2014) plays a pivotal role in the mechanical properties of RA. It is also known; that different construction tradition exists across the globe, consequently variety of CDW class ensues. Furthermore, history record of old structures are scarcely available, hence it is difficult to determine important information like concrete strength, mix design, etc of the structure. The way out of any undesirable consequences of RA with no history data or from variety of sources, is to adjust the total mortar volume of RAC to match that of its companion natural aggregate concrete (NAC). To this end, Fathifazl et al. (2009) in their new mix proportioning technique proposed that, residual mortar in RA should be treated as part of the overall mortar content of RAC. With the method, they achieved RAC with greater elastic modulus than that of its source concrete. This implies therefore that the problem with RA is not inherent but on the method adopted for the mix proportioning of RAC.

3 RECYCLED CONCRETE AGGREGATE FOR STRUCTURAL USES

According to World Business Council for Sustainable Development (WBCSD) (2012), although demolition waste is the most notable source of RA, it is highly heterogeneous. Other aforementioned sources of RA, that is, unused fresh concrete and waste from pre-cast production facility contain insignificant contaminants compared to those of CDW origin. However, RA sourced from structures of high alumina cement instead of Portland cement should not be employed in producing RAC for structural use. More so, fragmented bricks from refractory containing high Periclase and MgO have been reported to show serious negative effect even when present in a very little quantity of 0.01% (Hansen 1986). Even when other prominent impurities like iron, wood, plastics, etc. have been screened out of the demolition waste, BRE Digest 433 (1998) maintained that the most important issue with RA is the relative proportions of concrete to brick masonry. The report classified RA into three based on brick content as shown in Table 1. From Table 1, Class RCA (II) which they described as relatively high quality material, originated from crushed concrete and contains the least amount of brick masonry by weight.

Table 1: Classes of Recycled Aggregate. Adapted from (BRE Digest 433 1998)

Class	Original (normal circumstances)	Brick content by weight
RCA(I)	Brickwork	0 - 100%
RCA(II)	Concrete	1 - 10%
RCA(III)	Concrete and brick	1 - 50%

Both tiny and large particles are obtained from recycling process. Etxeberria et al. (2007) and Schubert et al. (2012) reported that fine aggregates obtained from recycling process are susceptible to large shrinkage and the water available for hydration of cement is hugely affected by the absorption affinity of recycled fine aggregates (RFA), leading to reduction in overall water-cement ratio of concrete. Hansen (1986) pointed out that, although when concerned with mechanical properties, less than 5% by weight of bricks rubbles or lightweight concrete in RA will have no consequential effect but could otherwise if durability is the focus. Therefore, for the purpose of structural applications, RFA should be restricted. BRE Digest 433 (1998) recommended that, due to the adverse effect of fines from recycling activity, RA passing through a 5mm sieve should not be employed for general use in concrete. This is because, the absorption capacity of RA increases with decrease in size of aggregate particles.

4 PROSPECTS FOR RECYCLED AGGREGATE

So far, significant progress has been made on RA and there is general perception that the dry cement mortar coating its surface is responsible for its poor performance in concrete. The most recent breakthrough in record is the introduction of fibres in RAC for strength supplement. Of all common fibres, Vaishali and Rao (2012) concluded that in concrete, SF performed best compared to glass and poly-propylene fibres. Also, the influence of SF is more in concrete made with RA than that with NA, although the effect is greater with recycled coarse aggregates (RCA) than combined RCA + RFA as shown in Figure 1. Figure 1 shows the percentage decrease in flexural strength of various fibre-reinforced high performance concrete (FRHPC) prepared with SF, glass fibre (GF) and poly-propylene fibre (PF) using RCA and RCA + RFA, respectively. Similar trend was reported by the authors for both compressive and tensile splitting strengths.

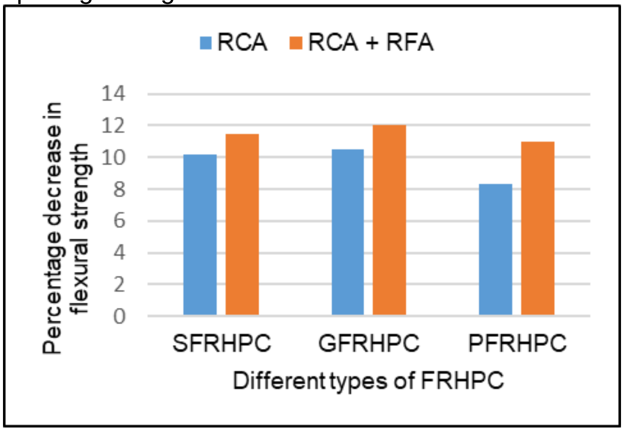

Figure 1: Decrease in flexural strength of FRHPC made with RA as compared to the one with NA at 0.5% fibre dosage. Adapted from (Vaishali and Rao 2012)

Nevertheless, there is need for further experimental investigation using RA produced from normal strength concrete. SF improves the structural performance of concrete, however limited study is available on its combination with RA in the production of RAC (Senaratne et al. 2016). Mostly material testing was carried out in a few studies that have adopted the use of SF in RAC production. Detailed study on structural behaviour of the combined effect of RA and SF is scarce. An ongoing study at Coventry University proposes a composite material, constituting RA and SF, prepared using a new mix design method. To the best of the authors' knowledge, no previous study has utilized the new mixture proportioning approach in combination with SF to produce RAC. RA obtained from waste pre-cast beam production facility is employed for the current research.

5 CONCLUSION

The exploitation of natural resources is not sustainable and the dumping of construction and demolition waste into landfills for disposal has negative environmental implications. As global need for concrete is on increase, the use of recycled aggregate as an alternative to natural aggregate in concrete production, is deemed appropriate. Consequently, investigations are on by researchers for many decades now, to ensure that RA is used beyond secondary needs. Conclusions from a review carried out are highlighted below:

- If the desire to reuse concrete rubbles in new concrete is borne in mind prior to demolition of structures, RA with reduced impurity would be achieved.
- With high quality parent concrete, RA of desirable characteristics can be produced. Also good quality RA is ensured by regulating the quantity of RFA.
- RA sourced from concrete debris offers a better quality than one sourced from mixture of concrete and brick masonry and/or brickwork
- The major problem with RA is its high water absorption capacity caused by the dry cement mortar coating the surface of the aggregate. Hence, RA is a heterogeneous material and should be treated differently from NA when used in concrete.
- Inclusion of SF improves mechanical properties of RAC by the way of crack resistance and induction of ductile failure.

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