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Financial assessment of manufacturing recycled aggregate concrete in ready-mix concrete plants

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ABSTRACT

Concrete waste is crushed in the present recycling operation to produce crushed concrete (CC), which is mostly used as a road base filler material. The coarse portion of CC, referred to as recycled concrete aggregate (RCA) can be used in structural concrete replacing coarse natural aggregate (NA). The resultant concrete which is referred to as recycled aggregate concrete (RAC), would create a sustainable end use for concrete waste, and reduce the demand for NA, leading to its preservation. However, the concrete industry has been reluctant to embrace production of RAC to its full potential. Beside uncertainty regarding material performance, options available to effectively set up the existing plant operations to manufacture RAC is yet to be explored. This paper attempts to simulate the manufacturing set up to produce RAC by integrating processes involved in concrete waste recycling and readymix concrete (RMC) production environments. It presents a model to evaluate the financial effect of manufacturing RAC in lieu of normal concrete, calibrated with data from RMC manufacturing and recycling plants. Analysis of the response to produce RAC highlights that the price of RAC differ significantly based on the type of RMC manufacturing plant and the cement content of the mix. It is observed that it is highly probable that the price of RAC is 0–10% higher than that of natural aggregate concrete (NAC). Probabilistic estimation of the price difference between RAC and NAC concludes that RMC plants having aggregate feeding mechanism with front-end loader (FEL) would be an appropriate entry for industrial scale manufacturing of RAC.

1. Introduction

The demolition waste from a reinforced concrete building typically consists of 50% of concrete waste by weight (Tam, 2008). Concrete waste is processed to produce crushed concrete (CC) and the coarse portion of CC is separated as an aggregate product, referred to as recycled concrete aggregate (RCA), while the fine portion is referred to as fine recycled concrete aggregate (FRCA). Replacing RCA with coarse natural aggregate (NA) in concrete results in recycled aggregate concrete (RAC). Use of RAC to replace natural aggregate concrete (NAC) in structural applications has recently gained increased importance due to a number of reasons. First, it provides a sustainable end use for concrete waste and encourages recycling, rather than disposal via landfills. Second, it reduces demand for NA, addresses its scarcity and encourages conservation of quarried NA. Equally, the initiative enables the concrete industry to use concrete in a closed loop for construction.

Despite many advantages, commercial production of RAC to use in structural applications currently does not occur in Australia. Equally, the rate of recycling of construction and demolition (C&D) waste stands at 55% in Australia presently, where several other countries have achieved much higher recycling rates by the 1990s (Denmark and Estonia >80%, Japan >98%) (Hiete et al., 2011; Hyder Consulting, 2011). Considering that Australia has immense potential to improve C&D waste recycling rates as well as to promote industry uptake of the commercial production of RAC, this paper conducts a financial assessment of manufacturing RAC in ready-mix concrete (RMC) manufacturing plants, based upon the present Australian context.

In order to conceptualise the production of RCA as a constituent material in concrete (CMC) by the concrete waste recycling industry, and the production of RAC as a concrete product by the RMC industry, the changes to the present industrial set-up have been considered in this study. The changes involve extension of operations, modifications to the existing manufacturing process and infrastructure additions as applicable to the context.

2. Background

This section provides background information on the present industrial set-up relevant to the study, reviews the methods used

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in the theoretical approach and provides a review on the relevant existing literature.

2.1. Present industrial set-up of manufacturing RAC

CC currently produced in Australia is mostly used as a road-base material and the quality of the product is governed by the Roads Authority standards (VICRoads, 2009). The lower density of CC in comparison to natural rock makes it attractive to be used as a road-base material, due to higher volumes in filling (Cement and Concrete Association of New Zealand, 2011). Equally, it has the ability to incorporate FRCA as a product of crushing of concrete waste. The disadvantage of the use of CC as a road-base material is that, it poses environmental risks such as leaching of hexavalent chromium to the ground (Dosho et al., 2011).

CSIRO Guide to the use of recycled concrete and masonry materials (HB 155:2002) presently provides general guidelines for the use of RCA in structural applications in Australia (Commonwealth Scientific and Industrial Research Organisation, 2002). It specifies to use Grade I RCA up to 30% in applications less than 40 MPa. However, specific operational guidelines on processing and quality control of RCA as a CMC, mix proportioning and manufacturing of RAC at an industrial scale facility are not addressed in the Guide. Lack of detailed technical specifications and guidelines to produce RAC is considered one factor retarding industry uptake of manufacturing RAC (Rao et al., 2007).

In addition to this, lack of knowledge on the financial perspective to RAC manufacturing is a specific area requiring attention as it drives the industry dynamics. It is unknown whether costs for adoption, quality control and processing costs in a standard manufacturing process of RAC outweighs the benefits of obtaining RCA as a low cost CMC compared to the NA. Exploring this is a specific area addressed in this paper.

It is also observed that the business structure of large, already established RMC manufacturing companies would be a reason for the lack of industry uptake for RAC production. RMC industry generally attains a lower industry profit margin compared to cement and aggregate manufacturing. The gross profit margin of the ready mix concrete industry in Australia stood at 6.5% in 2013–2014 (Kelly, 2013). For large RMC companies which have upstream vertical integration, the low profit margin together with the capital intensive nature of the industry poses a problem to make costly changes in the manufacturing process, unless there is a valid and promising business case (Robinson et al., 2004). Presently nearly 65% of the Australian RMC industry is operated by large companies which have upstream vertical integration (Kelly, 2013). Equally, to sustain the business interests of the consolidated business entity, most of the companies tend to purchase aggregate products from their subsidiary counterparts rather than going for competitively priced alternative sourcing (Ready-mix plant operator 1, 2015b, Ready-mix plant operator 2, 2015c, Ready-mix plant operator 3, 2015). Financial assessment of RAC manufacturing therefore helps to unravel the industry dynamics which needs attention in promoting RAC usage.

2.2. Review of the methods used in the theoretical approach

In the financial assessment conducted on RAC, the price of RAC is assessed using the incremental costing approach. This approach considers a base cost; either based on a period or a product system as a benchmark, and develops costing for the new situation/product/period considering it to be a deviation from the base. The opposite of this approach is zero based costing approach, where all the costs relating to a product are analysed and derived based on the fundamentals (Achim, 2014). Zero-based costing has no bias on base data, encourages creativity to find ways of reducing costs; yet could be labour intensive in compilation. Incremental costing, on the other hand is simple, less time consuming as it requires less details of absolute cost to account for new changes. However, it has the limitation of relying on base data.

Identification and classification of costs are necessary, as the paper conducts costing for a new product for its manufacturing in the RMC production environment. A basic classification is to identify them as direct or indirect costs, where direct costs are those that can be clearly assigned to a product or cost object while indirect costs do not have such a clear association (Compton and Brinker, 2005). Classification based on fixed or variable nature identifies whether incurring of the cost is related with the output produced of the product. They are classified as variable, if costs are incurred based on output; else they are classified as fixed. All these classifications have items which carry common characteristics of both classes, and identified to be mixed or hybrid in nature (Compton and Brinker, 2005).

Following identifying and classifying the costs, their allocation to products is necessary. For product costing, two main costing systems can be identified which are; job order costing and process costing. Job order costing identifies costs for a particular product based on its resource consumption, while process costing assumes that all units of a product or service consume the same amount of labour, material and indirect costs (American Management Association International, 2000). Activity-based costing (ABC) is a costing approach, which traces costs to products based on the factor (cost driver) that causes or correlates highly with a product's or customer's use of an activity's resources (Kee and Schmidt, 2000). The ABC approach enables identification of the components of overheads more precisely and assigns cost of resources to products more accurately (Sievanen and Tornberg, 2002). While it acts as a decision support tool, it relies on the assumptions used on the base of allocation to reflect the actual operational statistics (Al-Araidah et al., 2012). Adoption of ABC can be simplified to process-based costing (PBC), or process costing, when the production has a regular pattern of processes, with the output consisting of homogeneous products. The process-based costing follows the same framework as ABC, and implements it for a two dimensional system based on activities and processes (Sievanen and Tornberg, 2002). This paper uses activity-based costing (ABC) approach simplified to process-based costing (PBC) approach, to estimate the incremental processing cost of RAC.

2.3. Review of the existing studies related to financial assessment

This section draws the latest knowledge from literature on existing research. There are currently a few publications relating to finance and cost effects of RAC manufacturing. Tam (2008) has conducted an economic benefit investigation of recycling of concrete waste. The study concludes that there is a negative net benefit associated with the current practice of land filling waste and a positive net benefit is associated with concrete recycling. This study however, does not cover the applications of RCA and manufacturing of RAC.

Zhao et al. (2011) conducted a study on the feasibility of recycling facilities and established that the key factors affecting feasibility are: profit, the unit recycling cost and the extra revenue from location advantage. Coelho and de Brito (2013a, 2013b) have conducted an economic viability analysis of C&D waste recycling plant considering the period of operation, the input gate fee and the plant capacity as the key variables. Marzouk and Azab (2014) have used the system dynamics approach to evaluate the economic and environmental impact of recycling against disposing of C&D waste, while a cost-benefit assessment of C&D waste management options using the same approach has been carried out by Yuan et al. (2011), Marzouk and Azab (2014). Duran et al. (2006) has evaluated the economic viability of creating markets for recycled C&D waste.