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Sustainable Concrete in Transportation Infrastructure: Australian Case Studies

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Abstract. Whilst generally concrete and steel are the most common substances for civil engineering construction, new trends and development such as sustainable and green material have a lesser effect on the environment. Typically, approximately 90% of a concrete structure's CO_2 emissions are a result of the energy consumed during its life, there is much that can be done to reduce that 10% associated with its construction. Thus, innovative engineering materials, such as Recycled Concrete (RC) have emerged with the potential to influence the future of an environmentally sustainable construction industry. This research investigates the RC as the basis of sustainable concrete for civil engineering construction such as roads, rail and so on. Furthermore, number of examples, 6 roads and 6 rail segments in Sydney, were reviewed. Overall, this research found that for the 6 road and rail case studies generally only RC is utilized as the basis of sustainable material. Although, this is a very small sample, however, a pattern can be noticed. Unfortunately, the pattern is the lack of innovative sustainable material other than concrete for such transportation infrastructure. Appropriately, further investigation is required to review the possibility of other sustainable materials including those incorporating waste-by products as the basis consolidated sustainable material usage in transportation infrastructure.

1. Introduction

The general aim of sustainable materials is to expend less energy, and to reduce environmental impacts [1-4]. Utilizing such materials is detrimental to ensure a sustainable living. An example of such material is Recycled Concrete (RC). Typically, approximately 90% of a concrete structure's CO_2 emissions are a result of the energy consumed during its life, there is much that can be done to reduce this [5-7]. Gharehbaghi [8] noted that, within the building and construction field, concrete is the primary starting point for the CO_2 emissions reduction. This is because concrete is responsible for approximately 10% of global CO_2 emission [9-11]. For sustainable concrete, more greener forms of substance can be formed which utilizes recycled materials in its mix [12,13]. For example, crushed glass can be added, as can wood chips or slag – a byproduct of steel manufacturing. Whilst these changes do not fundamentally transform concrete, however, using such processing methods would ultimately reduce the CO_2 emissions associated such material manufacturing. As shown in Fig 1, the use of concrete is on-going regardless of its CO_2 emissions footprint.

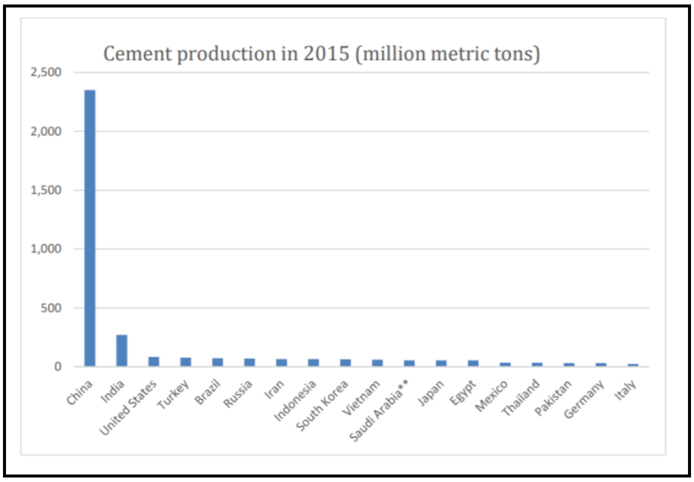

Figure 1. concrete use by individual nations [38].

For emerging economies including China and India, concrete is still an essential material. Such popularity is due to concrete's performances for different conditions and climates together with its ease of use [14-16]. Nonetheless, the concrete's environmental impact is still an on-going concern. Thus, innovative engineering materials, such as RC have emerged with the potential to influence the future of an environmentally sustainable construction product industry. Further, for the transportation infrastructure such modern material processing will be also significantly beneficial.

2. Literature review

2.1. Sustainable concrete in transportation infrastructure

Although there are various systems available to utilize in material selection, processes are not universal, and the importance of factors alters depending on the country of location [17-20]. Fehling et al. [21] identified multiple barriers to incorporate sustainability into material selection practices. These include perceived costs, time to source materials, education and training, understanding in-house experts. Akadiri [22] further investigated the barriers of implementing a sustainable selection practice and mentioned that a lack of sustainable material information, perception of extra costs being incurred, perception of extra time being incurred, perception that sustainable materials are low in quality and an unwillingness to change the conventional way of specifying are the most influential barriers affecting the incorporation of sustainable design within high-rise construction. A review of literature revealed cost figured predominantly as a barrier to achieving sustainability [2,23,24]. In selecting sustainable concrete, benefits such as the overall productivity, performance and so on need to be considered [25,3]. Chevalier et al. [26] argued that specific factors to consider when using sustainable concrete such as RC, include its functioning capabilities among others. The sustainable concrete's functioning ability aligns with its structural capabilities [27]. This includes load bearing capability, stress and strain probabilities and so on. Gharehbaghi and Georgy [28] noted that, the greatest problem facing sustainable concrete is early deformation and degradation. Transportation infrastructure and their subsequent connection systems use concrete in their assembly and configuration including structural support and so on [29]. While for roads, concrete is extensively utilized for decks and carriageway surfacing, for railways it is used for sleepers and other structural systems. Subsequently, recycled concrete aggregates would be sustainably favorable for transportation infrastructure [30]. However, one of the greatest concerns of recycled concrete is its durability and performance. Such concern also includes using recycled concrete for transportation infrastructure [31,32].

Mamlouk and Zaniewski [33] along with Sadeket al. [23] and, Singh et al. [17] noted that, some of the concerns in using recycled concrete, significant deterioration rate due to excessive exposure to substantial water, significant temperature changes and air contaminants which all are common in transportation infrastructure. Furthermore, table 1 summarizes some risk associated with sustainable concrete in transportation infrastructure. However, based on the examination of the literature, it is therefore evident that engineers do not perceive that there is a widespread demand for sustainable concrete in transportation infrastructure. Accordingly, a review into new trends and developments for such infrastructure needs to be undertaken.

2.2. New trends and developments

Hibbeler and Vijay [34] together with Öchsnerand Altenbach [35] as well as Jahan et al. [36] highlighted that traditional material selection for transportation infrastructure generally include longevity. Nonetheless, over the past few years many recycled materials including RC are been used in such infrastructure [37]. Specifically, recycled cement, plastic and asphalt are being used more and more [39]. These sustainable materials are used for low use areas such as local roads [39, 40]. However, for major arterial road together with rail networks currently, only RC seems to be the best option [41]. The reason for such limitation of material selection is based on: highly complex design of the structure together with exceedingly cost due to the size of roads and rail networks [42,43]. For these reasons the use of sustainable concrete in transportation infrastructure is still unfortunately limited. Dejectedly this has led to lack of available sustainable materials for such infrastructure. Due to high performance concrete composition together with long-term material performance, the RC is still the only major sustainable concrete in transportation infrastructure. To support such claim 6 road and six rail segments have been studied.

3. Research methodology

The research will use qualitative method and therefore utilises Australian case studies to review new trends of sustainable concrete in transportation infrastructure. In achieve such outcome, document search was undertaken to define the sustainable concrete specifics of road and rail infrastructure.

4. Case studies

As the basis of case studies, 6 roads and 6 rail segments in Sydney, are investigated. Both tables 1 and table 2 present the overview of these case studies.

Table 1. Overview of roads case studies.

Road segment #	Road classification	Sustainable material and portion	Sections used
SydEast0097	Major collector road	Recycled concrete <10%	Bituminous layer
SydNorthEast0024	Major collector road	Recycled concrete <10%	Bituminous layer
SydSouthEast013	Principal arterial	Recycled concrete <3%	Bituminous layer
SydWest0016	Minor arterial	Recycled concrete <5%	Bituminous layer
SydSouthEast008	Minor arterial	Recycled concrete <5%	Bituminous layer
SydNorthEast0151	Local road	Recycled concrete <15% and plastic <5%	Bituminous and surface layers

As observed, for the 6 road segments only a small portion possess sustainable materials. For such infrastructure recycled concrete were the main composition of sustainable materials. While the Bituminous base course consisted of traditional Sub-grade gravel, stones and sands; the Binder course also possessed conventional materials. On the other hand, Bituminous concrete layer is where all the sustainable material was utilised. For theses six case studies, recycled concrete was the only material used. Only for SydNorthEast0081 recycle plastic was used as basis of surface covering.

Table 2. Overview of rails case studies.

Rail segment #	**Rail classification**	**Sustainable material and portion**	**Sections used**
T1032	Class 3: Local railroad	Recycled concrete <10%	Rail sleepers
T4016	Class 3: Local railroad	Recycled concrete <10%	Rail sleepers
T5009	Class 3: Local railroad	Recycled concrete <10%	Rail sleepers
T5019	Class 3: Local railroad	Recycled concrete <10%	Rail sleepers
T7005	Class 2: Switching terminal railroad	Recycled concrete <10%	Rail sleepers
T9037	Class 3: Local railroad	Recycled concrete <10%	Rail sleepers

Sydney currently has 9 main rail network lines, ranging from T1 to T9. For these, standard Australian intermediate gauge railways are used. In addition, for these 6 case studies, steel is also used as the basis of rails, while recycled concrete is utilized for sleepers along with stones for ballast. Overall, as it can be noticed, for these 6 road and rail case studies generally only RC is utilized as the basis of sustainable material. Although, this is a very small sample, however, a pattern can be noticed. Unfortunately, the pattern is the lack of innovative sustainable material other than concrete for such transportation infrastructure.

5. Conclusion and recommendations

Concrete together with steel form part of the primary materials used in transportation infrastructure. Due to ever increase in CO_2 emissions, new sustainable materials are sought for such infrastructure. Innovative engineering materials, including RC are the back-bone of greener propositions for such environmental considerations. Subsequently, this research found that the new trends and developments for transportation infrastructure is limited mainly to RC. To demonstrate such dilemma, 6 Australian road and six rail segments were reviewed. Due to such limitation new and improved substance other than RC are essential to embrace sustainable material specifically for transportation infrastructure. Areas for further research could include the investigation of other sustainable materials including those incorporating waste-by products. Other sustainable materials which are in testing phase or have recently been developed, could further promote sustainability in transportation infrastructure.

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