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Recycling Of Concrete Waste to Produce New Structural Concrete: A Review Study

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Abstract

Legislation is pushing the concrete industry towards environment-friendly options, including the recovery of concrete waste (CDW) as a secondary raw material. Concrete recycling is one such case that minimizes the consumption of natural mineral resources. In this review study, the main properties and the efficiency of using recycled concrete were discussed in addition to the factors influencing using it and the challenges it faces be reviewing the main studies that studied the use of recycled concrete in construction. The discussion showed that most studies have shown that using recycled concrete, especially recycled aggregates, has proven to be efficient in terms of compressive strength and durability; however, using recycled concrete is facing many challenges that can be overcome by studying the factors that control managing the concrete waste.

Keywords: *recycled aggregates*, *concrete*, *sustainability*, *concrete waste*

Introduction

The construction sector is vital for the socioeconomic progress of the countries (Nuñez-Cacho et al., 2018). With the rapid growth this sector is undergoing, different factors are contributing on this growth including the rise in living standards, unstable shopping habits, enlarged demand for mega infrastructure projects, besides the population growth. Consequently, the concrete production has significantly increased in the demolition and construction stages (Luangcharoenrat et al., 2019). As a result, the concrete waste has developed into a worldwide environmental threat that requires a rapid response. The concrete waste, which is not disposed properly, can be dangerous for the environment. According to Bakchan et al (2019), concrete waste has become a pollution source that can develop into a serious problem, if not properly managed. As concrete waste can be worthless, contractors might choose to dispose it in landfills instead of recycling facilities. Additionally, project owners and contractors might have additional costs by concrete waste managing. In this case, recycling concrete waste is not an option; but, it is essential (Badraddin et al., 2021).

According to Tam et al. (2018), concrete recycling that includes converting concrete waste into aggregates, is the most common recycling concrete waste methods. Furthermore, concrete recycling is considered as an essential practice for minimizing the environmental impact of concrete waste (Luangcharoenrat et al., 2019). Concrete recycling has a huge potential (Islam et al. 2019). Due to the many concrete recycling's advantage, many countries have started to obligate it. However, Islam et al. (2019) also reported that the global rate of concrete recycling still low at around 5%. Precisely, such rate can be found in the developing countries (Saadi et al., 2016; Zhang et al., 2019).

This study aims to evaluate the use of recycled concrete as a new construction material; therefore, the main properties and the efficiency of using recycled concrete will be discussed in addition to the factors influencing using it and the challenges it faces be reviewing the main studies that studied the use of recycled concrete in construction.

Methodology

As mentioned above, the main objective of this study is to evaluate the use of recycled concrete as a new construction material. Thus, a literature review was performed to collect the studies that use recycled concrete components as "structural material" in buildings. This study focuses on aggregate recycling, by reviewing some of the most relevant scientific empirical studies and reviews their results. In order to depict the most important contributions to the effectiveness of using recycled concrete as structural material, an extensive literature review has been conducted, mainly within the literature indexed in the most widespread databases on different scientific fields which are frequently used for searching the literature: Scopus and Web of Science (Chadegani et al., 2013). Each of the previous online scientific databases confers several advantages to any researcher who tries to conduct a literature review. Thus, Norris and Oppenheim (2007) state that Scopus and Web of Science have a significant advantage over the other databases, when issues of functionality and the quality of record processing and depth of coverage are taken into account. Moreover, Web of Science and Scopus are the most widespread databases on different scientific fields which are frequently used for searching the literature (Norris & Oppenheim, 2007).

Efficiency of using recycled concrete as a new structural material

In order for recycled concrete to have a role in high strength concrete, the composition should provide the required compressive strength. Many research was conducted out on the recycled concrete have pointed the following aggregates parameters to be used to achieve the essential strength according to ACI; water absorption, adhered mortar, strength of parent concrete, size of aggregates, interfacial transition zone, age of curing, moisture state in which used, ratio of replacement, controlled environmental condition and impurities present (Ahmed, 2019).

With the proper thermal and sound insulation properties and controlled manufactured production, ECO-SANDWICH®, which is an innovative energy-efficient pre-cast panel system, can be used as similar sandwich wall panel on the market, as it is an example on using recycled concrete in the concrete industry (Pečur et al., 2014).

Subaih et al. (2005) showed that 30MP and 25MP strength can be achieved using recycled aggregate as a coarse material. With nearly 35% of fine recycled aggregate result in a clear weakness in the strength of the concrete. Xiao et al. (2006) stated that the recycled concrete compressive strength as aggregate usually decrease with the increasing aggregate contents of the recycled concrete where the replacement percentage of the recycled concrete aggregate is 100%, while the elastic modulus reached 45%.

Ahmed et al. (2020) stated that the workability was acceptable and can be handled satisfactorily for 0% recycled concrete aggregate to 80% recycled concrete and with more recycled concrete replacement percentage used in the concrete specimen, the remained tensile strength percentage are decreasing gradually. Khatib et al (1999) showed that recycled aggregates concrete has a compressive strength that reached 22%-32%, which is less than the natural aggregates concrete strength. Zuhud (2008) stated that recycled aggregate concrete produced from concrete waste has a compressive strength of about 27% - 30%, which is less than the natural aggregates concrete strength with 10%.

Yehia et al. (2015) evaluated the effect of the quality of recycled aggregate on the concrete properties. Assessment of the mechanical and physical properties of the aggregate showed an obvious difference in properties. On the other hand, gradation's requirements limitations included aggregate strength and high absorption could be determined throughout the proportioning stage by reaching higher packing density. Moreover, recycled concrete from various combination of fine and coarse aggregate without change in particle distribution or size showed that splitting, flexural strength, comparable compressive strength and modulus of elasticity can be achieved. All mixes did not show acceptable performance in the RCPT due to the high supported porosity by the microstructure examination of the hardened concrete. High concrete permeability and porosity could be attributed to the existence of contamination and variability in aggregate gradation.

Dabiri et al. (2022) found that integrating recycled aggregate could lower compressive strength slightly. The reduction in the concrete containing recycled fine aggregate long-term strength is less compared with those containing both fine and coarse aggregate or coarse aggregate.

Tran et al. (2022) showed that the most vital variable influence on the concrete made with recycled concrete compressive strength is the cement content, whatever the concrete made with recycled concrete performance strategies. The materials quantity can be easily computed for the designed compressive strength.

Mohammed et al. (2018) experimental results showed that the average concrete compressive strength for the recycled concrete decreases from 30.85 MPa to 17.58 MPa when the percentage of recycled aggregate increased from 0% to 100%. However, when silica fume was used, the compressive strength of the concrete increased to 29.2 MPa for samples with 100% of recycled aggregate.

González-Taboada et al. (2016) indicated that the most important recycled aggregate quality properties are absorption and density. Furthermore, the study analyzed how the recycled aggregate (both quality and percentage) and the mixing procedure (adding extra water or pre-soaking) affect the strength of recycled concrete of various categories (low or high water to cement ratios). When the absorption of recycled aggregate is low (under 5%), adding extra water or pre-soaking to avoid loss in workability will affect concrete strength negatively (due to the bleeding effect), while with high water absorption this does not happen and both of the aforementioned correcting methods can be employed accurately.

Adnan et al. (2007) work covered recycled concrete mixtures at various water-cement ratios (0.4, 0.5, 0.6). It was concluded that recycled concrete mixtures had lower compressive strength than natural aggregate concrete. At the age of 28 days, recycled concrete mixtures with water-cement ratio 0.4 had the highest strength.

Han (2006) showed that the concrete slump did not change effectively at a 10% replacement rate. When 20% recycled aggregates were used, the concrete was too hard where the concrete mixture homogeneity could not be guaranteed. The compressive strength considerably decreased using 10% of recycled aggregates and significantly decreased using 20%. Consequently, 20% of recycled aggregate replacement was not suitable and using recycled aggregates at a rate of 10% is optimal.

Factors influencing using recycled concrete as a new structural material

Practitioners and researchers are exploring a wide range of related issues to concrete recycling. Previous works have emphasized vital factors influencing concrete recycling implementation. For instance, in Kuwait, many factors affect concrete recycling: the recycled material purity; the transportation and collection cost; the sorting cost, conversion into reusable material, and residual material disposal costs to incineration or landfills; and the obligation that recycled concrete meet the applicable standards and specifications (Kartam et al., 2004).

Likewise, collected data from different questionnaire surveys and sources with concrete project managers, contractors, and manufacturers in Thailand showed that the most significant factors affecting the Thai industrial sector include concrete quality, regulations and law, confidence, price, standardization, and (Duangmanee et al., 2018). Consistent with the data, the most vital aspect in determining whether to recycle concrete is site activity and market. It is the most vital of the three elements.

Furthermore, severe competition within the business and available recycled markets inadequate number are important challenges (Chinda, 2016). While earlier studies have provided perceptions into the characteristics that drive concrete waste recycling, the results indicated that several factors can be involved. Consequently, such factors should be investigated. Developers and clients are attempting increasingly to set the requirements of concrete waste management (Kareem et al., 2015). Udawatta et al. (2015) claimed that construction and demolition project participants and clients have less positive attitudes regarding concrete waste management practices.

Several reasons contribute to the concrete waste management practice difficulty in practice. Those reasons include the failure to expect the production environment, time pressure, unique project characteristics, besides cost limitations (Kareem et al., 2015). Furthermore, demolition and construction processes can produce waste because of less management attention and unsuitable handling. For example, leading project team members offer more attention for the new concrete compared to the attention given to concrete waste management. Concrete waste management activities are insignificant to contractors (Udawatta et al., 2015). This negative thinking about concrete waste has delayed the innovations implementation that targets its reduction (Kareem et al., 2015).

Incentives and training for the operators of concrete waste to enhance their knowledge and to participate in activities that are less wasteful, which can help in promoting a good viewpoint and attitude of the management operations in concrete waste (Kareem et al., 2015). Researchers have highlighted the major challenge to waste reduction in the developing countries (Kareem et al., 2015; Teo & Loosemore, 2001). In relation to one of the problems, uncertainty regarding the leadership support and commitment for concrete waste reduction has affected the project team members attitudes, contributing to a deficiency in resources, time available and workforce for the management activities in concrete waste. The second cause of the difficulty is the lack of management performance criteria in the concrete waste.

The third challenge that facing the advancement is the unwillingness of the construction industry to adapt its recognized work routines. Moreover, the fourth argument is that the activities of waste reduction are mainly motivated by financial gain. Lastly, one of the problems with concrete waste recycling in is that the waste is usually bulky, hard to compress, and require more space during the recycling process (Yeheyis et al., 2013).

Challenges facing using recycled concrete as a new structural material

The possibilities of using recycled concrete aggregate are mostly connected with recycled aggregate properties and quality. The core barriers in using recycled concrete aggregate are the high water absorption that influence fresh concrete workability negatively and unwanted impurities that could reduce the concrete mechanical properties (Verian et al., 2018). The coarse recycled concrete aggregate water absorption is between 0.5% and 14.75%, which is 20 times higher than natural aggregate. The coarse recycled concrete aggregate dry density is usually lower than that natural ranges and gravel from 1900 to 2700 kg/m3 (Verian et al., 2018). The fine recycled concrete aggregate water absorption is between 4.3% and 13.1%, while the fine recycled concrete aggregate dry density is from 1900 to 2360 kg/m3 (Evangelista & De Brito, 2014). Lower density and higher water absorption of recycled concrete aggregate is resulted from attached old mortar on the origin aggregate surface, because of that mortar is less dense and more porous than the aggregate particles (Verian et al., 2018).

Several studies have been conducted on the obstacles and challenges facing the recycling of concrete waste, in particular concrete rubble, which prevent it from being converted into high-quality managed raw materials, such as a professional study in the field of concrete rubble recycling (Maio, 2019), and researchers as an example (Wildermuth, 2008; Jain , 2012; Fu et al., 2014), which shows in general, the obstacles and challenges are inherent and have links to cultural, environmental, economic and organizational factors, in addition to political constraints.

Badraddin et al. (2021) showed thirteen key challenges to recycled concrete including lack of national programs for concrete recycling, increased project duration, lack of comprehensive rules and regulations for concrete recycling, low demand for recycled concrete and increased project cost. The main thirteen challenges can be categorized into three correlated groups: technical and people; environmental and legal; besides economic challenges.

Conclusion

This study discussed the efficiency, influencing factors and challenges of using recycled concrete as a new structural material. Recycled concrete is a viable material for the construction sector. On the other hand, it is not the same as natural concrete and its properties and compliance with standards are mainly dependent on the operations type that are made both by the contractor and the concrete waste plant.

The many production methods of recycled concrete indicate that it is a variable material which results in hesitations by the industry. On the other hand, legislation is expected to adjust the existing paradigm and recycled concrete will become a common raw material in the industry. For that reason, concrete waste plants should produce recycled concrete that comply with the standards to be used in construction in a consistent way. These standards aim to ensure that the recycled concrete is good enough for their use as a new structural material.

Recommendations

The main concerns can be solved by the standards requirements and national specifications by:

- The aggregates classification based on their components and the minimum contents definition of intended components and unintended one's maximum contents, with the intention of demolition and construction plants guarantee that unintended components are taken from the recycled concrete aggregates throughout production.
- Defining directly specific properties minimum demands, such as the related properties to mechanical behavior and chemical contamination.
- The components classification is relevant particularly due to chemical contamination and because of the clay detrimental effect on concrete. Washing would lessen both problems, but then is not known in concrete waste plants. The recycled concrete compliance with the constituents' content lessens both effects, as clay content is decreased and components are removed to the possible extent, minimizing the potential deleterious chemical reactions.

- As a result of the recycled concrete properties variability, it is common for standards to determine higher test frequencies for recycled concrete in comparison to natural concrete.
- As water density and absorption are correlated with the recycled concrete overall quality and with industrial challenges for the recycled concrete production, some regulations choose to determine minimum values for density and maximum values for water absorption.

As a result of the significant differences in recycled concrete processing methods, concrete waste plants could not consider the best potential methods, which ensure the sufficient quality of recycled concrete to follow to the applicable standards. The clear minimum best-practice demands definition for demolition and construction plants to produce recycled concrete with acceptable quality for the applications of structural concrete would be a significant step in this direction. For the further research, the following are recommended:

- Investigation on the recovery of recycled concrete and recycled aggregates for industrial acceptance. Furthermore, recycled concrete have also no clear goal where research on the recycled cement use, including the recovery process, is required with the alternatives for such materials.
- The central motivation for using recycled concrete is sustainability; so, the general environmental influences of the recycled concrete production should be lower compared with the normal concrete. However, this is not the usual case and methods for the further environmental impacts estimation of both should be advanced to help decision-making.
- The coarse recycled concrete performance is still not completely understood in what regards some phenomena, including leaching and alkali–silica reactions. Well understanding of the coarse recycled aggregates conditions to lead to unintentional performance would be a key step to help in future regulations.

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