INVESTIGATING THE EFFECTIVENESS OF USING GREEN CONCRETE TOWARDS PROMOTION OF SUSTAINABLE BUILT

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ABSTRACT

About 8-10% of carbon dioxide (CO2) emissions are generated by the cement industry. Moreover, when natural aggregates are crushed and heated at elevated temperatures, greenhouse gases are released to the atmosphere creating environmental burdens. There is a necessity to build a bright and sustainable future. In order to gain an improvement in the sustainability of modern society, this research is aimed to examine the effectiveness of using green concrete. The main aim of this research is to identify how green concrete can help towards promotion of sustainable built environment. The research is based on literature review and interviews of concrete professionals from the industry. Based on the results, it can be concluded that green concrete has the ability to minimise waste and encourage sustainability.

Keywords: Green concrete, Effectiveness, Sustainable built environment

1. INTRODUCTION

Concrete has a global consumption rate of 25 gigatonnes per year and it is the most widely used building material used in construction today. About 10% of carbon dioxide (CO2) emissions are generated from concrete production and transportation. Different kinds of strategies are being implemented to improve sustainability of concrete [1]. One of the strategies include incorporating recycled materials in concrete. Another important goal is to reduce CO2 emissions by reducing the Portland cement content. This can be achieved by partially replacing Portland cement with cementitious by-product materials. Lastly, reduce long-term resource consumption, and select low impact construction methods [1,2]. If either of the above strategies are instigated, a 'green concrete' would be accomplished.

Construction and Demolition (C&D) waste, which originates from demolition of existing structures, is creating environmental problems globally [3]. C&D waste is usually disposed of into landfill. When this action takes place, it occupies land space and creates environmental burdens such as global warming. Preventive measures need to be taken to ensure that no harm continues to affect the environment [3,4,5].

Large volumes of industrial waste materials such as fly ash (FA), slag, silica fume (SF), glass powder are creating environment burdensome [6]. Current statistics suggest that about one billion tonne of FA waste and about 270-320 million tonnes of slag are produced worldwide annually [7]. These by-products contain significant levels of leachable toxic elements which create serious ecological problems for air, water and soil. Thus, there is a need to reduce the disposal of these by-products into landfill in order to protect the environment from the harmful emissions caused by these by-products [7].

About 1.5 billion tyres are manufactured globally. In addition, more than 50% of these tyres are disposed to landfills. It has been predicted that more than 1200 million tyres will be sent to landfills by 2030. There is a need to find alternatives on how to prevent these waste tyres from getting disposed to landfills. If this action is not performed, the landfills globally will be occupied with numerous amounts of toxic waste tyres [8].

One of the possible solutions to prevent these waste from getting disposed into the landfill is by producing a 'green concrete'. Green concrete is defined as an environmentally friendly concrete that uses waste material as one of its components in concrete mix. In other words, concrete that comprises of either by-product waste or C&D waste or a combination of both can be defined as green concrete [2].

The main objective of accomplishing a green concrete is to reduce the greenhouse gas emissions such as CO2 that generate from the production of cement. This can be achieved by replacing cement contents with industrial by-product contents. The other goal of accomplishing a green concrete is to reduce the use of natural resources such as limestone, clay, natural river sand and natural rocks. If these objectives are achieved, the end result would be a sustainable concrete that is produced with less carbon emissions [2,9].

Various tests have been carried out on the compressive strength of green concrete. Some sources suggested improvements in concrete's compressive strength [6,10,11,12,13]. However, others designated no enhancements in concrete's compressive strength [4,7,14,15,16]. There is a need to perform a research on the compressive strength properties of green concrete and validate the results in an analytical way to show that green concrete has superior properties.

2. RESEARCH OBJECTIVES AND QUESTIONS

2.1 Research Objectives

The main purpose of this research is to investigate the effectiveness of using green concrete towards promotion of sustainable built environment. The objectives can be defined as followed:

- Examine the alternative techniques to reduce consumption of natural aggregates, sand and cement.
- Investigate the compressive strength properties of concrete made out with FA, slag, SF, glass, rubber and RA and compare its performanceto ordinary concrete.
- Determine the benefits of using green concrete.
- Identify the applications of green concrete.

2.2 Research Questions

The main research question is defined as follows: How can green concrete help towards promotion of sustainable built environment?

In order to get an answer to this research question, it is necessary to get answers to the following questions:

1. What are the alternative techniques of reducing consumption of natural aggregates, sand and cement?

2. How do fly ash, slag, silica fume, glass, rubber and RA improve properties of concrete?

3. What are the benefits and applications of green concrete?

3. LITERATURE REVIEW

3.1 Fly Ash Concrete

An experimental investigation was undertaken specifically concentrating on the mechanical and durability properties of polymer concrete. Recycled glass sand, fly ash (FA) and metakaolin (MK) were used as fine aggregates in the concrete mix design. Five concrete mixes were prepared from which one was the control mix (Had no FA or MK content). The mixes were cast into moulds from which specimens in form of cylinders and prisms were prepared. These specimens were then tested to evaluate the performance of polymer concrete [10]. The test results are presented in Figure 1.

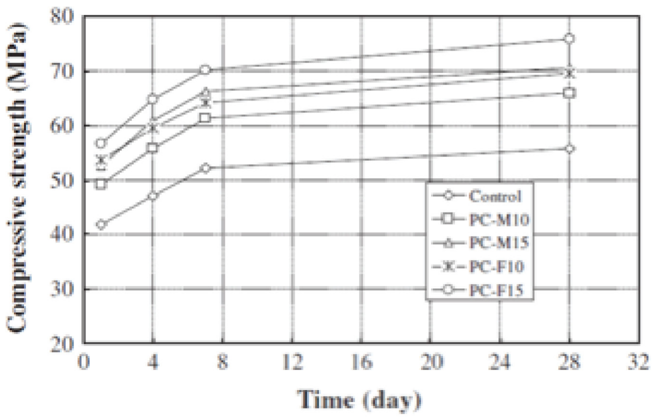

Figure 1: Development of Compressive Strength of Recycled Glass Waste Polymer Concrete Made With MK and FA (Source: Kou & Poon, 2013)

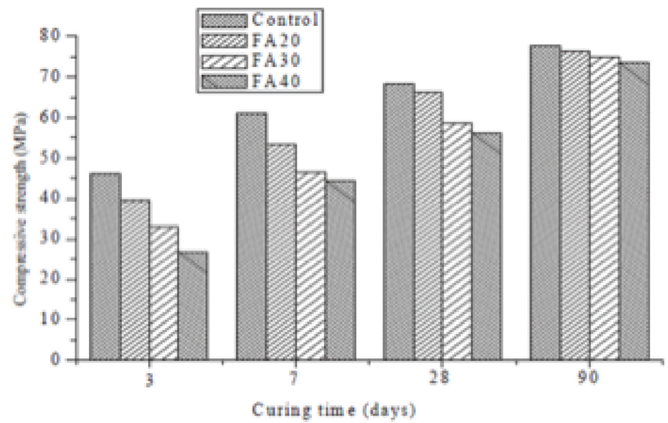

Figure 2: The Compressive Strength Development of the SCC with FA (Source: Zhao et al., 2015)

From the graph, M stands for metakaolin and F stands for fly ash whereas, the numbers designated the percentages of materials added to the mixture. It could be perceived that MK and FA mixes exhibited higher compressive strengths compared to the control mixes. After 28 days, the strength started to increase significantly. Mixes containing 15% FA attained the highest compressive strength after 28 days [10].

Other tests were also performed apart from the compressive strength test. Test results suggested that polymer concrete had good mechanical integrity and enhanced chemical characterization. FA and MK helped to improve the elasticity of polymer concrete. In addition, polymer concrete comprising MK, FA and recycled glass had good strength properties that could be used in a number of structural applications [10].

Another experimental investigation was carried out to study the properties of self-compacting concrete (SCC) comprising FA and ground granulated blast furnace slag (GGBFS) admixtures. Portland cement was replaced with FA and GGBFS by rates of 20%, 30% and 40%. One control mix mixture, three FA mixtures and three GGBFS mixtures were prepared [11]. The results are presented in Figure 2.

From Figure 2, it could be seen that the compressive strength of FA mixes were slightly lower than the control mixes. After three days, the strength of 20% FA dropped by 5MPa. However, after 90 days the strength of all mixes was almost the same as the control mix [11].

3.2 Silica Fume Concrete

A laboratory investigation was performed to examine the properties of concrete comprising FA and SF. Cement was substituted with SF at portions ranging between 0-10%. Mixtures comprising both FA and SF were found to be effective in improving the strength properties of concrete. In addition, chloride resistance of concrete was also improved [17,18].

Similarly there was another investigation performed towards the behaviour of concrete containing ordinary Portland cement (PC), SF and FA. Cement was replaced with various SF and FA contents. Nine different concrete mixtures were made. One mixture had no SF or FA content whereas, the remaining mixtures had either SF or FA content or a combination of both. It was found that mixtures containing FA, SF and PC exhibited better results in comparison to plain PC concrete. Moreover, SF improved early age performance of concrete whereas, FA helped to cultivate properties of hardened concrete.

Mixes containing 5-10% SF and 15-25% FA exhibited adequate performance in both fresh and hardened concrete. The best mix in terms of compressive strength, tensile strength and elastic modulus was the mix containing 10% SF [12].

An experimental research was performed to study the effects of SF on mechanical and physical properties of recycled aggregate (RA) concrete. Portland cement was replaced with SF by rates of 0%, 5% and 10%. Moreover, RA were replaced with natural aggregates (NA). The compressive strength results suggested that SF recycled aggregate concrete experienced reductions in early age compressive strength. However, after 28 days the strength of these mixes increased when compared to the control mix. Concrete mixes comprising 10% SF exhibited better performances in terms of mechanical and physical properties [4].

3.3 Slag Modified Concrete

The relationship between mixing proportion parameters of self-compacting concrete (SCC) were examined in a further research. In that same research, the environmental impacts of SCC were also examined. Sixteen portions of SCC mixtures incorporating various by-products such as FA, slag and metakaolin were created. The test results suggested that the addition of by-products reduced CO2 emissions. Furthermore, adding three mineral mixtures into SCC was more operative in reducing the environmental impact compared to the addition of single or two mineral admixtures. Therefore, addition of by-products such FA, slag and metakaolin not only reduced CO2 emissions but also reduced environmental impacts [1].

Laboratory study was performed to study the effects of concrete containing a combination of high volume fly ash (HVFA) and slag. Four different mixtures with various contents of HVFA and slag were prepared. After the mixes were prepared, specimens were constructed and tested. The test results suggested that the compressive strength of HVFA concrete was lower than PC concrete. Moreover, addition of slag to the concrete mix, further reduced the strength. However, HVFA concrete displayed better fire performance compared to PC concrete. It was recommended not to mix slag with FA as it reduced the strength of concrete [7].

In another research, durability characteristics and mechanical properties of concrete containing solid waste materials were examined. Sand was replaced with copper slag (CS) by rates ranging between 0-50%. Coarse aggregates

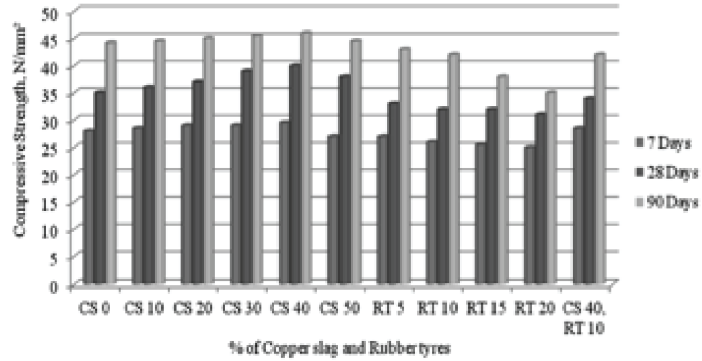

Figure 3: Compressive strength of cubes for 7, 28 and 90 days. (Source: Thomas & Gupta, 2013)

were substituted with rubber tyre (RT) at amounts between 0-20%. Thereafter, specimens in the form of cubes of size 150 by 150 by 150 mm were constructed and tested [14]. The test results are displayed in the figure below.

The test results suggested an overall improvement in the compressive and flexural strength of concrete when CS was cooperated in the mix design. It could be seen from Figure 3 that the compressive strength of CS mixes were either similar or slightly higher than those of the control mix (CS 0). However, there was a 5% reduction in strength when RT was cooperated in the mix. Concrete mix comprising 40% CS and 10% RT experienced better strength properties. This kind of mix was recommended for pavements and, structural and non-structural works [14].

3.4 Recycled Aggregate Concrete

A study was performed to examine the properties of self-compacting concrete using RA. NA were replaced with RA by rates of 10%, 20%, 30% and 40%. Six different mixes were prepared. Thereafter, specimens were created and tested. Test results suggested that an increase in RA content lead to a reduction in compressive strength, flexural strength and split tensile strength. Moreover, the properties of concrete in terms of strength were not improving when RA were used in the mix. Additionally, 30% replacement of RA helped to achieve the required compressive strength [15].

Laboratory investigation was performed to evaluate the mechanical properties of concrete comprising RA. A total of 12 mixes were prepared where NA were substituted with RA by rates of 20%, 50% and 100%. It was discovered from the test results that the mechanical properties of concrete were improved. Moreover, the compressive strength increased by 14% whereas modulus of elasticity raised up to 22%. RA proved to be a feasible alternative solution for the production of sustainable structural lightweight concrete [19].
A life cycle assessment (LCA) of recycled and conventional concrete for structural applications was performed in a research. The research, analysed the life cycle impacts of 12 recycled concrete (RC) mixtures. It was found that RC reduced the environmental impacts up to 70%. It was suggested that C&D waste re-use had potentials to conserve natural resources and limit waste streams to landfills [20].

Another research carried out towards the combination of RA and SF in concrete. The mechanical and physical properties of recycled aggregate concrete (RAC) with and without SF were examined. NA were replaced with RA. Three sets of mixes were prepared. In the first set there was no SF content. In the second set, 5% cement was replaced by SF whereas in the third set, 10% cement was substituted by SF. The test results designated that the compressive strength of RAC was found to be reducing. However, the addition of SF increased the compressive strength of RAC. It was concluded that 5% SF would help improve the properties of RAC [16].

3.5 Glass Modified Concrete

There was a research performed towards glass waste in the production of cement and concrete. In this research, the performance and durability of glass modified concrete was reviewed. The findings suggested that glass waste could offer an environmentally friendly solution. In addition, the research suggested that the particle size of glass played a vital role to the performance of concrete. The percentage of glass replacement also played an important role to the performance of concrete. It was concluded that waste glass helped to achieve an environmentally friendly concrete [21].

A laboratory investigation was performed by towards macro and micro properties of concrete containing liquid crystal glass (LCD) glass. Cement was replaced with waste LCD by rates of 10%, 20%, 30%, 40% and 50%. In addition, natural sand was replaced with glass sand by rates of 10%, 20% and 30%. Various tests were performed to evaluate the performance of LCD glass. The test results suggested that addition of glass sand enhanced the compressive strength. Moreover, glass sand provided higher resistance and it improved properties of concrete with age. By utilising glass in concrete, usage of cement and sand could be minimised which could help preserve the natural resources and reduce carbon emissions [13].

3.6 Rubber Modified Concrete

In one research, the properties of concrete tactile blocks prepared with recycled tire rubber were studied. Sand was replaced with waste tire rubber by proportions of 10%, 20%, 30%, 40% and 50%. Six concrete mix designs were prepared, out of which one was the control mix. From each concrete mix, three specimens of sizes 150 by 150 by 500mm were prepared for flexural and compressive strength test. The test results revealed that rubber modified concrete obtained the same consistency as the control mix. The highest compressive strength was achieved when 10% rubber was cooperated in the mix design (see Figure 4). This strength was also found to be higher than the control mix. It was concluded that 10% recycled tire mix could be used to make tactile paving blocks [22].

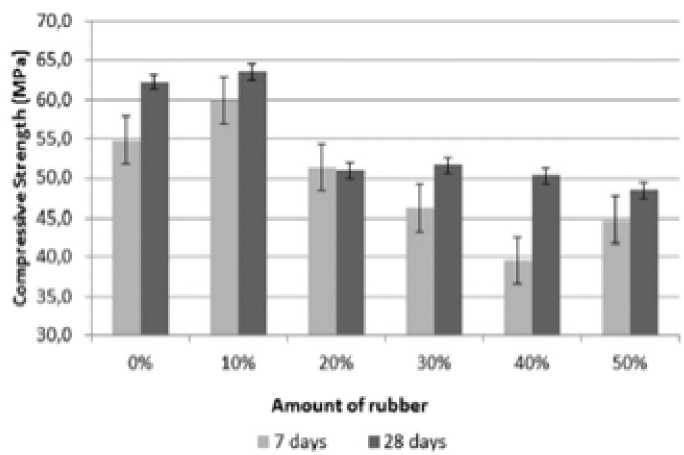

Figure 4: Compressive Strength of Rubber Mixes.
(Source: Silva et al., 2015)

A quantitative research was performed towards the applications of waste tire rubber in asphalt and Portland cement. The research revealed that waste tire rubber applications in asphalt were proven to be successful over the past decades. In addition, waste tire rubber in asphalt improved three major modes of asphalt pavement distress which were rutting, fatigue cracking and low-temperature cracking. However, the application of waste tire rubber in Portland cement concrete (PCC) had not been successful because of incompatibility issues caused by chemical composition and stiffness. It was concluded that waste tire rubber performed well in asphalt mixtures and performed poorly in PCC [23].

4. METHODOLOGY

4.1 Methodology Selection

A qualitative case study analysis approach has been selected for this research project where interviews will be conducted with key participants. The key participants are individuals who are experts in the concrete field. The reason behind the selection of this approach was that all answers to the research questions could be answered from a small group of people within a short time frame. Whereas, if a quantitative research was performed it would have involved accessing more people and it would have taken longer to gather answers to the research questions.

4.2 Methodology Outline

Figure 5 summarises the methodology outline. In order to answer the main research question (RQ), it was necessary to get answers to RQ1, RQ2 and RQ3. The questions for the interviewee were developed in a way that they could provide answers to each RQ. The reason behind developing open-ended questions was to gather additional information in context to the research topic. This could help provide a broader answer to a particular question.

After preparing the open-ended questions, interviews would be conducted with different people who were experts in the concrete field. After the conducting the interview, the interview would be transcribed. Data would be collected from the transcription which would help perform the analysis

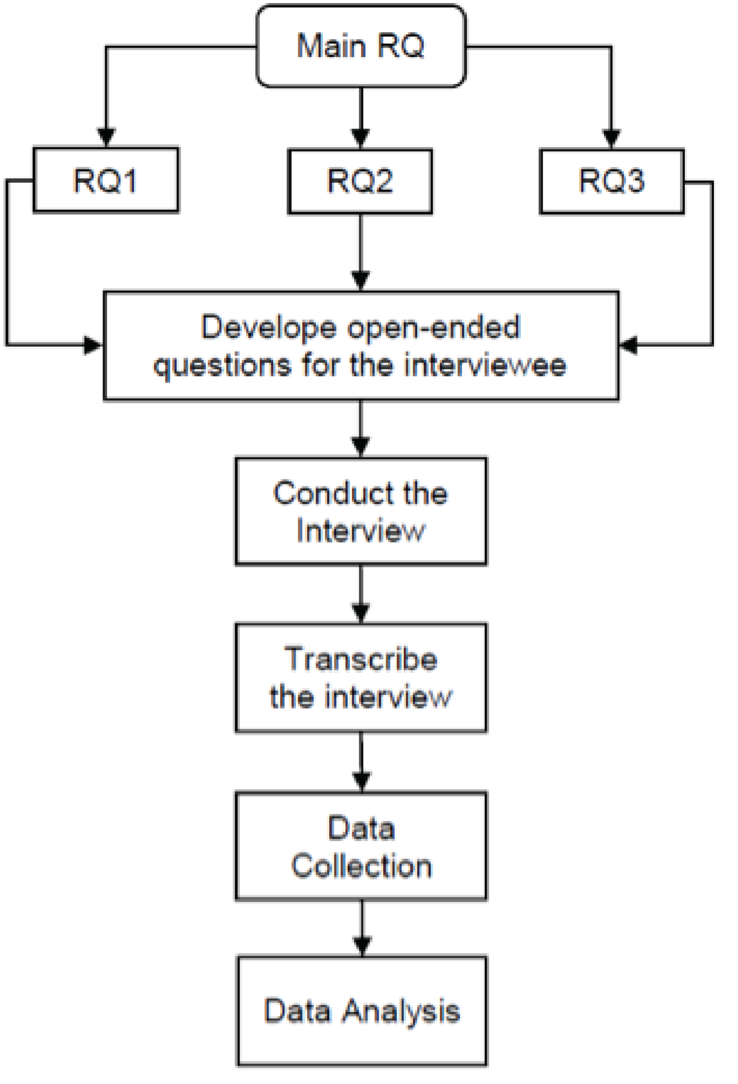

Figure 5: Methodology Outline

5. RESULTS AND ANALYSIS

Five interviews have been conducted with concrete professionals and the responses are based on professional experience. All names of the interviewees will be kept confidential. A code has been assigned for each participant in order to protect confidential information.

5.1 Participant Summary

The interviews were carried out among various concrete professionals around the Australasia region. Since all participants came from various concrete backgrounds, it was assumed that the information that was conversed would be beneficial to answer the research question. Table 1 summarises the participant's summary.

Table 1: Participant Summary

Code	Occupation	Interview Type	Company Specialization	Company Location
T1	Civil Engineer	Telephone	Building/ Construction	Perth, Australia
T2	Civil Engineer	Telephone	Building/ Construction	Perth, Australia
F1	Group General Manager	Face-to-face	Concrete Supply	Auckland, New Zealand
F2	Service Manager	Face-to-face	Concrete Supply	Auckland, New Zealand
F3	Concrete Plant Engineer	Face-to-face	Concrete Supply	Auckland, New Zealand

5.2 Results

• Reducing consumption of cement, sand and NA

Almost all participants suggested fly ash (FA) as a replacement of cement. Other names that were declared for cement substitutes included silica fume (SF), micro silica, ground granulated blast furnace slag (GGBFS), rice husk. It was quite interesting to know that there were some new names mentioned like micro silica and rice husk that could be used as cement substitutes.

Examples for recommended sand replacements were quarry dust, manufactured sands (crush dust) and fine glass. Manufactured sand was the left over dust that was collected when aggregates were crushed.
Substitutes for natural aggregates (NA) mentioned by the participants comprised of C&D waste (RA), rubber, tyres and glass.

• Properties of green concrete
• FA, SF and slag modified concrete

One of the participant's response on how FA, SF and slag improve the properties of concrete was as follows, "The fine particles of these products tends to fill in the voids that exists between the aggregates and the cement matrix. Technically, when these products react with cement and water they form additional calcium silicate gel that tends to densify the pores structure thereby retarding the movement of water thus improving both the mechanical and durability properties of concrete." (T1). FA, SF and slag improved the mechanical and durability properties of concrete according to this participant's experience.

Similarly another respondent suggested FA reacts with the calcium hydroxide to form calcium silica hydrate. FA densifies the concrete making it more water proof and dense. Since FA concrete is less permeable, it makes the concrete more durable. The same respondent suggested that strength performance higher than cement can be achieved when using SF and slag.

One of the participants did his research project towards green concrete. He substituted cement with 10% SF and 30% FA. He proposed that when FA was cooperated in the mix design, after 28 days it would have a strength which would be about 20% lower compared to the control mix. However, as days passed by, FA mix would start to gain strength. In addition to this, the participant mentioned, "The good thing about fly ash is that it decreases water absorption and sorptivity of concrete." (T2). For SF, the participant proclaimed that by adding 10% SF in place of cement, the sorptivity and water absorption would reduce by 50%.

There was another participant who stated that FA, SF and slag were finer than cement which help to improve the durability properties of concrete. Moreover, concrete prepared from these by-product waste tends to be acid resistance.

• Glass modified concrete

Out of the five respondents, two respondents had no experience with glass modified concrete. However, one of the respondent's explanation was as follows, "I support glass. The only thing with glass is that we have to watch ASR. As a coarse material, I think it's less risk as fine material there is a risk of ASR." (F1). Alkali silica reaction is what ASR stands for. During ASR, cement reacts with glass and forms a gel that blows the concrete apart. If coarse glass is used, then there are less chances of ASR occurrence. The respondent suggested to use 10% coarse glass as aggregate replacement. Similarly another respondent suggested to use the same content. The respondent mentioned that if more than 10% glass content was used, the strength of concrete would start to reduce.

According to another respondent's opinion, the source of glass played a vital role in the design mix of concrete. The respondent suggested that the glass had to be clean and should not contain any alkaline fluids. Moreover, it was suggested to be used as an aggregate replacement no more than 10%.

• Rubber modified concrete

For rubber modified concrete only two respondents shared their views whereas the remaining respondents did not have experience with rubber.

This is what one of the respondents mentioned, "They can act as fibres. Will give not a compressive but tensile strength. But again it depends on the dosage. You cannot use on a higher dosage because it will reduce the strength. To increase the strength, you will put more cement so it's not environmentally friendly." (F3)

The other respondent clarified rubber modified concrete as follows, "With rubber, it would give an increase in tensile strength because of the rubbery reaction. The other thing is that rubber will also reduce the water absorption and sorptivity because rubber will never absorb water so it would always have a reduction in sorptivity and water absorption." (T2).

Both respondents suggested that rubber would increase concrete's tensile strength. However, a higher percentage of rubber would not be recommended as it would reduce the compressive strength.

• RA modified concrete

All participants agreed with the fact of replacing NA with RA. In addition, they all clarified that RA could not be fully replaced with NA as it would affect the performance of concrete. One of the participants suggested replacing 60% RA with NA. Other two participants recommended using up to 50% replacement. The strength achieved with these replacements was greater than 40 MPa which would be beneficial for structural applications according to one respondent.

Two respondents suggested that the grading of RA needs to be controlled. If the RA had a controlled grading, then only it could be used.

• Benefits and Applications of green concrete

The benefits that the participants mentioned towards green concrete were as follows:

- Cost effective and environmentally friendly
- Reduces mining of river sand
- Reduces carbon emissions generated from manufacturing cement and crushing aggregates
- Helps to conserves natural resources
- Helps to reduces landfill.

There were a variety of green concrete applications mentioned by participants. These were kerbing, paving, slabs, floors, driveways, footpaths, footings, any kind of landscaping, pier foundations of a bridge and general construction.

5.3 Discussion

This section of the paper discusses the findings in relation to the literature review. It helps to assess the answers to the three sub questions. This would allow to form an answer to the main research question.

• Reducing consumption of cement, sand and NA

Based on the results, cement can be substituted with by-products such as FA, SF, micro silica, rice husk and GGBFS. These results correlate with the findings obtained from the literature. It was quite interesting to know that there were other cement substitutes such as micro silica and rice husk that had not discovered in the literature.

Sand replacements discovered in the literature included; polyethylene terephthalate (PET), recycled glass sand, stainless steel oxidizing slag (SSOS), copper slag (CS), fine glass and fine rubber. However, based upon the interview responses, quarry dust, manufactured sands (crush dust) and fine glass could be used as sand replacements. The only common sand replacement between the findings and the results was fine glass.

Coarse rubber, RA, oil palm shells, limestone and coarse glass were all aggregate replacements mentioned in the literature. The interview responses showed similar results. However limestone and oil palm shells were not mentioned by the interviewees.

• Properties of green concrete
• FA, SF and slag modified concrete

In terms of the mechanical properties, one respondent stated that FA, SF and slag improve the compressive strength properties of concrete. Compressive strength is an example of a mechanical property. This statement was also supported from the literature by authors like [10,11]. They all suggested FA mixes improved the compressive strength properties of concrete.

There was another respondent who mentioned that the compressive strength can be achieved depending on the type of FA used. Different FA exhibit different properties. For example class-F FA can attain a higher compressive strength compared to class-C FA.

Almost all participants suggested that FA, SF and slag improve the durability properties of concrete. One of the respondent mentioned that FA reacts with the calcium hydroxide to form calcium silica hydrate. FA densifies the concrete making it more water proof and denser. Since FA concrete is less permeable, it makes the concrete more durable. This kind of mixes could improve the durability properties.

There was another participant who stated that FA, SF and slag tend to be finer than cement which help to improve the durability properties of concrete. Moreover, concrete prepared from these by-product waste tends to be acid resistance. This information correlates with [9,10,14] who also suggest that FA, SF and slag improve the durability properties of concrete.

One of the participants stated that FA and SF decreases water absorption and sorptivity of concrete. For SF, the participant affirmed that by adding 10% SF in place of cement, the sorptivity and water absorption would reduce by 50%. This meant that these kind of mixes would require less amounts of water. This would be beneficial as it would help reduce water content which is a natural resource. This property of sorptivity and water absorption was also supported by [9].

• Glass modified concrete

There was one respondent who revealed interesting information about the alkali silica reaction (ASR) properties. The respondent suggested to using coarser glass in order to avoid ASR. Moreover, the respondent also suggested to use 10% coarse glass as an aggregate replacement. Similarly another respondent suggested to use the same content. The same respondent mentioned that if more than 10% of glass was used, the strength would start to reduce. This idea was also in support of [21] who suggested 10% as the optimum level of glass replacement.

The source of glass played a vital role according to another respondents view. The respondent suggested that the glass had to be clean and should not contain any kind of alkaline substance.

• Rubber modified concrete

For rubber modified concrete only two respondents proposed that rubber would increase concrete's tensile strength. However, a higher percentage of rubber would not be recommended as it would reduce the compressive strength. This information correlates with [22]. They found that 10% was the optimum rubber replacement ratio. If the replacement ratio surpassed 10%, the compressive strength would start to reduce [22].

• RA modified concrete

The participants suggested replacing 50-60% RA with NA. The strength achieved with these replacements was greater than 40 MPa which was beneficial for structural applications. However, research performed by [15] indicated that replacement up to 30% could help to achieve the required compressive strength properties.

• Benefits and Applications of green concrete

Findings from the literature and the respondents' response had similar benefits of green concrete. There was one respondent who mentioned that recycling process of aggregates is costly and generates carbon emissions. However, another respondent suggested that recycling process of aggregates was cheaper compared to the mining process of natural aggregates.

The participants suggested that green concrete could be used in a wide range of applications. It could be used for structural applications and non-structural applications. Examples of structural applications of green concrete were as slabs, floors, footings, pier foundations of a bridge and general construction. Whereas, the non-structural applications comprised of kerbs, pavements, driveways, footpaths and any kind of landscaping. From the literature review, if concrete's compressive strength showed improvement, it would be used for structural applications. However, if there was no improvement in terms of strength, it could be used for non-structural applications.

6. CONCLUSION

From the results accomplished, the following conclusions have been made for this research project:

• The alternative techniques of reducing consumption of cement identified from the findings and literature were mainly by-product waste such as fly ash (FA), silica fume (SF), micro silica, rice husk and ground granulated blast furnace slag (GGBFS). Moreover, the replacements that were identified for sand were recycled glass sand, fine glass, manufactured sands (crush dust), quarry dust, stainless steel oxidizing slag (SSOS), copper slag (CS) and fine rubber. Furthermore, natural aggregates (NA) could be replaced using coarse rubber, recycled aggregates (RA), oil palm shells, limestone and coarse glass.

• It was important to note that the quantity of by-product or waste replacement played a vital role to the properties of concrete. In addition, the choice of by-product waste such as FA also played an important role to the hardened properties of concrete.

• Concrete containing by-product waste such as FA, SF and slag had improved mechanical and durability properties. In addition, sorptivity and water absorption rates for by-product waste concrete was found to be reducing which suggested that these kind of concrete required less water contents.

• There were a list of benefits mentioned in the literature and respondents. Green concrete was cost effective and environmentally friendly. It helped to reduce mining of river sand. Moreover, it helped to reduce carbon emissions that were generated from manufacturing cement and crushing of aggregates. It helped to conserve natural resources and reduces landfill space.

• Green concrete could be used in a wide range of applications. If concrete's compressive strength showed improvement, it would be used for structural applications. However, if there was no improvement in terms of strength, it could be used for non-structural applications.

Overall it can be concluded that green concrete help towards promotion of sustainable built environment. It helps minimise waste and encourage sustainability.

7. ACKNOWLEDGEMENTS

First and foremost, I tribute this research project to the almighty, Lord Shree Swaminarayan. The wisdom and perseverance that he has imparted upon myself throughout my life has been phenomenal and will always be invaluable.

I would like to extend my ultimate gratefulness to my project supervisor Dr. Ali Ghaffarian Hoseini. His keen interest, inspirational attitude and insight into the project have enabled me to successfully complete this project.

The support provided by the post graduate staff at AUT University is also valued. I would like to recognise the continuous help received from Kathryn Owler.

Lastly, I am thankful to my family. The continual encouragement that my parents provided throughout my life has been instrumental to my success in this research project.

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