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CHARACTERISTICS OF SUSTAINABLE CONCRETE USING CRUMB RUBBER INTEGRATED WITH CARBON NANOTUBES

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ABSTRACT

Modern civil infrastructures are constructed using concrete materials. Currently, cement and concrete production is at all-time high resulting in significant carbon dioxide emissions. In addition, concrete structures have low tensile strength and low ductility increasing the risk of failure. Therefore concrete is currently neither environmentally nor economically sustainable. This experimental investigation has been highly promising in identifying an alternative solution to solve the sustainability issue regarding concrete. Our critical literature showed that there have been successful in identifying the most optimum solution to solve the issue of carbon dioxide emissions related to concrete production but concrete structures still lacks of self-monitoring ability for failure or any changes in the structure. This paper will identify the factors that influence the self-monitoring ability as mainly the conductive filler, fabrication and dispersion, which are the critical parameters. Experimental study has been carried out to identify the most environmentally sustainable solution with a minimum of 40MPa strength; over 30 concrete mixtures were tested for compressive strength at 28 days. We found that the R7.5S60SF mix with CNT (Carbon nano tubes) has the self-monitoring ability and reduces carbon dioxide emissions by 140kg per meter cubed of concrete produced in comparison to a meter cubed of ordinary portland cement concrete.

Keywords: Sustainable concrete, Self-sensing material, Self-monitoring concrete, Innovative material, Carbon nanotube.

1. INTRODUCTION

The majority of civil infrastructure is constructed out of concrete, currently at a rate of 2 billion tonnes per year; this is responsible for 5% of global carbon dioxide emissions annually. Despite the high usage, concrete has several disadvantages such as low tensile strength, low ductility and high susceptibility to cracking. This causes the structure to deteriorate and lose its integrity when subjected to harsh environmental conditions or loading (Remennikov and Kaewunruen, 2008). Thus, when exposed to these conditions, concrete structures are at a risk of failure. The high global usage of concrete combined with the large amount of pollution produced every year is also a major concern. Therefore a sustainable approach needs to be taken to find solution to these existing issues in concrete production. The sustainable approach within this project involves developing a method to reduce carbon emissions and to improve the resilience of concrete structures. Numerous approaches have been taken for centuries to enhance the properties of concrete. Previously, there has been a breakthrough in concrete development by Chung (1998) introducing self-monitoring concrete. The self-monitoring ability implemented into concrete permits the assessment of safety and resilience of the structure throughout its service life - this ensures the structure remains serviceable (Kaewunruen et al., 2017). This self-monitoring ability is owed to conductive fillers, for example carbon nanotubes (CNT). Therefore, it would be of great advantage to identify a conductive filler that enhances the properties of concrete along with developing a concrete mix, which minimises environmental impact. An approach that can be taken is to minimise the use of cement, which is a significant contributor to carbon emissions during its manufacturing process. Hence, the aim of this study is to identify a concrete mixture, which is able to self-monitor as well as reduce carbon emissions.

The study comprises firstly of a literature review, which discusses existing concrete mixtures containing waste materials for the purposes of reducing carbon emissions and also outlining the significance of self-monitoring concrete and a superior conductive filler. The literature review is used to provide guidance to create a methodology, which in turn develops a series of concrete mixtures for strength testing at 28 days. This is to identify a superior mix which does not only reduce carbon emissions but also has significant compressive strength i.e. 40 MPa, which is the minimum required strength to be classified as high strength concrete (Gamage et al., 2017a; 2017b). Once a superior mix is identified, appropriate conductive filler will be added to this to implement the self-monitoring ability. This superior mix containing the conductive filler will be tested for numerous mechanical properties. The results obtained from these tests will be presented and compared to results obtained from a control mix. Once the results are obtained they will be critically analysed and will be compared against experimental results from existing literature. Finally, recommendations for application and improvement of the superior mix with conductive filer will be presented. The main aim of this research is to develop a concrete mixture, which reduces environmental impact and has self-monitoring ability.

2. LITERATURE REVIEW

Initially, a concrete mix that reduces carbon emissions in comparison to ordinary portland cement concrete (OPCC) is identified, thus creating a environmentally sustainable variant without deteriorating properties of OPCC significantly. The method to make such an environmentally sustainable concrete is to replace components of OPCC with waste materials in order to reduce carbon emissions. This approach is based on the assertion that primary materials of production are more greatly responsible for carbon emissions rather than waste materials of production. Also some of the waste materials are less carbon dioxide emission intensive in comparison to cement. Extensive research has already been carried out in making concrete environmentally sustainable. There are many alternative methods presented for substitution of cement and aggregates. The most common substitutes for cement are ground granulated blast-furnace slag (GGBS), silica fume and fly ash, and for aggregate are glass and rubber.

2.1. Tyre Rubber

The UK generates around 55 million waste tyres annually that are not recycled, as shown in Fig. 1 (Government UK, 2016). Instead of sending the waste to landfill, the tyres can be processed by mechanical means and converted to crumb rubber. This can be used to replace proportions of fine aggregate in concrete mixtures. Tyres are an environmental hazard; they are an ecological threat that can cause a reduction in biodiversity, as they are known to leachate into water and affect the aquatic life forms. This problem can be addressed by recycling tyre rubber into concrete, where it will remain inert and cause no harm to ecosystems. It is a step towards making the UK and the world more sustainable.

Fig.1. Waste Tyres

2.2. Combination of GGBS, Rubber Tyres, Silica Fume and other substitutes

Gupta et al. (2012) carried out an experimental study and found that replacing cement with 50% copper slag and fine aggregate with 10% tyre rubber by volume gives a compressive strength of 30MPa. The study shows the feasibility of slag and tyre concrete mix to be used as structural concrete. However the study uses copper slag but this research study focuses on GGBS, therefore it is not a reliable study to accurately estimate the effects of GGBS, as they are two different materials. Therefore this study will initially focus on creating a mixture, which replaces significant proportion of cement with GGBS, fine aggregate with rubber and has a minimum compressive strength of 40MPa at 28 days. This will help achieve environmental sustainability in term of concrete production. Economical sustainability can be achieved by ensuring the structure lasts for a long period, this is ensured via an effective monitoring, i.e. incorporating self-monitoring ability.

2.3. Self-sensing Concrete

In the past two decades there has been considerable progression in the development of self-monitoring concrete. Initial studies showed that a self-monitoring cement composite has the ability to sense any applied strain and damage. The conclusions made by Chung (2008) over 20 years ago are valid and true as they are the fundamental principles of the self- monitoring ability. Recently there has been advancement in research and now the self-monitoring ability is not only limited to sensing strain, but also stress, cracks and dynamic loading. OPCC does not have the ability to conduct electricity; however adding conductive fillers, such as carbon fibre allows electrical conduction thus providing the ability to self-monitor. Electricity is conducted through the conductive filler concrete composite via electronic and/or hole conduction and ionic conduction, due to the cement concrete matrix. However there is no need for a large addition of conductive filler for the material to be conductive. For example, an experimental study concluded that the cement composite containing carbon fibre of only 0.2% showed the self-monitoring ability - this is below the percolation threshold of 1%, so there is no need for fibres to be touching. Intuitively, it may be considered a full continuous circuit without any breaks is required to conduct electricity; therefore percolation threshold guarantees a complete chain in the material. However, an experimental study by Chung (2008) showed that a full circuit does not need to be present for electrical conduction to take place.

Table 1 Properties of fibrous materials.

Fibre Material	Specific Density	E (TPa)	Strength (GPa)	Ultimate Strain (%)
Carbon Nanotube	1.3-2.0	1.0	10-60	10
HS Steel	7.8	0.2	4.1	<10
Carbon Fibre – PAN	1.7-2.0	0.2-0.6	1.7-5	0.3-2.4
Carbon Fibre – Pitch	2-3.2	0.4-0.96	2.2	0.27-0.60
E/S – glass	2.5	0.07	2.4	4.8
Kevlar 49	1.4	0.13	3.6-5.1	2.8

There are a number of functional fillers, which can be used to give concrete the self-monitoring capability such as carbon fibre, CNT, steel fibre, carbon black and steel slag. For superior sensing ability, cement composite can be made up of two or more fillers (Han et al., 2009). The self-monitoring ability is beneficial for maintenance and identifying the serviceable life of a concrete structure. This is due to the change in electrical properties of a material, when there is a change in properties of the conductive concrete composite such as strain and stress. Table 1 summarises the properties of a few fibrous materials, which can improve properties of concrete. It can be clearly seen that CNT is a superior material in comparison to other materials such as high strength steel, carbon fibre, glass and Kevlar. Carbon fibre and CNT are comparable due to their similar chemical composition. Experiments show CNTs have a higher thermal conductivity (>3000 W/m.K) in comparison to carbon fibre (1000 W/m.K) and copper (400 W/m.K). When electricity is conducted through the CNT cement composite, the CNT will be able to dissipate the generated heat quickly. If heat is allowed to build up, it can have a negative effect on the concrete, for example causing expansion, resulting in cracks. The low electrical conductivity compared to copper and carbon fibre is beneficial (Meesit et al., 2017; Kaewunruen et al., 2017a; 2017b). A highly conductive material can cause the material to have extremely low resistivity, resulting in a considerably small change in resistance, making it extremely difficult to detect any change in strain.

3. MIX DESIGN OF CONCRETE

The design of concrete mixtures is designed using the guidance provided in ‘Design of Normal Concrete Mixes’ (Teychenne et al., 1997). The control concrete mix, which is the standard OPCC mix with a target mean strength of 53 MPa at 28-days, is designed using this guidance. All mixtures are based on the reference concrete mix. 30 different sustainable mixtures are developed. Each mixture contains varying amounts of GGBS between 20 and 60%, rubber 5 to 10% and/or 10% silica fume. This study will mainly focus on the mixtures outlined in Table 2.

Table 2 Proportion of materials in each mix.

Mix	Units - kg/m^3								
	Cement	Water	Gravel	Sand	Rubber	Slag	Silica Fume	LASS	CNT
Control	530	233	986	630	-	-	-		
R7.5S60SF	159	233	986	583	47.25	318	53		
Control + CNT	530	233	986	608.8	-	-	-	10.6	10.6
R7.5S60SF + CNT	159	233	986	562	47.25	318	53	10.6	10.6

The whole process of mixing CNT is summarised in the Fig. 2. Once the CNT, dispersant and water mixture are created following Fig. 2, the CNT and dispersant are added in same manner.

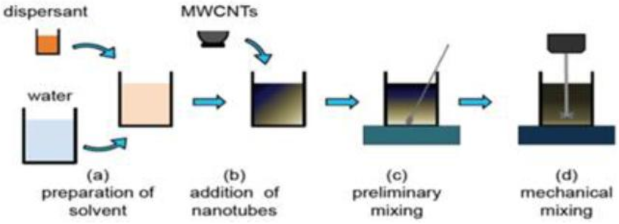

Fig.2. Mixing process

4. RESULTS AND DISCUSSION

Slump testing was carried out on all the samples mentioned in Table 2. All the concrete mixtures were observed by visual inspection to be cohesive with no presence of segregation or bleeding during the mixing, placing or compaction. Fig. 3 shows the slump values obtained from all the tested mixtures. The highest slump recorded was 105 of the control mix. The Control mix + CNT, R7.5S60SF, R7.5S60SF + CNT had slump values of 20% (21 mm), 35% (37 mm) and 49% (51 mm) lower than that of control mix. It is interpreted from these results that this reduction in slump is due to the components of the control mix being replaced; as the proportion of replaced component increases, the slump decreases. The control mix was designed with a slump of 60-180mm.

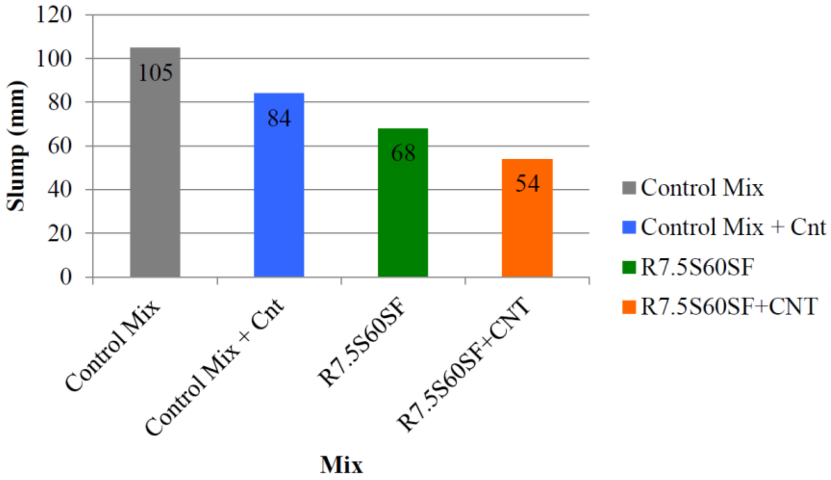

Fig.3. Slump of concrete mixes

The results obtained are in agreement with previous studies when CNT is added to the control mix. The mix having a slump of 84mm is not near the lower limit value of workability of 60mm; therefore it is easy to work with this mix. In terms of the R7.5S60SF mix, no previous study has investigated the workability of concrete containing GGBS, rubber and silica fume. However the components of the mix can be assessed individually to assess the effect on workability. Recent studies [10] on the effect of rubber on workability correlate with results obtained in Fig. 3 as they both show a reduction in slump in comparison to control mix. The reason for the result obtained in reduction of slump is due to the higher water absorption by the rubber particles in comparison to sand, these results in reduction in availability of free water, resulting in a more viscous mix.

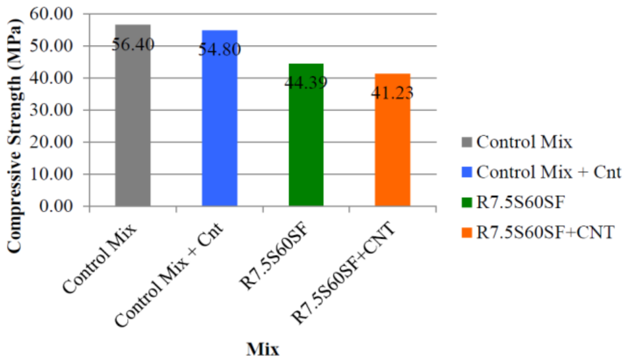

Fig.4. Compressive strengths of concrete mixes

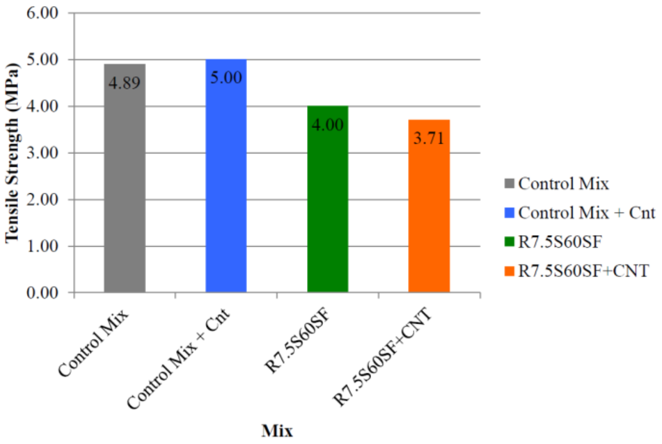

Fig.5. Flexural strengths of concrete mixes

The compressive strength testing was carried out on the mixtures mentioned in Table 2. All test specimens were surface dry before testing. The compressive strength results are outlined below in Fig. 4. The highest compressive strength value was obtained by the control mix with strength value of 56.40MPA. The control mix with CNT, R7.5S60SF and R7.5S60SF with CNT had compressive strength values of 2.8% (1.6 MPa), 21.3% (12 MPa) and 27% (MPa) lower than the control mix, respectively. Therefore it can be concluded that adding rubber and GGBS result in a reduction in strength. However, the use of silica fume can improve the lost performance of concrete, enabling the sustainable uses of crumb rubber from wasted tires and plastics.

Based on our experimental results, the flexural strength results obtained are inconclusive to comment on the effect of CNT on flexural strength. Electrical resistivity helps to assess the self-monitoring ability of the samples. The recording of electrical resistivity was carried out and processed on the control mix with CNT and the R7.5S60SF mix with CNT. The electrical resistivity measurement was only conducted on these materials as adding CNT provides electrical conductivity. The processed results are presented in Fig. 6.

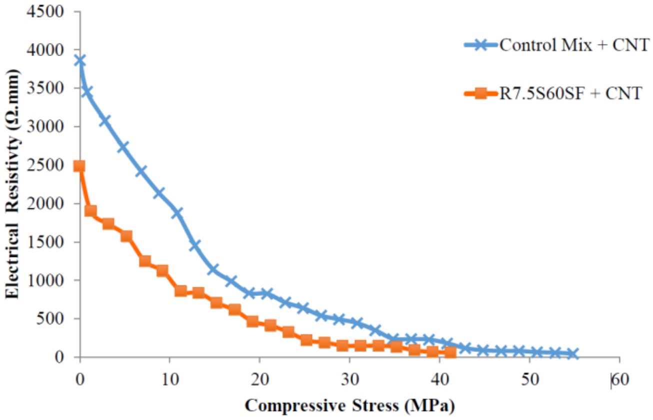

Fig.6. Change in electrical resistivity of concrete subjected to compression

Based on the obtained results, it is important to note that the electrical resistivity for both mixtures seems to plateau as it reaches the failure mode.

5. CONCLUSION

This experimental investigation has been highly promising in identifying a solution to solve the sustainability issue regarding concrete. The GGBS, rubber and slag mix reduces carbon dioxide emissions, making the concrete produced environmentally sustainable. The experimental study investigates the workability, compressive strength, flexural strength and electrical resistivity. The results exhibit that slag, rubber and silica fume can be added to a mix along with carbon nanotubes to create self-monitoring concrete as the electrical resistivity becomes more sensitive. Addition of slag and/or rubber reduces the strength, however such lost performance can be improved by silica fume, enabling potential use of crumb rubbers and reducing wastes in environment.

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7. REFERENCES

Chung, D. (1998). Self-monitoring structural materials. Materials Science and Engineering: R: Reports, 22(2), 57-78.

Gamage, E.K.; Kaewunruen, S.; Remennikov, A.M.; Ishida, T. (2017a) Toughness of Railroad Concrete Crossties with Holes and Web Openings. Infrastructures, 2, 3. doi:10.3390/infrastructures2010003

Gamage, E.K.; Kaewunruen, S.; Remennikov, A.M.; Ishida, T. (2017b) Reply to Comment on Toughness of Railroad Concrete Crossties with Holes and Web Openings. Infrastructures, 2, 5. doi:10.3390/infrastructures2010005

Gov.uk. (2016). 2010 to 2015 government policy: waste and recycling - GOV.UK. [online] Available at: https://www.gov.uk/government/publications/2010-to-2015-government-policy-waste-and-recycling/2010-to-2015-government-policy-waste-and-recycling [Accessed 30 Apr. 2016].

Gupta, R., Thomas, B. and Gupta, P. (2012). Utilization of copper slag and discarded rubber tyres in construction. Int J OF Civil & Structural Engineering, 3(2), 271-281

Han, B., Yu, X. and Kwon, E. (2009). A self-sensing carbon nanotube/cement composite for traffic monitoring. Nanotechnology, 20(44), 445501

Kaewunruen, S., Meesit, R., (2016), Sensitivity of crumb rubber particle sizes on electrical resistance of rubberised concrete, Cogent Engineering, 3(1): 1126937. doi: 10.1080/23311916.2015.1126937

Kaewunruen S, Sussman JM and Matsumoto A., 2016, Grand Challenges in Transportation and Transit Systems. Front. Built Environ. 2:4. doi: 10.3389/fbuil.2016.00004

Kaewunruen, S, Singh, M, Akono, A-T & Ishida, T. (2017a), Sustainable and self-sensing concrete. in Proceedings of the 12th Annual Concrete Conference., MAT31, Cha Am, Thailand , pp. 1-10.

Kaewunruen, S., Meesit, R., Mondal, P., (2017b), Early-age dynamic moduli of crumbed rubber concrete for compliant railway structures, Journal of Sustainable Cement-Based Materials, in press

Meesit, R., Kaewunruen, S., Mondal, P., (2015) Dynamic properties of early-age micro-and nano-engineered concrete for compliant railway structures, RILEM International Conference on Strategies for Sustainable Concrete, Rio de Janeiro, Brazil, December 14-16.

Meesit, R., Kaewunruen, S., (2017), Vibration characteristics of micro-engineered crumb rubber concrete for railway sleeper applications, Journal of Advanced Concrete Technology 15 (2), 55-66.

Remennikov, A.M. and Kaewunruen, S., (2008) "A review on loading conditions for railway track structures due to wheel and rail vertical interactions," Progress in Structural Engineering and Materials, incorporated in Structural Control and Health Monitoring, 15 (2), 207-234.

Teychenné, D., Franklin, R., Erntroy H., (1997), Design of normal concrete mixes. 2nd ed. London: H.M.S.O. Building Research Establishment, Transport and Road Research Laboratory, London, UK.