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Sensitivity of crumb rubber particle sizes on electrical resistance of rubberised concrete

Sakdirat Kaewunruen^{1*} and Rattaphong Meesit¹

Abstract: Railway track components often suffer from high aggressive loading and vibrating conditions of railway environment, causing high maintenance costs due to impact damage, rail seat abrasion and excessive noise and vibration to surrounding equipment. Thus, it is essential to have novel improvement of material capabilities in order to solve or reduce these problems. A nanoengineered improvement method for concrete material using crumb rubber has been recently introduced to railway applications. However, for modern electrified railway tracks, structural materials will need to provide electrical and signal insulation for effective operations of track circuits and electrification. This paper firstly highlights the importance of the particle sizes of crumb rubbers on the electrical resistivity of the concrete modified by crumbed rubbers. It shows that microscale crumb rubbers induce lesser electrical conduction capacity than nanoscale crumb rubber.

Subjects: Built Environment; Civil, Environmental and Geotechnical Engineering; Materials Science

Keywords: crumb rubber; concrete; electrical resistance; sensitivity; particle size; engineered concrete; railway track; insulation

ABOUT THE AUTHORS

Sakdirat Kaewunruen is Senior Lecturer in Railway and Civil Engineering with over 220 technical publications, and Rattaphong Meesit is formerly a graduate student at The University of Birmingham. The University of Birmingham is host to the world-leading Birmingham Centre for Railway Research and Education (BCRRE), a multi-disciplinary group of staff from the Schools of Civil Engineering, Electronic, Electrical & Systems Engineering, Mechanical Engineering and Materials & Metallurgy. This study is part of a collaborative research project between the University of Birmingham (UoB) and The University of Illinois at Urbana Champaign (UIUC) through BRIDGE grant. The project will build on research strengths of both UoB and UIUC to perform investigations on dynamic damping, dielectric property and dynamic resistance of micro and nanoengineered crumbed rubber concrete (CRC). The applications of the advanced materials such as modified CRC in railway tracks could potentially improve safety, resilience and reliability of rail infrastructure.

PUBLIC INTEREST STATEMENT

This research is the world first to deal with electrical resistance of innovative nano and microengineered concrete, of which this electrical property is crucial. The investigation will lead the way on the practical applications of the new materials to railway industry. An important focus on this research is the recycling of crumb rubbers, which are derived from wasted rubber tires and plastics. Its wide spread applications in railway construction and maintenance will strengthen environmental impact to societies. Insights into the sensitivity of the crumb rubber particle sizes on the dielectric property of modified concrete will assure better material design and its compliance and compatibility with systems requirements.

1. Introduction

Railway infrastructure owners all over the world are suffering from many of wheel and rail irregularities, resulting in increased maintenance, more frequent monitoring and track patrol, and the rapid track degradation that can lead to poor ride quality. This mechanism also undermines structural capacity of materials used in railway environments. As such, railway track components often wear and tear rapidly from the aggressive loading and vibrating conditions. Some of the problems are impact damage, rail seat abrasion and excessive noise and vibration to surrounding equipment. These problems play an important role in sustainable and effective railway operations. Therefore, it is essential to develop new techniques to mitigate these problems. Nowadays, several innovative methods are developed in order to suppress the impact load and vibration before and after passing through sleepers to other track components (ballast, subgrade and ground). For example, rail and sleeper pads are installed underneath the rail and sleepers, respectively, to increase the damping of the track system (Carrascal, Casado, Polanco, & Gutiérrez-Solana, 2007; Connolly, Kouroussis, Laghrouche, Ho, & Forde, 2015; Kaewunruen & Remennikov, 2009, 2010; Remennikov & Kaewunruen, 2008). However, these two composite products can wear and come off from the main structure due to various factors such as looseness of fastening system, climate change and so on (Griffin, Mirza, Kwok, & Kaewunruen, 2014; Kernes, Edwards, Dersch, Lange, & Barkan, 2011). Therefore, finding the sustainable way to reduce the impact load and vibration problem is still a big challenge in railway industry.

A method for improving dynamic resistance and vibration energy absorption of railway concrete material has recently been introduced for manufacturing railway sleepers. The dynamic damping of concretes can be improved using waste rubber tyres as microfiller. Not only can the crumb rubber improve dynamic damping property while maintain structural strength at acceptable level, such the method provides an environment-friendly avenue by recycling synthetic wastes such as wheel tires, plastic and other industry rubbers. Thanks to significant and popular utilisation of cement and concrete composites in railway infrastructure, the total environmental benefit of such method in railway systems is potentially substantial.

This paper highlights the evaluation of electrical resistance of crumb rubber concrete (CRC) and focuses on the sensitivity of particle sizes of crumb rubber on the electrical conductivity. Monitoring electrical resistance of structural concrete is critical for effectiveness of modernised railway operations. Electrification, signalling control, train communication and detection, track circuits, automatic train control, and level crossing safety control within railway corridor are among the subsystems that require the ability of structural concrete for electrical insulation at certain extent. For instance, rail/sleeper fastening assemblies and sleepers shall ensure a minimum electrical resistance between the running rails of 10 Ohms per track kilometre (Kaewunruen & Vaughan, 2009; RailCorp, 2012). As a result, material design must comply with systemic requirements in order to avoid multi-million dollars penalty when the railway track malfunctions. This study is the first to address the sensitivity of particle characteristics on the dielectric property of engineered concrete. The outcome of this research will help material engineers to develop and improve construction materials for real-world applications.

2. CRC

In this development, CRC has been designed as structural material for manufacturing concrete sleepers. The fundamental characteristics of CRC include:

2.1. Properties of fresh concrete

The fresh density of CRC with rubber aggregate was observed by Siddique and Naik (2004) and Su, Yang, Ling, Ghataora, and Dirar (2015). They illustrated that fresh CRC has lower density than normal concrete, and increase in percentage of crumb rubber affects the reduction in fresh density. This is because the crumb rubber has low specific gravity. In addition, non-polar nature of rubber particles may repel water and attract air on rubber surface, which would cause air void increase. Workability of CRC was evaluated by measuring slump of fresh concrete. Various researches have stated that

increase in crumb rubber replacement reduces the workability of fresh CRC (Najim & Hall, 2011, 2012; Pacheco-Torgal, Ding, & Jalali, 2012). In addition, the size of crumb rubber also has an impact to the workability of concrete. Su et al. (2015) found that there is a reduction of slump, once the size of rubber particle is decreased. However, this workability issue can be solved by adding proper amount of plasticizer admixture (about 2–3%) into the concrete (Aiello & Leuzzi, 2010; Topçu & Bilir, 2009).

2.2. Properties of hardened concrete

As well known, compressive strength is one of the main properties of concrete. For CRC, most of previous researches have obviously shown that increase in rubber content leads to reduction in compressive strength (Aiello & Leuzzi, 2010; Chou, Lin, Lu, Lee, & Lee, 2010; Eldin & Senouci, 1993; Güneyisi, Gesoğlu, & Özturan, 2004; Issa & Salem, 2013). In addition, a smaller reduction in compressive strength was observed when only fine aggregate was replaced by crumb rubber. Su et al. (2015) studied about the effect of different sizes of rubber particles (3, 0.5, 0.3 mm) to the compressive strength of CRC. They revealed that at 28 days, cube compressive strength of concrete increases with a decrease in the rubber particle size due to a better void filling ability of finer crumb rubber. Moreover, the types of crumb rubber also have an significant impact to the compressive strength.

According to the reduction of compressive strength, tensile strength of CRC is also influenced on the amount of rubber content. Increase in rubber content decreases both splitting and flexural strength (Güneyisi, Gesoğlu, & Özturan, 2004). However, reduction of tensile strength seems to be less impact than in the case of compressive strength (Pacheco-Torgal et al., 2012). The reduction of tensile strength also depends on the size of rubber particle. Greater rubber particle will negatively impact to the tensile strength (Ganjian, Khorami, & Maghsoudi, 2009; Su et al., 2015). Furthermore, the types of aggregate that is substituted also have an effect to tensile strength. Larger decrease in tensile strength occurs when replacing coarse aggregate rather than fine aggregate with rubber waste (Aiello & Leuzzi, 2010). Elastic modulus of the concrete tends to reduce when increasing the percentage replacement of coarse or fine aggregate with waste rubber (Ganjian et al., 2009; Kumar, Sandeep, & Sudharani, 2014; Onuaguluchi & Panesar, 2014). Even though the elastic modulus of CRC decreases, the strain rate property increases considerably when increasing rubber content. This makes CRC has lower brittleness index than plain concrete, which causes CRC has greater ductility performance (Snelson, Kinuthia, Davies, & Chang, 2009; Zheng, Huo, & Yuan, 2008). In addition, it was revealed that CRC also has higher toughness and better energy absorbing ability compared to normal concrete (Aliabdo, Abd Elmoaty, & AbdElbaset, 2015; Li et al., 2004). Therefore, this property could be advantageous for railway application.

For CRC, very few researches have been dedicated to dielectric property. In principle, rubber content in concrete performs as an electrical insulator which influences the resistivity of CRC becomes higher than that of plain concrete (Issa & Salem, 2013). Sukontasukkul (2009) has conducted the experiment to investigate noise absorption ability of CRC. Two size of crumb rubber were considered: passing sieve No. 6 (3.36 mm) and 26 (0.707 mm). These groups of crumb rubber were used to replace fine aggregate. The noise absorption ability of each concrete mix was compared using noise absorption coefficient (α). As a result, CRC seemed to have better noise absorption ability compared to reference concrete. Even though temperature is different (low, normal and high), CRC still performed well in terms of sound absorption than plain concrete (Holmes, Browne, & Montague, 2014).

Thermal resistance of CRC has been studied by Kaloush, Way, and Zhu (2005). The result illustrated that coefficient of thermal expansion of CRC will decrease when crumb rubber content is increased both heating (expansion) and cooling (contraction) cycles. This means CRC can be more resistant in thermal changing than normal concrete. In addition, Sukontasukkul (2009) also found the relationship between the size of crumb rubber and thermal resistivity. Smaller rubber particles provided a better thermal resistance to concrete. Sukontasukkul and Chaikaew (2006) have found that concrete with smaller rubber particles seemed to have less per cent weight loss than concrete contained bigger rubber particles as shown in Figure 1.

Figure 1. Abrasion test results (Sukontasukkul & Chaikaew, 2006).

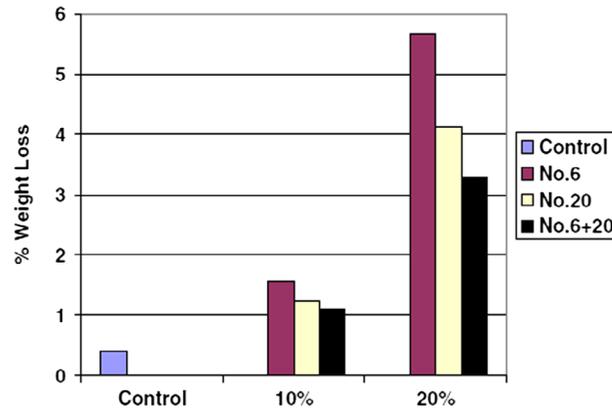


Table 1. Mixture proportions of concrete(kg/m³)

| No. | Mixes | Cement | Gravel | Sand | Silica fume | 425 μ rubber | 75 μ rubber |
|-----|-------------|--------|--------|------|-------------|--------------|-------------|
| 1 | RFC | 530 | 986 | 630 | - | - | - |
| 2 | SFC | 477 | 986 | 630 | 53 | - | - |
| 3 | SFRC-425-5 | 477 | 986 | 599 | 53 | 31.5 | - |
| 4 | SFRC-425-10 | 477 | 986 | 567 | 53 | 63 | - |
| 5 | SFRC-75-5 | 477 | 986 | 599 | 53 | - | 31.5 |
| 6 | SFRC-75-10 | 477 | 986 | 567 | 53 | - | 63 |

However, Kang, Zhang, and Li (2012) have found the opposite results when only replacing same volume of fine aggregate with crumb rubber. They found that CRC seemed to have a better abrasion resistance than plain and silica fume concrete (lower per cent mass loss). The abrasion resistance of CRC tended to increase as rubber content increase. This may be because the CRC has excellent dynamic performances in terms of energy absorption, toughness and cracking resistance. Therefore, these parameters results in better abrasion resistance in CRC.

After reviewing the characteristics of CRC, it can be obviously seen that CRC has a lot of advantages. However, there are still some aspects of mechanical properties requiring improvement such as compressive and tensile strength, and elastic modulus. The critical review suggests that mixing a smaller size of rubber waste particle at micro and nanoscales into the concrete can mitigate those problems. Therefore, this study is the first to investigate the electrical properties of high-strength CRC aimed for railway applications. The very small particles of rubber waste as microscale (75 μ) were selected to use in the experiment.

2.3. Design of engineered concrete

Six concrete mixes have been designed in accordance with British Standards (British Standards Institution, BS EN 197-1, 2011). The reference concrete (RFC) is designed using water-cement ratio of 0.44 and slump value of 60–180 mm, in order to achieve a target mean strength of 63 MPa at 28 days. The second mix is the reference concrete, which 10 weight per cent (wt%) of cement is replaced by silica fume (SFC). For the remaining concrete mixes, they are modified from the second mix by replacing 5 and 10 wt% of fine aggregate with 425 and 75 μ rubber powders, respectively. All of mixture portions are presented in Table 1.

3. Measurement of electrical resistance

In general, two methods used for measuring the electrical resistivity of concrete are two-pole and four-pole method (Konsta-Gdoutos & Aza, 2014). Both methods are very similar in terms of

Figure 2. Four poles resistivity testing, after Konsta-Gdoutos and Aza (2014).

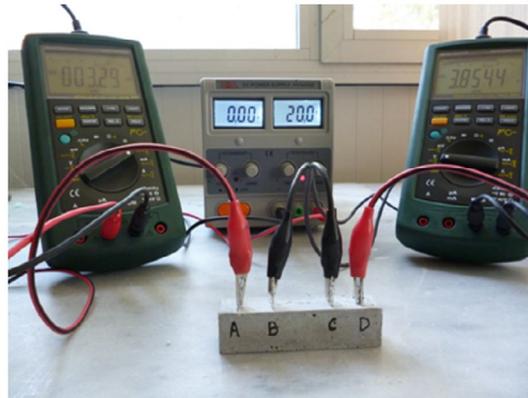


Figure 3. Arrangement of electrical resistivity.



(a) Moisture Controlling



(b) Experimental Set Up

application of current and voltage passing concrete. However, two-pole method applies two electrodes at both ends of the concrete, and they are used to measure the current intensity and voltage difference. While in four-pole method, there are four poles of electrodes applied on the concrete sample. Two outer poles are used for measuring the current and other two poles are used for determining the voltage as shown in Figure 2.

In this study, two poles method was selected. The type of concrete specimen used in the test was $W45 \times H20 \times L120$ mm prism. The equipment used was insulation tester (Victor VC60B⁺) which can be applied to determine electrical resistance (Ohms) of concrete samples. Before the test, the concrete samples were removed from the curing tank at 28 days. Then, they were cleaned and put into the oven where the temperature was controlled to be constant at 30°C (see Figure 3(a)). After 24 hours, the samples were taken out from the oven, and the experiment was set up by connecting the lead wires to both ends of the concrete as shown in Figure 3(b). The insulation tester was turned on, and the voltage was kept constant at 1,000 V. After that, the electrical resistance of concrete specimen was measured, and the value at 60 sec was recorded as an electrical resistance of that sample.

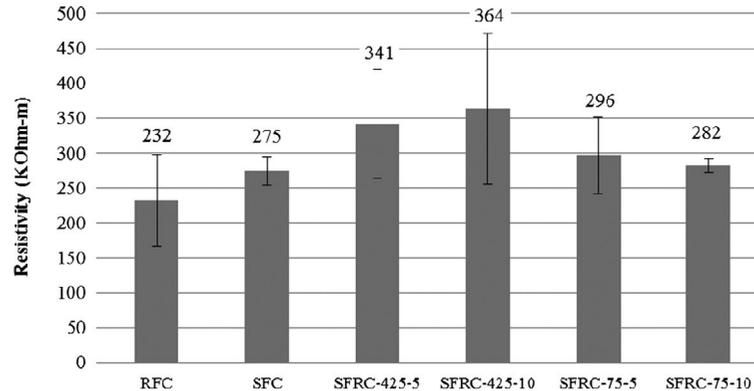
4. Particle-based sensitivity on dielectric property

In this study, the electrical resistivity experiment was conducted when the concrete samples had age of 28 days. The data obtained from the test was the electrical resistance (Ohms). Therefore, to convert it into electrical resistivity, the common equation was used as presented below:

$$\rho = \frac{RA}{L} \quad (1)$$

where ρ is the electrical resistivity (Ohm-m), R is the electrical resistance (Ohms), A is the cross-sectional area of specimen and L is the length of specimen.

Figure 4. Electrical resistivity of each concrete mixes.



As shown in Figure 4, the RFC had the lowest electrical resistivity (232 KOhm-m) when compared to other mixes. The silica fume tended to have a positive impact to this kind of concrete properties (Onuaguluchi & Panesar, 2014). It made the electrical resistivity increase approximately 18.53% in this study. Replacing very fine aggregate with microcrumb rubber either 5 wt% or 10 wt% could significantly enhance the electrical resistivity compared to RFC and SFC. This is because the rubber is dielectric material, thus, crumb rubber inside concrete acted as an insulator preventing the current transfer between two measuring electrodes. Small particle of rubbers can fills the void better and replace tapped moisture inside concrete, resulting in higher electrical resistance. Moreover, this study also found that the concrete contained the bigger size of rubber particles has a higher electrical resistivity than that of finer one. This is because the insulated spherical dimension of the rubber particles is larger. Accordingly, when there is more amount of the larger crumb rubber, the electrical resistivity becomes higher. In contrast, nanoparticle rubbers do not improve the electrical performance even there is more amount of such particles.

Overall, the electrical resistivity of rubberised concrete mixes tends to be relatively higher than ordinary high-strength concrete. Interestingly, the results are quite consistent when compared to the results obtained by previous researches (Issa & Salem, 2013).

5. Concluding remarks

Railway track components are usually subjected to high aggressive loading and vibrating conditions within railway corridor. Novel improvement of material capabilities to mitigate such problems becomes a new research agenda. This study focuses on a nanoengineered improvement method for concrete material using crumb rubber, which has been recently introduced to railway applications. This paper firstly highlights the importance of the particle sizes of crumb rubbers on the electrical resistivity of the concrete modified by crumbed rubbers.

This research establishes the development of the environment-friendly concrete using waste rubber tire (425 and 75 μ) as microfiller to comply with the requirements for making railway concrete sleeper. Six different types of concrete have been designed and manufactured in accordance with British standards. The experiments have been conducted to determine electrical resistance of the specimens at 28 days. CRC concrete specimens have exhibited a better characteristic in electrical resistance in comparison with ordinary high-strength concrete. Replacing very fine aggregate with microscale crumb rubber can significantly enhance the ability to resist the current flow inside the concrete. This property is very meaningful and highly practical in modern railway track applications because better electrical resistance of concrete sleeper can ensure the reliable and safe railway operations using track circuits.

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