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Fundamental properties of rubber modified self-compacting concrete (RMSCC)

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HIGHLIGHTS

- ▶ No noticeable improvement of flow rate in RMSCC despite high dosage of super plasticiser.
- ▶ RMSCC exhibits high viscosity and low filling ability because of low density rubber particles.
- ▶ RMSCC exhibits lower strength but has better dynamic properties and flexibility.
- ▶ The increased dosages of super plasticiser had little impact on dynamic properties of RMSCC.
- ▶ Significant potential for RMSCC where better dynamic properties are desirable.

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ABSTRACT

A series of laboratory investigations were undertaken on rubber modified self-compacting concrete (RMSCC) to study the workability of the mixture during its production and the fundamental mechanical and dynamic properties of cured specimens. The results showed that, compared to the self-compacting concrete (SCC), the slump together with passing and filling ability of RMSCC mixtures are lower despite a higher dosage of super plasticiser in the fresh mixtures. In addition, as expected, the strength of the RMSCC was lower, although improved dynamic properties such as lower natural frequencies, marginally lower dynamic modulus of elasticity, and higher dampening were observed. The results indicated that if the durability issues are tackled properly, RMSCC has the potential to be used as a vibration attenuation material.

1. Introduction

The utilisation of rubber in self-compacting concrete (SCC) can be seen as a positive step forward in supporting sustainable development as scrap road vehicle tyres form a major part of the world's solid waste management problem and will continue in coming years. For example, each year the UK alone produces around 30 million waste tyres with 1 billion being produced globally. Almost half of them are landfilled or stockpiled with the rest being recycled, exported, and disposed of illegally. Since 2006, the European Union's Landfill Directive has barred disposal of most tyres as a landfill material. As a result, if alternatives to landfill disposal are not found, disposal costs will increase and issues relating to illegal dumping or inadequate storage will continue to worsen. The fire risk associated with illegal dumps has the potential to cause significant environmental harm. In the last two decades, utilisation of scrap tyres as a construction material, especially in concrete and asphalt mixtures, has gained significant popularity in the research community as an alternative use of waste material to consume a large quantity in an environmentally friendly way [12,10,1,16]. The application of rubber into the SCC can be a added value to the mitigate the environmental issue [32].

Self-compacting concrete (SCC) is a special type of concrete material where vibration/compaction is avoided by adding super plasticiser into the fresh mixtures to achieve a similar level of compaction [22]. This relatively new technology is gaining increased popularity in the construction industry as it provides an environmentally friendly and safer way of producing concrete without compromising its quality. In last 20 years, significant progress has been made in SCC research and development, covering design, specifications, production, and durability of the mixtures. Among many advantages, SCC with a similar water cement ratio tends to be slightly stronger compared to vibrated ordinary concrete (OC). This is due to the reduction of vibration/compaction within the

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structure, leading to an improved interface between aggregate and hardened paste [3].

The compressive and flexural strength for SCC have been found to be higher than OC [24,38,33,36,9]. The higher tensile strength for SCC is due to the improvement in homogeneity and a denser micro structure [8,34]. The characteristic strength of SCC is at least equal to that of conventional concrete, and it has a similar strength development for the same grade [17]. Due to the low water/cement ratio used in SCC, the compressive strength will generally be above 40 MPa to as much as 100 MPa. The tensile strength is also comparable to the same grade of OC [17].

However, previous research found that although SCC is seen as a promising evolution in concrete, it does present the disadvantage of a higher shrinkage cracking tendency than OC. Turcry et al. [34] reported that the shrinkage of SCC was 10–50% higher when compared to OC. This is because the mix design for SCC increases the volume of paste which is known to increase shrinkage [5]. However, other studies have found that the shrinkage of SCC is similar to OC of the same compressive strength [24,25].

2. The potentiality of rubber modified self-compacting concrete

The Rubber Modified Self Compacting Concrete (RMSCC) is a type of SCC with partial replacement of aggregate by rubber particles manufactured from the waste tyres. Despite a considerable amount of research into rubber modified concrete, the research into the RMSCC remains limited. This is because the addition of rubber aggregate in the concrete mixtures exhibits a loss in strength [12].

The common misconception that has held the application of this innovation back has been the traditional idea that the most important property of concrete is its compressive strength. This view needs to challenge by a "design by function" approach which will allow concrete incorporating rubber to be the preferred material over the applications [21]. If the quantity of rubber is kept within 20–30% of the fine aggregate, the mixture may provide a distinct advantage by absorbing vibration without significantly compromising strength. The research conducted by Ei-dieb et al. [10] reported that by adding less than 10% rubber through the replacement of coarse aggregate does not significantly hinder the performance of the concrete, reducing strength by around 10–15%.

Despite the issue regarding strength, several researchers report enhancement of other properties. For example, Eldin and Senouci [12] found that the rubberised concrete exhibits a ductile and plastic failure. Therefore, RMSCC has the ability to absorb a large amount of plastic energy under compressive and tensile loads. They also reported that, in general, the rubberised concrete batches have acceptable workability in terms of ease of handling, placement, and finishing. Similar findings were reported by Topcu [29], Topcu [30], Topcu and Avcular [31], Fattuhi and Clark [15], El-Gammal et al. [13] and others.

Adding flexible rubber particles offers an attractive solution to counteract the shrinkage cracking and strain failure of SCC through incorporating waste rubber particles which lead to more deformability under pre-failure loads, as well as an increased toughness, impact resistance and ductility [20]. If the range of rubber particles content used is kept within 10–40%, it has beneficial effects on the decreasing of drying shrinkage of SCC. This allows the use of recycled rubber particles in a greater quantity with natural sand in SCC [35]. Tests carried out in accordance to ASTM standard C 1581-04 demonstrated that adding rubber particles is a suitable solution for reducing the potential for cracking due to restrained shrinkage [33].

There are a wide-range of possible civil engineering applications for RMSCC. It can be used for architectural applications such as nailing concrete, false facades, stone backing as well as interior construction due to its light unit weight. Although RMSCC may have lower strength than similar mixtures without rubber content, it can still be used for the construction of footpath, driveways and selected road construction applications like crash barriers around bridges, bunkers, Jersey barrier (a protective concrete barrier used as a highway divider and a means of preventing access to a prohibited area), due to its high toughness qualities [12,21,26,35]. Recent research has indicated that the addition of rubber can increase the vibration absorption of a concrete slab [37]. Therefore, RMSCC can also be used for vibration dampening in foundation pads for machinery, railway stations and light rail vibration reduction in cities. El-Gammal et al. [13] reported that RMSCC can also be used in the production of road kerbs, and non-bearing concrete walls. Other beneficial applications would be for trench filling and pipe bedding, pile heads, railway track beds and paving slabs.

The use of RMSCC has also been found beneficial for roadway central reservations that offer combined protection and traffic noise reduction, improved thermal and acoustic insulation for small machinery housing structures as well as improved thermal insulation for flooring in buildings [20,6]. The energy absorption qualities of rubberized concrete have also been confirmed by Khaloo et al. [18]. These positive characteristics can be useful in supporting the development of sustainable concrete in order to achieve greater environmental and economic benefits.

3. Research objectives

If RMSCC material is to be adopted widely, it is important that this type of mixture satisfies the same performance requirements as normal and SCC concrete. In order to understand the fundamental properties of RMSCC and how it performs in its intended application, a study was undertaken to carefully monitor the production of RMSCC, investigating the effect of adding rubber particles in SCC on the fundamental physical properties such as workability, resistance to segregation (viscosity), and the flow ability of the fresh mixture. The research was then extended to determine the fundamental dynamic mechanical properties such as dynamic modulus of elasticity, Poisson's ratio and dynamic shear modulus on the cured specimens.

This paper presents results from a laboratory study undertaken on RMSCC investigating the workability issues such consistency, passing ability, viscosity and filling ability at the production stage followed by the determination of strength and dynamic properties of the cured specimens. The dynamic properties were calculated from the natural frequencies determined by non-destructive test (NDT) methods. All results were compared against the conventional SCC with similar mixture specifications.

4. Dynamic mechanical properties of concrete

The dynamic modulus of elasticity, poisson's ratio and shear modulus are the main parameters for concrete that are subjected to dynamic loading. Researchers have developed relationships to calculate dynamic properties from the natural frequencies of the material determined by means of non-destructive testing (NDT). In this paper, some of the most widely used formulae are utilised to calculate these properties.

4.1. Dynamic modulus of elasticity (E_d)

The measured frequency and Ultrasound Pulse Velocity (UPV) were utilised to calculate the dynamic modulus of elasticity. Five methods were chosen from published literatures and they are shown in Table 1.