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A STUDY ON THE PROPERTIES OF CONCRETE AGGREGATE REPLACEMENT IN RUBBER CEMENT COMPOSITE

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ABSTRACT

The automobiles industry has grown rapidly in the last three decades throughout the world and the increasing use of cars as the main mode of transport has brought a huge boom in car tyre production. This means that an enormous number of waste car tyres are left at the end of its life. Apart from domestic cars, a large number of tyres wastes are also generated from commercial and heavy goods vehicles. Producing rubberised concrete by utilising waste tyre rubber as an aggregate can prove to be an effective approach to massively reduce tyre waste.
In this study, the performance of concrete mixtures containing rubber as fine and coarse aggregate was investigated. Scanning electron microscopy (SEM), water absorption, density, compressive strength and non-destructive tests were performed using test specimen (w/c = 0.43) containing two types of rubber. Two mix designs were designed containing 10% of as-received rubber or cement paste treated rubber. The results of two mixtures have been compared with the control mix which is used as a reference. It was found that using 10% v/v of crumb rubber into concrete reduced 12% of compressive strength while only 2% reduction was observed when 5% crumb rubber with 5% chipped rubber coated with cement paste was utilised. Overall the results showed that the use of cement coated rubber in concrete gave favourable results when compared to the control.
The SEM observation for interfacial transition between cement, aggregate and rubber was also studied. It was observed that a strong interface bonding occurs between cement paste and aggregate, but a weak interface bonding is formed rubber, cement paste and aggregate.

Keywords: Waste tyre, crumb rubber, chipped rubber, Cement paste, Rubberised concrete.

1 INTRODUCTION

It is estimated that about 1.5 billion rubber tyres are manufactured in the world and more than 50% of waste tyres are discarded without any treatment [1]. According to the Environment Agency, UK, every year the United Kingdom produces more than 55 million waste tyres. This is now becoming one of the major waste management problems in the UK and this number is set to increase by more than 60% in 2021, in line with the growth in road traffic and car ownership [2]. At present, it is thought that 11% of post-consumer tyres are exported, 62% are reused, recycled or sent for energy recovery and 27% are sent to landfills (shredded tire), stockpiled or dumped illegally.

It is reported [3] that about 32 million tyres are produced annually in Brazil, and it is estimated that 10-15 million units are discarded each year. Similarly, in China, the production of waste tyres is increasing with an annualised rate of 15%. The production of waste tyres was 0.2 billion (6 million tonnes in weight) in 2009, about 65% of the waste tyres were not recycled or received any treatment [4].

The major issue lies within the fact that rubber tyres are not biodegradable and these waste tyres can last many years. There is no doubt that if they are to be landfilled then they are a serious threat to the environment. Rubber tyres compound contain large quantities of oxygen within their particles, which aids burning, hence they are classed as a major fire hazard. Furthermore, the toxic smoke of burning tyres can cause serious damage to human health and the environment [5. Additionally, rubber tyres accumulation into landfills and dumps provides a breeding ground for mosquitoes causing a further problem to human health [6]. These are the major reasons that the European Union (EU) has adopted laws to prevent the disposal of tyres to landfill sites. The European landfill directive [7] means that this type of waste disposal would be illegal in Europe and from 2006 EU legislations have banned the disposal of tyres in landfills, leaving about 480,000 tonnes of recyclable shredded rubber every year [8]. The legislation forces the UK and other EU member countries, that they must be recovered, recycled and reused tyres. This, however [9] not only calls for environmental concern but also represent a waste of useful resources, considering the enormous number of £1.8 billion that is spent annually only in the United Kingdom on concrete products, it is easily understandable that this is a very potential market for this material.

Rubber from vehicles tyres, after being shredded into smaller pieces, can be used in various Civil Engineering applications, mainly as aggregates and sand substituents in concrete. The two methods used to grind tyres to the required size: the first method is related to ambient size reduction using mechanical processes at or above room temperature while the second method is related to cryogenic size reduction by the use of liquid nitrogen or commercial agents to reduce the tyre to the desired size. The first process produces rubber chips with a rough surface, while cryogenic grinding is generally used for the production of rubber in the form of powder or crumbs. By reducing the particle size of worn tyres, separation of steel wires and textile fibres can also be achieved as well as a further treatment of the worn tyres so that commercial particle sizes are created. Scrap tyres are shredded into sizes ranging from >300 mm to <500 μm, depending upon the intended use.There is no doubt that the number of waste tyres is increasing every year, about 112 million scrap tyres remained in the stockpiles, only in the UK. These statistics bring out the importance of the more widespread and durable application program for the reuse of scrap tyres. Tyre rubber mainly consists of a complex mixture of elastomers including poly-isoprene, polybutadiene, styrene-butadiene, some stearic acid (1.2%), zinc oxide (1.9%), extender oil (1.9%), and carbon black (31%) [12]. As a flammable material, stockpiling of waste tyres is dangerous not only due to potential negative impact but it presents a fire hazard.

In this research, the scrap tyre rubber aggregates are used to substitute the natural aggregates in the concrete to improve the flexibility and durability of the concrete. Rubber aggregates were also coated with cement paste to enhance their bonding properties. The mechanical properties, the morphology of hydration productions and the microstructure of the interfacial transition zone (ITZ) were observed using Scanning Electron Microscopy (SEM).

2 MATERIALS AND METHODS

Previous work conducted on rubber substitution in concrete [12, 13, 14, 15] recommended incorporating lower percentages as replacements. Therefore, this study assesses the behaviour of rubberised concrete with a maximum of 10% replacement of aggregates (See Table 1). This work also evaluates the results from SEM to understand the ITZ between rubber and natural aggregates. Table 1 shows the concrete mixtures produced during this study.

Table 1 Concrete mixtures

MIX NO	DESCRIPTION
1	The control according to mix design, without any replacement of rubber aggregates.
2	Crumb rubber replaces fine aggregate by 10% (v/v).
3	Crumb rubber replaces fine aggregate by 5% (v/v) and chipped rubber coated with cement paste replaces coarse aggregate by 5% (v/v).

2.1 Aggregates

The traditional limestone aggregates and the rubber aggregates were used in this project. Traditional limes stone aggregates included, coarse aggregates (10mm and 20mm) and fine aggregates (sand, 0.2-0.3mm). All-natural aggregates were held at room temperature (20-25°C). Figure 1 shows rubber aggregates utilised as replacements, this included, chipped rubber (10-14 mm), chipped rubber pre-coated with cement paste (10-14 mm) and crumb rubber (0.6 mm). All substitutions were made according to weight taking into account the ratio between the specific weight of rubber and natural aggregates. The rubber aggregates were supplied by Crumb Rubber Ltd, Plymouth, UK. For Mix 3 (see Table 1), cement paste was prepared blending 800g cement with 400g of tap water. Chipped rubber was added to the cement paste and was mixed thoroughly for about 5 minutes. After which, the chipped rubber was spread on a clean dry surface and left for drying at room temperature for 24 hours.

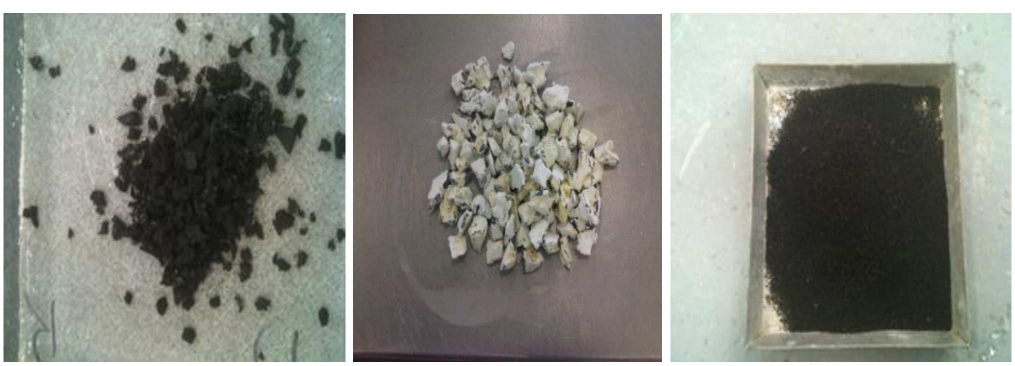

Figure 1 Chipped rubber, Cement coated chipped rubber and crumb rubber

2.2 Concrete mix design

The purpose of this study was to investigate the general procedure for the production of fresh and hardened concrete and to evaluate differences between control and waste tyre rubber modified concrete. Three separate concrete mixes were produced (Table 2) for this study.

Table 2 Concrete mix design proportions (kg m^{-3})

MIX	CEMENT	WATER	FINE AGGREGATE	COARSE AGGREGATE		CRUMB RUBBER	CHIPPED RUBBER	UNIT WEIGHT
				(20mm)	(10mm)			
1	390	195	582	394	789	0	0	2350
2	390	195	523.8	394	789	25.3	0	2317.1
3	390	195	552.9	374.3	549.5	12.6	25.4	2299.8

3 RESULTS AND DISCUSSION

Recent research into rubberised concrete [11, 15, 22] suggested that replacing greater than 10% rubber with natural aggregate adversely affects the mechanical and durability properties of concrete. Therefore, in this investigation, we have evaluated the performance of rubberised concrete by incorporating crumb and chipped rubber as 10% replacement (see Table 1).

3.1 Compressive strength test

It is widely accepted [12, 14, 26, 27] that the substitution of rubber mainly affects the density, compressive strength, and split tensile strength of concrete. These studies indicated that in rubberised concrete approximately 85% reduction in compressive strength, whereas the splitting tensile strength is reduced by about 50% when the coarse aggregate was fully replaced with chipped tyre rubber. Results in Fig. 2 shows that for 10% of crumb rubber into concrete (MIX 2) there is a reduction of 12% strength, while MIX 3 showed only 2% reduction when compared to the control. In comparison four rubber contents (5%, 10%, 15% and 20%, v/v) were studied [12]. We observed only 2% reduction when coated chipped rubber (5%) and crumb rubber (5%) was used. This shows that by coating the chipped rubber, a significant improvement in compressive strength can be achieved. Furthermore, It is suggested that the maximum of 10% rubber, with coated chipper rubber, can be used in structural concrete while up to 40% could be utilised for non-structural works [14].

3.2 Beam flexural and elastic young's modulus tests

Figure 3 shows the beam flexural strength for the three mixes. It can be seen that for both rubberised mixes there is no significant difference in flexural strength compared to the control, Mix 2 and 3 showed a reduction of only 3%. In contrast a recent study on beam flexural test
The results for elasticity young's modulus is shown in Figure 4. It can be seen that the 10% crumb rubber replacement presents a 21% reduction in elastic young's modulus. However, using MIX 3 elastic modulus value (34.76 GPa) was almost similar to the control (34.04 GPa). During this study, it was noticed from the cracks after the failure of the test specimens that the rubberised

concrete appears to be less brittle than the control mix, especially the samples containing chipped rubber. Thus, it is believed that the rubberised concrete could serve as an energy-absorbing material. The results of UPV tests showed that the average pulse velocities for MIX 1, MIX 2 and MIX 3 were 4.26 km/s, 4.61 km/s and 4.73 km/s respectively. All three mixes recorded pulse velocity >4 km/s which are classed as very good quality.

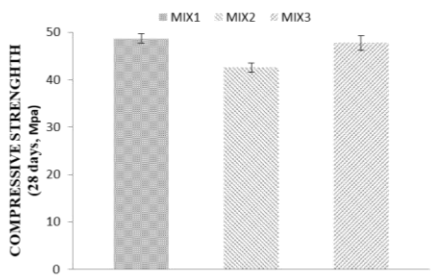

Figure 2 Compressive strength after *28* days (value represent means ± standard deviation, n=3)

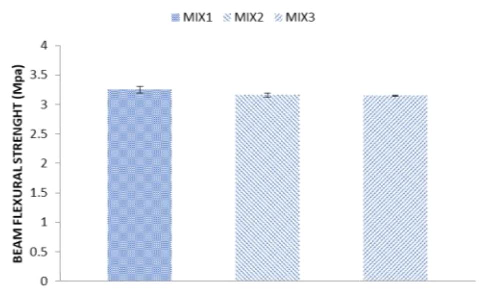

Figure 3 Flexural strength in beams (value represent means ± standard deviation, n=3)

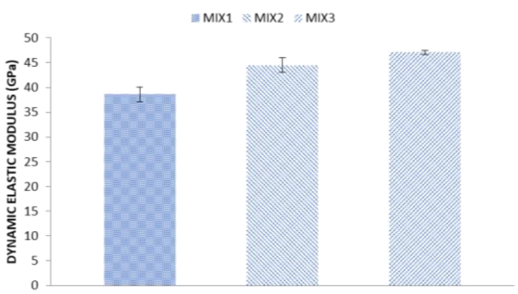

Figure 4 Dynamic elastic modulus (value represent means ± standard deviation, n=3)

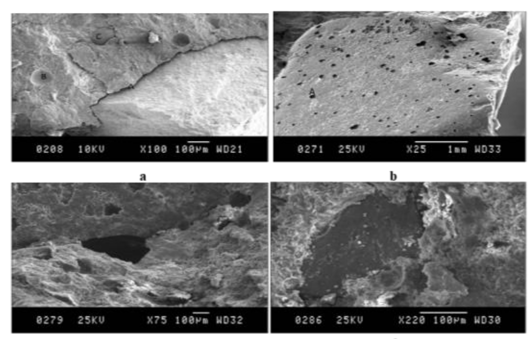

Figure 5 a) SEM image of fractured surface of control specimen A (Cracks), B (Air bubbles) and C (limestone aggregate), MIX1 b) ITZ between crumb rubber and cement paste, MIX2 c) ITZ between crumb rubber, aggregate and cement paste, MIX3 d) Image showing bond between cement coated chipper rubber and aggregate.

3.3 SEM analysis

It was observed that a strong interface bonding occurs between cement paste and natural aggregates (Figure 5a), while in the rubberised concrete there is no obvious interface bonding between cement paste and crumb rubber hence, a poor adhesion was observed (see Figure 5b). SEM images (Figure 5c and d) show that the cement paste coated rubber surface appears similar to natural aggregates and presents signs of a strong interface bonding between cement coated rubber and mineral aggregates.

4 CONCLUDING REMARKS

Based on this study it is recommended that high strength cement should be utilised for manufacturing rubberised concrete, to address compressive strength reductions. The flexural strength of beams containing cement coated chipped rubber did not crack completely and appeared less brittle compared to the other samples tested. It is believed that this was due to rubbers' ability to absorb energy. Overall, based on the results achieved, it is proposed that 5% crumb rubber and 5% cemented coated chipped rubber should be utilised in a wide range of structural applications including structures that require concrete to absorb energy.

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