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Experimental Study On Enhanced Crumb Rubber Concrete(CRC) For Rigid Pavements

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ABSTRACT:-
In many countries around the world, the adverse environmental impacts of stockpiling waste tyres have led to investigate alternative options for disposal of waste tyres. One option to reduce this environmental concern is for the construction industry to consume a high amount of recycled tyres accumulated in stockpiles.
There are different concerns regarding the introduction of rubber into concrete, which were addressed by previous studies. On the one hand, making a homogenous mix containing even distribution of rubber is a challenge. On the other hand, the severe reduction of concrete strength limits the rubber content. Moreover, replacing a portion of fine aggregates with low-stiffness rubber particles raises concerns regarding the generated shrinkage and cracking of rubberised concrete. This thesis investigates these concerns thoroughly and provides a comprehensive know-how of rubberised concrete characteristics, using crumb rubber.
In order to improve the strength of rubberised concrete different rubber treatment has been introduced by previous studies. A commonly applied rubber treatment method in the literature termed sodium hydroxide (NaOH) treatment has been assessed in this study. Numerous investigations examined using sodium hydroxide treatment of rubber. However, the level of improvement provided by different studies was not consistent. It was found that the sodium hydroxide treatment method is required to be optimised to achieve the most promising results. Two arrays of concrete specimens were prepared using different water cement ratios and a wide range of rubber contents. Then, the common fresh and hardened mechanical tests were conducted on the prepared samples. The results indicated that the duration of rubber treatment should be optimised based on concentration of the alkali solution and the type of recycled rubber. Consequently, the 24- hour treatment duration for crumb rubber resulted in the most suitable fresh and hardened concrete characteristics. Compared to untreated rubberised concrete, rubberised concrete produced with the optimised sodium hydroxide treated rubber, showed 25% and 5% higher compressive and flexural strength, respectively.
Index Terms- **Rubbersied concrete, sodium Hydroxide, Compressive strength, Flexural strength.**

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I. INTRODUCTION :

In many countries around the world, the adverse environmental impacts of stockpiling waste tyres have led to investigate alternative options for disposal of waste tyres. The disposal of waste tyres has been found to be an environmental concern due to waste tyres resisting degradation. Waste tyres occupy large landfill spaces that contain nesting insects and rats. Stockpiles of tyres destined for landfill are also known to be flammable. One option to reduce this environmental concern is for the construction industry to consume a high amount of recycled tyres accumulated in stockpiles. In Australia, the trend for accumulated waste tyres is rising at a rate of 2%, and it is estimated more than 20 million tyres were accumulated in landfills by the year 2010 (Atech Group 2001), which makes investigation into alternative options for disposing waste tyres a valid option. Moreover, according to a report prepared for the Australian Department of Environment only 3% of recycled tyres are used in civil engineering applications, which is far below the range of 9% to 14% average civil engineering usage of recycled rubber in other developed regions of the world, such as the United States and Europe (Houghton & Preski 2004). In addition, the Department of Environment in Australia emphasised the prospects for growth in using recycled crumb rubber, particularly in road construction applications (Atech Group 2001).

II. LITERATURE REVIEW

I. In this section, different characteristics of crumb rubber concrete (CRC) are investigated broadly. Based on the available research data, the function of rubber particles in the concrete matrix is critically reviewed. Moreover, different categories of recycled rubber and their effects on properties of concrete are elaborated.

II. The reduction in compressive strength of concrete manufactured with rubber aggregates limits its use in most applications (Khatib & Bayomy 1999; Zachar et al. 2010; Bewick et al. 2010; Ling et al. 2009; Khaloo et al. 2008). However, rubberised concrete has possibly some desirable characteristics such as lower density (Khaloo et al. 2008; Khatib & Bayomy 1999) and higher toughness and ductility (Topcu 1997; Zheng et al. 2008). Moreover, the better sound insulation, fire resistance (Bewick et al. 2010; Sukontasukkul 2009; Rangaraju et al. 2012) and resistance against cracking (Topcu 1995; Eldin & Senouci 1994) make rubberised concrete a preferred option to be used for pavement applications.

III. Concrete is a quasi-brittle material irrespective of whether rubber aggregate is used in the mix design. However, introducing rubber into the concrete mix can shift its mechanical properties from being a more brittle material to a more ductile one, especially when a high volume of rubber added into the concrete mix (Eldin & Senouci 1994). This performance is mainly due to the elastic properties of recycled rubber particles in the concrete matrix. The less brittle properties of crumb rubber concrete can be advantageous for various construction applications, such as driveways and roadway applications (Siddique & Naik 2004; Bewick et al. 2010). Many attempts were made to use rubber as a replacement for either coarse aggregates or fine aggregates in concrete mixes. The previous findings have revealed that the properties of rubberised concrete were critically affected by the type, size, and content of added rubber. According to Khaloo et al. (2008), the procedure of treating and introducing rubber into concrete mixes was also found to be significantly influential.

IV. The main sources of recycled tyres are listed as the bike tyres, passenger car tyres and truck tyres (Atech Group 2001). The breakdown by use of tyres is demonstrated in Figure 2.1.

III. EXPERIMENTAL PROGRAMME

This chapter is dedicated to describing the experimental program. It involves the introduction of different constituents of rubberised concrete and other materials utilised for this research, as well as the testing methods used for evaluating different properties of rubberised concrete. Moreover, the Australian pavement design criteria, used for assessment of the test results are introduced. Several concrete mixes have been prepared using materials with specific properties contents explained as follows.

Shrinkage Limited Cement

The Shrinkage Limited (SL) type cement has been used in this study. This cement type is designed for applications, where there is a desire to minimise concrete drying shrinkage such as pavement construction. Characteristics of cement utilised in this study, represented in Table 3.1, which satisfied specification requirements of AS3972 **-** General purpose and blended cements (AS3972 2010) .

Table 3.1: Properties of the used shrinkage limited cement vs. AS3972 requirements

Property	AS3972 limits	Properties of project cement
Initial setting time	>45 minutes	60 – 150 min
Final setting time	<10 hours	150 – 210 min
Soundness	<5 mm	<3 mm
28day Standard mortar drying shrinkage	<750 µstrain	550 µstrain
7day standard mortar compressive strength	>35.0 MPa	43 – 52 MPa
28day standard mortar compressive strength	>45.0 MPa	54 – 62 MPa

A recent study carried out by Yurdakul (2010), aimed to find the optimum cement content in concrete pavements. The optimum cement content was trialled for different WC ratios in order to achieve proper requirements regarding mix workability, strength, and durability. Moreover, the investigated optimum content was determined, considering the reduction of the carbon dioxide emission, energy consumption and costs. An experimental program was conducted by Yurdakul (2010) involved testing 16 concrete mix series with various WC ratios (0.35, 0.40, 0.45 and 0.50) and with different contents of cement (i.e. 240, 300, 355 and 415 kg/m^3). The study concluded that 300 to 355 kg/m^3 was the optimum cement content for conventional concrete.

In addition, previous research adding rubber into concrete mix was reviewed for determining a proper and conventional range for the cement content. John & Kardos (2011) stated that the cement content in range of 300-400 kg/m^3 utilised for preparing rubberised concrete. Zheng et al. (2008) mentioned the use of 400 kg/m^3 cement, while Taha et al. (2009) reported selection of cement content 350 kg/m^3. Lastly, Altoubat et al. (2001) investigated mixes with cement content of 362 kg/m^3. Taking into account all the performed studies in the past 370 kg/m^3 cement content is selected for preparation of research mixes. This content was marginally higher than the recommended content suggested for conventional concrete by Yurdakul (2010). Considering the reported cement content in previous studies and the negative impact that introduction of rubber has on the concrete strength, cement content was selected marginally higher than the optimised content range suggested by Yurdakul (2010) for conventionalconcrete.

It was reported that a limited addition of fly ash is allowed in pavement concrete mix. Adding fly ash is conducted for compensating aggregate grading deficiencies, reducing concrete shrinkage and improving workability and durability of concrete. Moreover, it offsets the usage of cement and hence reduces the costs, because cement is the most expensive component in pavement concrete. The applied fly ash quantities vary from nil to about 70 kg/m^3. However, the minimum total cementitious binder content (fly ash plus cement) should always be kept higher than 300–330 kg/m^3 range, which Austroad Standard suggested (Austroad 2009). It is addressed by specification that the minimum cementitious content of 300–330 kg/m^3 is typically specified for durability reasons.

The use of about 20% fly ash has become a routine practice in Australia. However, no fly ash was used in this study. It was decided to remove one extra variable from the investigation and to lower the complexity of the analysis. This decision was set based on the effects that both rubber and fly ash have on strength gaining of concrete.

It was reported by Khatib & Bayomy (1999) that the addition of more rubber resulted in less compressive strength gain of concrete samples from 7 to 28 days (Figure 3.1). It was revealed that by introduction of 30% or more rubber into the concrete mix, the 28- day compressive strength remained in the same magnitude of the 7-day compressive strength.

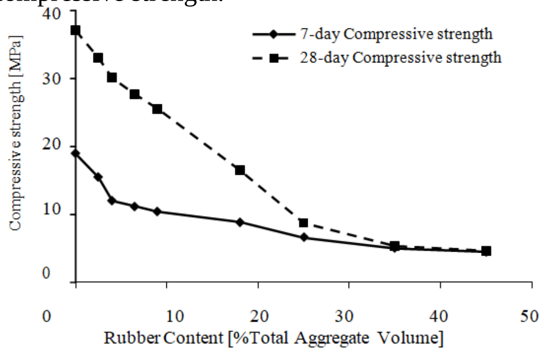

Figure 3.1: The effect of crumb rubber addition on strength gaining pattern (Khatib & Bayomy 1999)

Strength gaining is primarily a function of the hydration rate of cement and fly ash in a given mix (Pierce & Blackwell 2003). Previous investigations revealed the negative effects of adding rubber in the mix on the strength of concrete (Khatib & Bayomy 1999; Khorrami et al. 2010). Utilising both of the fly ash and crumb rubber in the pavement mix possibly results in complexity of strength gaining analysis for the prepared concrete. Moreover, it was reported by Youssf & Elgawady (2013) a better adhesion between rubber surface and pozzolanic constituents formed, which may result in improvement of rubberised concrete strength. In order to avoid any unwanted gain in strength of rubberised concrete due to the use of fly ash, it was decided to prepare mix series without fly ash. This enabled performing study of the pure negative impacts of introducing rubber on mechanical and shrinkage properties of rubberised concrete.

It is aimed that the trend of strength gaining for rubberised concrete becomes clear by this research. Moreover, the improving effects of different methods of rubber treating are investigated. Accordingly, considering the provided information by this study, for any future research, mixing fly ash with the cement is strongly suggested. The result of utilising fly ash in cementitious material can be compared with the current results to make a wider framework of understanding of introducing rubber into concrete mix.

IV. CONCLUSIONS

This research is intended to provide information that can ultimately be used for preparing rubberised concrete for rigid pavement applications. This study was carried out to assess crumb rubber concrete properties in which the crumb rubber particles were treated based on the water- soaking method. In addition, the best method of treating rubber with sodium hydroxide solution was studied. Moreover, the mechanical and shrinkage performance of rubberised concrete was studied in- depth. Referring to the results achieved for water soaking method, the following concluding remarks can be drawn:

The performance of different pre-treatment methods of crumb rubber were examined and evaluated. The "water-soaking method" was selected as the best treating method because of its advantages revealed according to the achieved results in this study. The benefits of this method can be listed as (i) it is an inexpensive and practical procedure; (ii) it can make homogenous and evenly distributed rubber particles in the concrete mix with a lower entrapped air, and
(iii) it improves the formation of the bond between rubber particles and the cement paste.

V. RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

In this research significant strides have been made to elaborate the best procedure of preparing and treating crumb rubber, mixing rubber into a concrete mix and conducting tests on rubberised concrete sample. Several aspects of rubberised concrete suitable for rigid pavement construction still need further investigation. The main areas considered for future studies are listed as follows:

a) The rubber type investigated in this research was crumb rubber size, which is classified as a fine rubber size. Introduction coarse size (>4.75 mm) of recycled waste tyre rubber is suggested for future research. This research only considered the conventional concrete pavement named base layer in Australia, with 28-day characteristic compressive strength of 32 MPa. A future suggested research can assess the application of coarse size rubber for preparing lean mix concrete. Lean mix is the most common form of bound subbase used in practice, which is placed as mass concrete under the base layer pavement. Introduction of rubber in a larger size can have higher negative impact on decreasing of concrete strength. The strength for lean mix should satisfy 28-day compressive strength of about 15 MPa according to the Australian specification (Austroad 2009). This research investigated the effect of introducing crumb rubber in the volume of up 70% fine aggregate. It was concluded that rubber content between 20% and 25% of the fine aggregate volume can be a suitable content, which can satisfy the Australian specifications. However, considering the lower requirement for strength of lean mix, for the coarse size of rubber, it is highly recommended to trial a wider range up to 100% of the coarse aggregatevolume.

b) This investigation assessed the effects of "rubber soaking method" on fine size of rubber named crumb rubber. It was revealed that this method had very positive effects to mitigate the strength drawbacks in preparation of rubberised concrete. Accordingly, it is highly recommended applying the introduced method of rubber soaking on coarse size of rubber, in order to assess the effectiveness of this method.

c) A limited addition of fly ash is allowed in pavement concrete mix. Adding fly ash is conducted for compensating aggregate grading deficiencies, reducing concrete shrinkage and improving workability and durability of concrete.

Moreover, it offsets the usage of cement, and hence reduces the costs as cement is the most expensive component in pavement concrete. Accordingly, considering the provided information by this study, for any future research, mixing fly ash with the cement is strongly suggested. The result of utilising fly ash in cementitious material can be compared with the current results to make

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