The optimum content of rubber ash in concrete: flexural strength

M S Senin1, S Shahidan1, S M Shamsuddin1, S F A Ariffin1, N H Othman1, R Rahman2, F S Khalid1 and F M Nazri3

1, Jamilus Research Center, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Johor Bahru Batu Pahat, Johor, Malaysia
2Smart Driving Research Center, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia
3 School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia
Corresponding author: shahironshahidan@gmail.com

Abstract. Discarded scrap tyres have become one of the major environmental problems nowadays. Several studies have been carried out to reuse waste tires as an additive or sand replacement in concrete with appropriate percentages of tire rubber, called as rubberized concrete to solve this problem. The main objectives of this study are to investigate the flexural strength performance of concrete when adding the rubber ash and also to analyse the optimum content of rubber ash in concrete prisms. The performance total of 30 number of concrete prisms in size of 100mm x 100mm x 500 mm were investigated, by partially replacement of rubber ash with percentage of 0%, 3%, 5%, 7% and 9% from the volume of the sand. The flexural strength is increased when percentage of rubber ash is added 3% from control concrete prism, RA 0 for both concrete prism age, 7 days and 28 days with value 1.21% and 0.976% respectively. However, for RA 5, RA 7 and RA 9, the flexural strength was decreased compared to the control for both age, 7 days and 28 days. In conclusion, 3% is the optimum content of rubber ash in concrete prism for both concrete age

1. Introduction
The accumulation of waste tyres is one of major environmental problems worldwide including Malaysia. Abdullah [1] stated the fact that one scrap tyre per person is generated constantly from all cars in the world every year. As scrap tyres are non-degradable materials, they can cause serious problems to the environment and public health. For example, they can become breeding sites for mosquitoes and rodents as the water becomes stagnant inside the tyres. It also causes diseases, accidental fires and takes up landfill space. The situation can worsen if it is illegally dumped in cities, disposed in lakes, streams, forest and not in the right places such as landfills. Other than that, there are also some people who use the easiest way to get rid of waste rubber tyres through open burning and using them as a source of fuel. These processes can lead to very serious health problems [2-9].

One way to solve the increasing amount of waste tyres is by incorporating waste rubber in concrete mixtures to produce rubberised concrete. Rubber can replace fine aggregates in the concrete mixture. This method can also create landfill avoidance [10-14]. A lot of previous research have been done regarding on rubberized concrete. Koreňová stated that concrete which contain rubber show excellent...
flexibility, ductility and energy absorbency as compared with controlled concrete [11]. Other researchers were used ground rubber powder and the crushed tyre chips particles range in size from about 15 to 4 mm as a replacement for coarse aggregate in normal concrete in various ratios. These group research are tested on the effect of rubber type and rubber content on strength and also modulus of elasticity [12,15-18]. Bakri worked on rubberized concrete by using waste tyre rubber as replacement of coarse aggregate to produce early age concrete and founded the decrease in compressive strength [8]. The compressive strength and density of concrete was affected on the amount of rubber added in the concrete [19]. Investigations on waste rubber in concrete applications are still in the process for better used. The previous researchers are mostly focusing in additive material and coarse aggregate replacement. Due to that matter, there need more detail investigation on the fundamental usage of waste rubber in concrete. Therefore, this study will be mainly emphasized on the use of rubber ash as partially replacement of fine aggregate concrete mixtures. The objectives for this study are to investigate the flexural strength performance of concrete when adding the rubber ash and also to analyse the optimum content of rubber ash in concrete prisms in term of flexural strength.

2. Rubber ash

Pyrolysis is a word basically based on the Greek words “pyr” which means fire and “lysis” which means separation. This means that pyrolysis is a process of decomposing material and usually the process operates at higher temperatures above 430 °C (800 °F). This process is done in the absence of oxygen otherwise the organic material is burned. Pyrolysis is also defined as one way of reprocessing scrap tyres through thermal degradation in the absence of oxygen. The products are fuel gas, oils, and a solid residue (char) which contains appreciable quantities of mineral matter and low-grade carbon black [20]. Products of tyre pyrolysis experiments are gases, liquid oils and solid carbon residues. The typical weight percentage of tyre pyrolysis are 33-38 wt. % char, 38-55 wt. % oil, and 10-30 wt. % gas which are affected by conditions such as temperature and heating rate. Gases produced from tyre pyrolysis are mainly hydrogen, carbon dioxide, carbon monoxide, methane, ethane and butadiene, with lower concentrations of propane, butane and other hydrocarbon gases. If water is present during the process, the production of hydrogen and carbon monoxide can increase from the occurrence of carbon gasification by steam. The yield of oil from tyre pyrolysis is high (50% of initial tyre rubber), reflecting the potential of tyre rubber as a substitute for fossil fuel and chemical feedstock. It is a potential source of energy and chemicals and can be used directly as fuel or added to petroleum refinery feedstock.

Furthermore, tyre pyrolysis can also be performed in an inert environment which can produce 33-38 wt. % of carbon residue and can become a marketable product if the properties are similar to those of manufactured carbons. Chars, 15 wt. % of ash, with the majority of this ash being zinc oxide are parts of the products from tyre pyrolysis. Factors that increase the char yield include a decrease in pyrolysis temperature and an increase in heating rate. Pyrolysis should also be performed under mildly oxidizing conditions, especially in the case of granulated tyres [18-20].

3. Laboratory work

3.1. Material preparations

3.1.1 Rubber ash. Rubber ash was used as partial sand replacement by using a different percentage of rubber which is 0%, 3%, 5%, 7%, 9% from the volume of the sand. Figure 1 shows the rubber ash that is used in this study. The rubber ash has been obtained from rubber factory process at Gopeng, Perak.
3.1.2 Cement. Ordinary Portland Cement (OPC: TYPE I) was used in this study because it has medium rate of hardening and suitable for most type of concrete work and easily available in market and it follow Standards ASTM C150 [21]

3.1.3 Coarse and fine aggregate. Crushed stone with maximum size of 20mm as coarse aggregate and natural sand with maximum size of 4.75 mm as fine aggregate has been used in this study.

3.2. Specimen preparations

There were 30 numbers of specimens (Prims size: 100mm x 100mm x 500mm) had been prepared in this study by using concrete mix design grade 30.

4. Results and discussions

This part discussed the result and analysis that was conducted in the laboratory. Flexural strength test was conducted using Flexural Testing Machine based on standard ASTM C1161-02C [22] at Jamilus Research Centre Laboratory, UTHM.

4.1 Flexural strength

Figure 2 illustrates the flexural strength results of different types of concrete prisms containing different percentages of rubber ash. RA 0, RA 3, RA 5, RA 7 and RA 9 underwent a curing process for 7 days. The maximum load was achieved by RA 3 with a value of 20.126kN. The second highest reading was achieved by the control concrete prism, RA 0, followed by RA 5, RA 7 and RA 9 which achieved readings of 19.886kN, 18.566kN, 18.406kN and 17.325kN respectively. When analysing the bar chart from figure 2, the difference in percentage for flexural strength can be determined by calculating the percentage ratio compared to the value achieved by the control concrete prism, RA 0. For RA 3, the flexural strength increased by 1.21% compared to RA 0. The flexural strength of RA 5 decreased by 6.64% compared to RA 0. Furthermore, the flexural strength of RA 7 decreased by 7.74% compared to RA 0. Lastly, RA 9 showed the highest percentage in terms of the reduction of flexural strength when compared to RA 0, which is 12.87%.
Figure 2. Flexural strength result for 7 days.

Figure 3 shows the maximum deflection of concrete prism for all types of concrete with different percentages of rubber ash. The highest value was 5.261mm for RA 3 followed by concrete prisms RA 0, RA 5, RA 7 and RA 9 with maximum deflection values of 4.877mm, 3.635mm, 0.648mm and 0.5099mm respectively. The difference in percentage in terms of maximum deflection for each concrete prism was compared with the control concrete prism, RA 0. RA 3 showed an increase of about 7.87% while RA 5, RA 7 and RA 9 showed a decrease in value of 25.5%, 86.7% and 89.54% respectively.

Figure 3. Deflection result for 7 days.

From both graphs in figure 2 and figure 3, RA 3 was found to have the optimum content for concrete prisms because it showed the highest values for both maximum load and deflection for the flexural test. For RA 5, RA 7, and RA 9, the flexural strength decreased due to increase in rubber ash content in the concrete. This is because of low bonding between the rubber and the particles in the concrete. Besides that, rubber also has lower bonding abilities compared to fine aggregates. The graph shows that flexural strength decreases when particles of rubber ash are added into the concrete prism. This is similar to a study by Grdic´ et al (2014) [23] where there was a reduction of about 14.6%, 30.4% and 51% with the inclusion of 10%, 20% and 30% of rubber sand respectively for the flexural strength test. It showed a reduction in flexural strength increased with increasing rubber sand content. This is due to the increase in voids and weaker bonding as the rubber content increases.

Figure 4 shows the maximum load of all concrete prisms which underwent 28 days of the curing process. RA 3 shows highest value which was 26.168kN, followed by RA 0, RA 5, RA 7 and RA 9
valued at 21.527kN, 21.647kN, 20.606kN and 18.125kN respectively. The different in percentage for the maximum load for each concrete prism was compared with the control concrete prism RA 0. RA 3 showed an increased value in flexural strength of about 0.976% while RA 5, RA 7 and RA 9 showed a decrease in flexural strength of about 0.006%, 0.043% and 0.158% respectively when compared with RA 0.

![Figure 4. Flexural strength result for 28 days.](image)

Figure 5 shows the maximum deflection of concrete prisms after a curing period of 28 days during the flexural test. This graph also showed that RA 3 had the highest value among the rest which is 3.923mm. This is followed by RA 0, RA 5, RA 7 and RA 9 with values of 1.842mm, 1.584mm, 0.930mm and 0.780 mm respectively. When compared with the control concrete prism RA 0, RA 3 showed an increase in percentage of about 1.13%. While the others, RA 5, RA 7 and RA 9 showed a decrease in terms of percentage difference of about 0.14%, 0.5% and 0.58%.

![Figure 5. Deflection result for 28 days.](image)

Overall, from both graphs in figure 4 and figure 5, increasing values were observed for concrete prisms cured for 28 days compared to those cured for 7 days. This is because the concrete prisms gained 99% in strength in 28 days compared to only 65% in strength for those cured for 7 days. Flexural tensile strength increases when the age of the concrete increases [18]. RA 3 has highest values for both graphs which means that RA 3 is the optimum content for concrete prisms. This trend is similar with a study by Parveen et al. [24] where the result of the flexural strength test for concrete cured for 28 days is higher than the ones cured for 7 days, with the inclusion of 0%, 5%, 10%, 15%, 20%, and 25% of rubber as a replacement for sand in concrete.
5. Crack pattern of concrete prism

![Crack patterns for each concrete prism](image)

**Figure 6.** Crack pattern for each concrete.

Starting from RA 0 to RA 9, the concrete prisms showed the same crack pattern in the middle. The crack happened due to the brittle nature of the concrete. This is because all of these concrete prisms did not provide reinforcement, causing the prism to have no stiffness. Therefore, the concrete prism cannot bear the increasing load capacity. The crack pattern of the concrete prisms only occurred in the middle due to the increasing bending stress in the prism during the flexural test. When compression failure happened, maximum deflection took place and all the concrete prisms became brittle and started to crack. There were no shear cracks at the support point because the concrete prisms are not resistant against shear forces [20,25].

6. Conclusions

RA 3 showed the highest flexural strength, 1.21% and 0.976% increased compared to the normal concrete for concrete aged 7 days and 28 days respectively. RA 3 was found to have the optimum content and the best strength for both concrete aged. However the used of rubber ash more than 3% decreased the flexural strength of the concrete. This concrete could be improved by adding silica fume or fly ash.

7. References

[1] Abdullah S R, Abidin W R W Z and Shahidan S 2016 Strength of Concrete Containing Rubber Particle As Partial Cement Replacement *MATEC Web of Conf.* vol 47 (Paris: EDP Sciences) pp 2–5

[2] Ali N, Zainal N A, Burhanudin M K, Abdul Samad A A, Mohamad N, Shahidan S, Abdullah S R 2016 Physical and Mechanical Properties of Compressed Earth Brick (CEB) Containing Sugarcane Bagasse Ash *MATEC Web of Conf.* vol 47 (Paris: EDP Sciences) pp 1–7

[3] Zheng L, Huo X S and Yuan Y 2008 Strength, Modulus of Elasticity, and Brittleness. Index of Rubberised concrete, *J. Mater. Civil Eng.* 20(11) 692-699

[4] Leman A S, Shahidan S, Senin M S and Hannan N I R R 2016 A Preliminary Study On Chemical And Physical Properties Of Coconut Shell Powder As A Filler In Concrete *IOP*
[5] Senin M S, Shahidan S, Leman A S and Hannan N I R R 2016 Properties of Cement Mortar Containing Rubber Ash as Sand Replacement IOP Conference Series: Materials Science and Engineering vol 160 (London: IOP Publishing) 12059

[6] Ramzi N I R, Shahidan S, Maarof M Z and Ali N 2016 Physical and Chemical Properties of Coal Bottom Ash (CBA) from Tanjung Bin Power Plant IOP Conference Series: Materials Science and Engineering vol 160 (London: IOP Publishing) 12056

[7] Senin M S, Shahidan S, Leman A S and Hannan N I R R 2016 Analysis of Physical Properties and Mineralogical of Pyrolysis Tires Rubber Ash Compared Natural Sand in Concrete material IOP Conference Series: Materials Science and Engineering vol 160 (London: IOP Publishing) 12053

[8] Bakri A M M A, Fadli S A S N, Bakar M D A and Leong K W 2007 Comparison of rubber as aggregate and rubber as filler in concrete 1st Int. Conf. on Sustainable Materials (Penang) (Perlis: Universiti Malaysia Perlis) pp 1-9

[9] Wójtowicz M A, Bassilakis R and Serio M A 2004 Carbon Black Derived From Waste Tire Pyrolysis Oil Retrieved on April 20, 2017 from https://www.researchgate.net/profile/Michael_Serio/publication/238102979_CARBON_BLACK_DERIVED_FROM_WASTE_TIRE_PYROLYSIS_OIL/links/00b7d-52ec1d7b067f3000000.pdf?inViewer=0&pdf3sDownload=0 &origin=publication_detail.

[10] Serio M A, Teng H, Bassilakis R, Marrison P W, Solomon P R 1993 Reprocessing Of Used Tires into Activated Carbon and Other Products, Ind. Eng. Chem. Res. 1995 34 (9), 3102-3111

[11] Juma M, Korňová Z, Markoš J, Anmus J and Jelemenský L 2006 Pyrolysis and Combustion of Scrap Tire, Petroleum & Coal 48(1) 15-26

[12] Khalid F S, Herman H S and Azmi N B 2017 Properties of Sugarcane Fiber on the Strength of the Normal and Lightweight Concrete ) MATEC Web of Conf. vol 103 (Paris: EDP Sciences) 01021

[13] Khalid F S, Herman S H, Azmi N B and Juki M I 2017 Sand Cement Brick Containing Recycled Concrete Aggregate as Fine-Aggregate Replacement MATEC Web of Conf. vol 103 (Paris: EDP Sciences) 01016

[14] Shahidan S, Senin M S, Kadir A A, Yee L H and Ali N 2017 Properties of Concrete Mixes with Carwash Wastewater MATEC Web of Conf. vol 87 (Paris: EDP Sciences) 1018

[15] Shahidan S, Leman A S, Senin M S and Hannan N I R R 2017 Suitability of Coconut Shell Concrete for Precast Cool Wall Panel-A Review MATEC Web of Conf. vol 87 (Paris: EDP Sciences) 1005

[16] Leman A S, Shahidan S, Yusuf M Y, Mohd Zuki M M and Misnon N A 2017 Workability and Compressive Strength for Concrete With Coconut Shell Aggregate 3 Behaviour Of Concrete With Coconut MATEC Web of Conf. vol 87 (Paris: EDP Sciences) 1017

[17] Jing L, Zhou T, Du Q and Wu H 2015 Effects of rubber particles on mechanical properties of lightweight aggregate concrete, Constr. Build. Mater. 91 145–14

[18] Antil Y, Verma V and Singh B 2014 Rubberized concrete with crumb rubber, Int. J. Sci. Res. (IJSR) 3(5) 1481–1483

[19] Shahidan S, Ismail I, Zulkarnaen M S S and Abd Rahman N 2017 Influence of Asphalt Dust Waste Material in Mix Design for Self-Compacting Concrete, Key Eng. Mat. 730 473-478

[20] Shahidan S, Pullin R, Bunnori N M and Zuki S S M 2017 Active crack evaluation in concrete beams using statistical analysis of acoustic emission data, Insight - Non-Destructive Test. Cond. Monit. 59(1) 24–31

[21] ASTM International 2017 ASTM C150 / C150M - 17 Standard Specification for Portland Cement (West Conshohocken: ASTM International)
[22] ASTM International 2017 ASTM C1161 – 02C Standard Test Method for Flexural Strength of Advanced Ceramics at Ambient Temperature (West Conshohocken: ASTM International)

[23] Grdić’Z, Topličić-Curčić G, Ristic’N, Grdić’D and Mitkovic P 2014 Hydro-abrasive resistance and mechanical properties of rubberized concrete, GRAĐEINAR 66 (1) 11–20

[24] Parveen, DassS and Sharma A 2013 Rubberized concrete: needs of good environment (overview), Int. J. Emerg. Technol. Adv. Eng. 3(3) 192–196

[25] McGraw-Hill Encyclopedia of Science & Technology 10th Edition (New York: McGraw-Hill) pp 557-558

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