Hardened properties of concrete with different proportion of crumb rubber and fly ash

A M Najmi¹, A K Mariyana¹², P N Shek¹³ and Z Nurizaty¹

¹School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
²Institute of Noise and Vibration, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
³UTM Construction Research Centre (UTM-CRC), Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

Email: mariyanaida@utm.my

Abstract. The utilisation of waste materials in concrete is one of the sustainable construction approaches introduced in the industry that can indirectly reduce the environmental issues arisen from the disposal problem of the wastes. The aim of this study is to investigate the hardened properties of rubberised pozzolanic concrete (RuPC) with different proportion of crumb rubber and fly ash as partial fine aggregate and ordinary Portland cement (OPC) replacement, respectively. The crumb rubber content replacing fine aggregate is in the range of 0% to 20% while fly ash replacing cement ranges from 0% to 30%. Testing of RuPC with different percentage of crumb rubber and fly ash were performed at the age of 28 days for density, compressive, splitting tensile and flexural strength, and were compared with properties of control specimens. Results showed that the density of RuPC decrease with increase in crumb rubber and fly ash content. The overall strength of RuPC decrease as crumb rubber content increase in which 5% crumb rubber show the least reduction in strength. Replacing 10% cement with fly ash shows improvement in the strength of RuPC when compared to specimens without fly ash, however still lower than strength of control specimen. The optimum crumb rubber replacement is 5% while fly ash is 10% to avoid significant reduction in strength.

1. Introduction
Concrete has been known as the most widely used construction materials in the world. Large amount of concrete production leads to huge consumption of sand, gravel, lime, and other natural resources. Non-stop extraction and increasing usage of the natural resources gave a negative impact on the environment and need to be controlled to preserve nature. Thus any solution that able to reduce even a small quantity of raw materials in concrete gives a significant contribution to the conservation of natural resources [1]. The concept of sustainable construction has been highlighted and one of the approach to assuage the problem is through the utilisation of recycled waste product as construction materials as concrete constituents.

Disposal of scrap tyres has become a worldwide environmental problem. It is estimated that one million tyres are disposed annually and more than half of the amount is discarded without any treatment [2]. Dumping of scrap tyres in landfills is not practical due to non-biodegradable properties of the tires which is space consuming. Improper method of scrap tyres such as burning disposal can lead to various health and environment threat. Thus, researches have taken initiatives to recycle scrap tyres into products that can be used in various fields. One of the approaches is by using crumb rubber
processed from scrap tyres as partial concrete constituent replacement to produce rubberised concrete. Previous research has shown the decrease in strength of concrete incorporating crumb rubber [3]–[6]. However, the reduction in rubberised concrete strength can be minimised through modification of concrete design mix and addition of admixtures such as fly ash and silica fume [7], [8]. Fly ash is an industrial by-product generated from coal-fired power plant and commonly used as mineral admixtures in cement concrete. The utilisation of fly ash in concrete allow for reduction in water consumption of cement, heat reduction of cement hydration and increase the long-term strength of concrete [7]. Furthermore, the usage of fly ash as partial cement replacement in concrete can help to reduce carbon dioxide emission through reduction in cement production [9].

The combination of crumb rubber and fly ash as sustainable green concrete materials has a bright future in the construction industry. Several researches have been carried out to study the performance of concrete with crumb rubber as a partial fine aggregate replacement and fly ash as partial cement replacement. The results have shown improvement in the strength of rubberized concrete with the addition of fly ash when compared rubberised concrete without fly ash [10], [11]. However, many studies are focused on crumb rubber replacing coarse aggregate while research on the performance of crumb rubber as fine aggregate replacement with fly ash in concrete is not much. This study is aimed to determine the hardened properties of concrete with crumb rubber as partial fine aggregate replacement and fly ash as partial cement replacement. Tests conducted in this study include compressive strength, splitting tensile strength and flexural strength. The results obtained were then compared with normal concrete to study the effect of adding crumb rubber and fly ash in concrete.

2. Experimental study

2.1. Materials

Class I ordinary Portland cement with characteristic strength of 42.5 N/mm² was used as the main binder. Tap water that is free from contamination was used. Natural river sand with a maximum size of 5 mm was used as fine aggregate while crushed gravel with a maximum size of 10 mm was used as coarse aggregate. Crumb rubber of size 1 to 3 mm obtained from local recycling plant was used to replace a partial amount of fine aggregate in the concrete mix. The crumb rubber was treated using Sodium Hydroxide (NaOH) solution, rinsed with water and air-dried for 24 hours. Fly ash obtained from the local coal-fired power plant was used as partial cement replacement. Figure 1 and Figure 2 show the crumb rubber and fly ash used in this study.

![Figure 1. 1 mm to 3 mm sized crumb rubber used as partial fine aggregate replacement](image1)

![Figure 2. Fly ash used as partial cement replacement](image2)

2.2. Mix design

Concrete mix design was according to the method as stated in “Design of Normal Concrete Mixes” [12]. The concrete mix was designed with characteristic strength of 30 N/mm² with a constant w/c ratio of 0.55. 17 concrete mixtures were produced included Normal Concrete (NC), Rubberised Concrete (RuC) and Rubberised Pozzolanic Concrete (RuPC) with different replacement percentage of
crumb rubber and fly ash. All mix design parameters were kept constant except for fine aggregate and cement content. Replacement of fine aggregate with crumb rubber was at 5%, 10%, 15% and 20% by weight, whereas cement was replaced by fly ash at 10%, 20% and 30% by weight. The replacement of crumb rubber by weight of fine aggregate is as carried out by previous research [3], [13]–[16]. For example, fine aggregate in normal concrete required 1065 kg/m$^3$ natural fine aggregate, where 5% of the weight is 53 kg/m$^3$, thus 5% crumb rubber directly replaced fine aggregate is equivalent to 53 kg/m$^3$. The mixture proportion is presented in Table 1.

| Specimens  | Cement (kg/m$^3$) | Water (kg/m$^3$) | Coarse aggregate (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Crumb rubber (kg/m$^3$) | Fly ash (kg/m$^3$) | Percentage of crumb rubber (%) | Percentage of fly ash (%) |
|------------|------------------|-----------------|-----------------------------|---------------------------|------------------------|-------------------|-----------------------------|---------------------------|
| NC         | 425              | 235             | 610                         | 1065                      | 0                      | 0                 | 0                           | 0                         |
| 5RuC       | 425              | 235             | 610                         | 1012                      | 53                     | 0                 | 5                           | 0                         |
| 10RuC      | 425              | 235             | 610                         | 959                       | 107                    | 0                 | 10                          | 0                         |
| 15RuC      | 425              | 235             | 610                         | 905                       | 160                    | 0                 | 15                          | 0                         |
| 20RuC      | 425              | 235             | 610                         | 852                       | 213                    | 0                 | 20                          | 0                         |
| 5Ru10PC    | 383              | 235             | 610                         | 1012                      | 53                     | 43                | 5                           | 10                        |
| 10Ru10PC   | 383              | 235             | 610                         | 959                       | 107                    | 43                | 10                          | 10                        |
| 15Ru10PC   | 383              | 235             | 610                         | 905                       | 160                    | 43                | 15                          | 10                        |
| 20Ru10PC   | 383              | 235             | 610                         | 852                       | 213                    | 43                | 20                          | 10                        |
| 5Ru10PC    | 340              | 235             | 610                         | 1012                      | 53                     | 85                | 5                           | 20                        |
| 10Ru10PC   | 340              | 235             | 610                         | 959                       | 107                    | 85                | 10                          | 20                        |
| 15Ru10PC   | 340              | 235             | 610                         | 905                       | 160                    | 85                | 15                          | 20                        |
| 20Ru10PC   | 340              | 235             | 610                         | 852                       | 213                    | 85                | 20                          | 20                        |
| 5Ru10PC    | 298              | 235             | 610                         | 1012                      | 53                     | 128               | 5                           | 30                        |
| 10Ru10PC   | 298              | 235             | 610                         | 959                       | 107                    | 128               | 10                          | 30                        |
| 15Ru10PC   | 298              | 235             | 610                         | 905                       | 160                    | 128               | 15                          | 30                        |
| 20Ru10PC   | 298              | 235             | 610                         | 852                       | 213                    | 128               | 20                          | 30                        |

NC: Normal concrete;  
5RuC: Rubberised Concrete (RuC) with 5% crumb rubber and 0% fly ash replacement;  
5Ru10PC: Rubberised Pozzolanic Concrete (RuPC) with 5% crumb rubber and 10% fly ash replacement.

2.3. Samples preparation
17 batches of concrete mixtures were prepared. 3 cubes (100mm), 3 cylinders (100 mm in diameter and 200 mm in length) and 3 prisms (100 x 100 x 500 mm) of concrete specimens were prepared for each concrete batch. A total 51 cube, 51 cylinder and 51 prism specimens were casted and water cured before tested for density, compressive strength, splitting tensile strength and flexural strength at 28 days.

2.4. Laboratory testing
All the laboratory testing of concrete samples were carried out at the age of 28 days. The compressive strength of hardened concrete was determined according to BS EN 12390-3 using cube concrete specimens. Compression at a constant rate of 0.6 MPa/s was applied onto specimens until failure. The hardened cylindrical concrete specimens were tested for splitting tensile strength according to BS EN 12390-6. The concrete specimen was placed horizontally on the testing platform and loading was applied continuously at a constant rate of 0.05 MPa/s. Concrete specimens were tested until failure and maximum loading were recorded. Tests on flexural strength of concrete specimens were conducted in conformity with BS EN 12390-5. Four point bending is applied in prism concrete specimens
continuous loading at a constant rate of 0.05 MPa/s until failure. The maximum loading for all tests was recorded and the mean of three specimens for every concrete mix was calculated as the final results.

3. Results and discussion

3.1. Density
The density of concrete with the addition of crumb rubber and fly ash is shown in Figure 3 and Table 2. In general, the density of concrete decreased when adding crumb rubber. Normal Concrete (NC) recorded the highest density of 2293 kg/m$^3$. Density of Rubberised Concrete (RuC) decreased by 3% to 11% when replacing natural fine aggregate with 5% to 20% crumb rubber where the density of RuC reduced with increased in crumb rubber content. The reduction in density of concrete containing crumb rubber is due to the ability of rubber to entrap air and the low specific gravity of crumb rubber compared to natural fine aggregate [15], [17], [18]. When cement was replaced with 10% fly ash, the density of Rubberised Pozzolanic Concrete (RuPC) was slightly increased higher compared to RuC, but 2% to 9% lower than NC. This is due to fly ash filling up voids thus increasing the density of the concrete mixture. Replacing cement with 30% fly ash shows the lowest density compared to other concrete specimens.

![Figure 3. Density of hardened concrete with different percentage of crumb rubber and fly ash.](image)

3.2. Compressive strength
In general, the compressive strength of concrete specimens is reduced when replacing natural fine aggregate with crumb rubber. This was confirmed through the test results of the cube compressive strength test at 28 days as shown in Fig. 4 and Table 2. Results showed that all concrete specimens containing crumb rubber had lower compressive strength compared to Normal Concrete (NC) with strength of 34.77 N/mm$^2$. The compressive strength of Rubberised Concrete (RuC) and Rubberised Pozzolanic Concrete (RuPC) decreased significantly with the increase in crumb rubber content. 5% crumb rubber replacement showed the lowest reduction in compression strength, followed by 10% and 15% rubber replacement, and 20% crumb rubber resulted in the lowest concrete strength. The same conclusion was recorded from previous studies [14], [15], stated that the reduction in compressive
strength of concrete with crumb rubber is due to softer crumb rubber compared to natural fine aggregate and lower density which induced crack at the contact zone of crumb rubber and cement matrix. Besides, the generation of voids due to the usage of crumb rubber also reduced the compressive strength of concrete.

The compressive strength of RuPC is slightly improved by replacing 10% of cement with fly ash when compared to RuC without fly ash. This is due to the densification of concrete matrix and pozzolanic reaction produced through utilisation of fly ash. 5Ru10PC with 25.42 N/mm² compressive strength, showed 27% reduction compared to NC while 20Ru30PC shows the highest reduction of 74%. Further replacement of cement with fly ash show lower compression strength compared to RuC. This shows that 10% fly ash replacement is the optimum amount to be used in RuPC to improve the compressive strength of concrete with crumb rubber.

Table 2. Hardened properties of concrete.

| Specimens  | Density (kg/m³) | Compressive strength (N/mm²) | Splitting tensile strength (N/mm²) | Flexural strength (N/mm²) |
|------------|----------------|------------------------------|-----------------------------------|--------------------------|
| NC         | 2293           | 34.8                         | 3.2                               | 4.9                      |
| 5RuC       | 2217           | 22.5                         | 2.5                               | 3.9                      |
| 10RuC      | 2160           | 16.7                         | 2.2                               | 3.5                      |
| 15RuC      | 2090           | 14.3                         | 1.8                               | 2.7                      |
| 20RuC      | 2033           | 10.8                         | 1.6                               | 2.6                      |
| 5Ru10PC    | 2238           | 25.4                         | 2.7                               | 3.9                      |
| 10Ru10PC   | 2168           | 17.7                         | 2.2                               | 3.5                      |
| 15Ru10PC   | 2115           | 15.2                         | 2.1                               | 2.6                      |
| 20Ru10PC   | 2078           | 11.2                         | 1.6                               | 2.4                      |
| 5Ru20PC    | 2225           | 21.8                         | 2.5                               | 3.4                      |
| 10Ru20PC   | 2163           | 16.2                         | 1.9                               | 3.1                      |
| 15Ru20PC   | 2082           | 12.7                         | 1.6                               | 2.6                      |
| 20Ru20PC   | 2053           | 10.4                         | 1.4                               | 2.5                      |
| 5Ru30PC    | 2185           | 19.4                         | 2.3                               | 3.3                      |
| 10Ru30PC   | 2128           | 14.7                         | 1.6                               | 2.8                      |
| 15Ru30PC   | 2070           | 11.6                         | 1.5                               | 2.3                      |
| 20Ru30PC   | 2013           | 9.2                          | 1.2                               | 2.1                      |
Figure 4. Compressive strength of all the concrete mixes at 28 days.

Figure 5 shows the relationship between the density and compressive strength of rubberized concrete with different percentage of crumb rubber and fly ash content. Normal concrete recorded the highest density and compressive strength compared to other rubberized concrete samples. 5% crumb rubber replacing fine aggregate and 10% fly ash replacing cement shows the highest density and compressive strength as stated in Table 2. Based on the graph, it can be said that the density has significant effect on the compressive strength of rubberized concrete. Crumb rubber with lower specific gravity than natural fine aggregate caused rubberized concrete to have lower density, thus reduced the compressive strength. The higher the crumb rubber content further reduced the density and compressive strength of rubberized concrete.

Figure 5. Compressive strength vs density of hardened concrete with different percentage of crumb rubber and fly ash.

3.3. Splitting tensile strength

Figure 6 and Table 2 show the splitting tensile strength at 28 days for NC and concrete specimens with different replacement percentage of crumb rubber and fly ash. Results show that the
splitting tensile strength of concrete behave in the same trend as compressive strength. RuC and RuPC specimens recorded lower splitting tensile strength compared to NC where the strength decreases as the crumb rubber content in concrete mixtures increases [3], [19], [20]. 5% replacement of fine aggregate with crumb rubber shows the least reduction in splitting tensile strength and further addition of crumb rubber caused a significant reduction in strength of concrete. When compared with NC, the decrease in strength of concrete containing 5% crumb rubber were 22% for 5RuC, 14% for 5Ru10PC, 22% for 5Ru20PC and 27% for 5Ru30PC. The reduction in splitting tensile strength is due to the same factors which affect the compressive strength [4]. Replacing 10% cement with fly ash show improvement in splitting tensile strength compared to rubberised concrete without fly ash. The reduction in strength was range from 14% to 48% for Ru10PC, higher than RuC which showed 22% to 50% strength reduction in comparison with NC. When more than 10% fly ash was used, splitting tensile strength drop significantly.

3.4. Flexural strength

Figure 6 shows the variation in flexural strength of concrete specimens with different crumb rubber and fly ash replacement percentage. A gradual reduction in flexural strength was recorded as crumb rubber content was increased as shown in Table 2 and the same conclusion was observed by other researches [15], [21], [22]. The results showed the same reduction pattern as for compressive strength and splitting tensile strength. 5% crumb rubber replacing natural fine aggregate showed the lowest reduction in strength of 21% for 5RuC, 20% for 5Ru10PC, 31% for 5Ru20PC and 33% for 5Ru30PC. The decrease in strength was the highest when replacing fine aggregate with 20% crumb rubber with about 50% reduction for all concrete specimens. When fly ash was considered in the concrete mix, 5Ru10PC and 10Ru10PC showed small improvement in flexural strength of 0.3% and 1% respectively, compared to RuC, whereas strength of other concrete mixes dropped significantly.

![Figure 6. Splitting tensile and flexural strength of concrete specimens at 28 days.](image)

4. Conclusion

This study highlights the effect of replacing natural fine aggregate with crumb rubber and cement with and fly ash at different proportion on concrete hardened concrete at 28 days. The conclusion are presumed:
a) The density of hardened concrete decrease as crumb rubber and fly ash content increase. This might due to lower specific gravity of crumb rubber compared to fine aggregates and increase in porosity caused by usage of crumb rubber.

b) Compressive strength of rubberised concrete decrease as crumb rubber content increase. The reduction in compressive strength is due to softer and lower density crumb rubber, and higher air void content which induced crack at the contact zone of crumb rubber and cement matrix. 10% fly ash replacing cement show improvement in compressive strength through densification of concrete matrix and pozzolanic reaction, compared to rubberised concrete without fly ash.

c) Splitting tensile strength and flexural strength of rubberised concrete decrease with increase in crumb rubber replacing fine aggregate. The same result was observed as compressive strength in which 10% fly ash replacing cement improve the strength of rubberised pozzolanic concrete.

d) In this study, the optimum replacement proportion for crumb rubber replacing natural fine aggregate is 5% while for fly ash replacing cement is 10%.

Results showed that crumb rubber and fly ash in concrete has a bright future to be used as construction material. Improvement on rubberised pozzolanic concrete (RuPC) strength to achieve comparable strength with normal concrete should be carried out to ensure the potential usage in construction. Different water-cement ratio in concrete design mix can be conducted to study the effect of water content toward the overall strength of RuPC.

**Acknowledgments**

The authors would like to acknowledge Universiti Teknologi Malaysia and Ministry of Education for the financial support provided under RUG grant, Q.J130000.2522.19H30 and HICOE grant, R.J130000.7822.4J222.

**References**

[1] K. Rashid, A. Yazdanbakhsh, and M. U. Rehman, “Sustainable selection of the concrete incorporating recycled tire aggregate to be used as medium to low strength material,” *J. Clean. Prod.*, vol. 224, pp. 396–410, 2019.

[2] B. S. Thomas and R. C. Gupta, “A comprehensive review on the applications of waste tire rubber in cement concrete,” *Renew. Sustain. Energy Rev.*, vol. 54, pp. 1323–1333, 2016.

[3] N. N. Gerges, C. A. Issa, and S. A. Fawaz, “Rubber concrete: Mechanical and dynamical properties,” *Case Stud. Constr. Mater.*, vol. 9, p. e00184, 2018.

[4] O. Omuaguluchi and D. K. Panesar, “Hardened properties of concrete mixtures containing pre-coated crumb rubber and silica fume,” vol. 82, pp. 125–131, 2014.

[5] H. Su, J. Yang, T. C. Ling, G. S. Ghataora, and S. Dirar, “Properties of concrete prepared with waste tyre rubber particles of uniform and varying sizes,” *J. Clean. Prod.*, vol. 91, pp. 288–296, 2015.

[6] N. Holmes, A. Browne, and C. Montague, “Acoustic properties of concrete panels with crumb rubber as a fine aggregate replacement,” *Constr. Build. Mater.*, vol. 73, pp. 195–204, 2014.

[7] A. Yilmaz and N. Degirmencı, “Possibility of using waste tire rubber and fly ash with Portland cement as construction materials,” *Waste Manag.*, vol. 29, no. 5, pp. 1541–1546, 2009.

[8] E. Güneyisi, M. Gesoğlu, and T. Özturan, “Properties of rubberized concretes containing silica fume,” *Cem. Concr. Res.*, vol. 34, no. 12, pp. 2309–2317, 2004.

[9] M. C. G. Juenger and R. Siddique, “Recent advances in understanding the role of supplementary cementitious materials in concrete,” *Cem. Concr. Res.*, vol. 78, pp. 71–80, 2015.

[10] V. Porwal and R. Dwivedi, “Studies on Tyre Aggregate Concrete with Fly Ash,” *Int. J. Sci. Res.*, vol. 5, no. 8, pp. 708–711, 2016.

[11] I. C. S. Reddy, J. D. Reddy, and V. R. Krishnan, “Influence of Fly Ash on Rubberized Concrete,” *Int. J. Innov. Res. Sci. Technol.*, vol. 3, no. 9, pp. 115–118, 2017.

[12] D. C. Teychenné, R. E. Franklin, H. C. Erntroy, J. C. Nicholls, D. W. Hobbs, and D. W. Marsh,
Design of normal concrete mixes, Second Edi. United Kingdom: BUILDING RESEARCH ESTABLISHMENT, 1997.

[13] M. S. Senin, S. Shahidan, A. S. Leman, and N. I. R. R. Hannan, “Properties of Cement Mortar Containing Rubber Ash as Sand Replacement,” IOP Conf. Ser. Mater. Sci. Eng., vol. 160, no. 1, 2016.

[14] G. Girskas and D. Nagrockienė, “Crushed rubber waste impact of concrete basic properties,” Constr. Build. Mater., vol. 140, no. November, pp. 36–42, Jun. 2017.

[15] K. Bisht and P. V. Ramana, “Evaluation of mechanical and durability properties of crumb rubber concrete,” Constr. Build. Mater., vol. 155, pp. 811–817, 2017.

[16] P. Sugapriya and R. Ramkrishnan, “Crumb Rubber Recycling in Enhancing Damping Properties of Concrete,” IOP Conf. Ser. Mater. Sci. Eng., vol. 310, no. 1, p. 012013, Feb. 2018.

[17] A. M. Rashad, “A comprehensive overview about recycling rubber as fine aggregate replacement in traditional cementitious materials,” Int. J. Sustain. Built Environ., vol. 5, no. 1, pp. 46–82, Jun. 2016.

[18] S. Raffoul, R. García, K. Pilakoutas, M. Guadagnini, and N. F. Medina, “Optimisation of rubberised concrete with high rubber content: An experimental investigation,” Constr. Build. Mater., vol. 124, pp. 391–404, 2016.

[19] K. B. Najim and M. R. Hall, “Mechanical and dynamic properties of self-compacting crumb rubber modified concrete,” Constr. Build. Mater., vol. 27, no. 1, pp. 521–530, 2012.

[20] M. Gesoğlu, E. Güneyisi, G. Khoshnaw, and S. Ipek, “Investigating properties of pervious concretes containing waste tire rubbers,” Constr. Build. Mater., vol. 63, pp. 206–213, 2014.

[21] B. S. Thomas and R. Chandra Gupta, “Properties of high strength concrete containing scrap tire rubber,” J. Clean. Prod., vol. 113, pp. 86–92, 2016.

[22] M. Safan, F. M. Eid, and M. Awad, “Enhanced Properties of Crumb Rubber and Its Application in Rubberized Concrete,” Int. J. Curr. Eng. Technol., vol. 7, no. 5, pp. 1784–1790, 2017.