A review: Study on waste rubber as construction material

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Abstract. Sustainable construction is highlighted in current development as the environmental issue is one of the major issues of global concern. This issue also relates to waste generated each year. The bulk of waste was estimated to increase, which can reduce space in the world and can cause pollution. Many researchers have come up with inventions and ideas to manage that situation. Some researchers use the waste rubber in a concrete mix as a partial coarse or fine aggregate replacement. The alternative in a concrete mix depends on the size of the rubber that is used and the appropriateness. In this paper, the critical perspective of waste rubbers discussed in detail. It is shown from the review that if compared with the existing one, there is some reduction in the workability and mechanical properties of concrete. Rubberised concrete, however, still has its superiority in terms of energy absorption. The use of pozzolanic material in the concrete mix, the application, the proportion of rubber and the choice of rubber types helps a lot to compensate for the weakness of rubberised concrete.

1. Introduction
Nowadays, the recent global concern is related to waste issues which include environmental issues. Waste production is a serious problem as the Kaza et al. [1] estimated that annually the waste production exceeds 2.01 billion tons of metric worldwide. Kaza et al. [1] also estimated that the waste would increase to 3.40 billion metric tons by 2050. Until now, the management of dumped waste has not been managed effectively since waste production increases every year, especially with the increase of the human population. The bulk of the waste has caused world space to decrease. Waste may be classified into waste which is degradable and non-degradable. Compared with non-degradable waste, degradable waste won't become a big concern. While, the non-degradable waste is not easy to decompose, and it may be expensive to decompose. It takes 10 to 100 years for the non-degradable waste to decompose. Plastic, metal, glass, and rubber are among the examples of non-degradable waste.

Rubber production is essential in the modernization era nowadays, especially for tyres. Tyre rubber has huge importance as a material for all modes of transport. It has been reported that about 1.5 billion tyres are being generated worldwide [2]. This also makes the production of rubber waste rising. The production of this material will rise with the population expansion as about 5 billion waste tyres are expected to be produced by 2030 [3]. The estimate is that one billion waste tyres are produced worldwide annually [4]. It will also make a huge proportion of waste output that can damage our environment. Tyre waste can cause air pollution because mostly they are burnt as this is the only cheap and easy way to discard it in a short time and minimize landfill area space, as shown in figure 1. This action can therefore cause pollution to the atmosphere. Besides, this waste has become one of the biggest issues since the
stockpile tyre tends to create health problems too [5]. The challenges include being helpful in the breeding of mosquitoes [5] and rodents which can cause illnesses [6] such as Dengue and Leptospirosis. Therefore, some countries in Europe have stopped the disposal of waste tyres in landfill areas since 2006 [7]. Many other countries also face the waste tyres in stockpile and these countries have set the rule to include some percentage of waste tyre rubber in construction use in order to solve these problems.

![Figure 1. Waste tyre rubber at landfill area [8].](image)

In civil engineering, rubber is frequently used as a partial replacement in concrete or pavement. It yields a lot of benefits in reducing the use of natural resources in concrete ingredients and can improve their performance at the same time. In concrete aggregate, as it has hydrophobic features, rubber faces some significant challenges to be compatible with concrete. Rubberised concrete also has strong characteristics in terms of shock absorber and sound absorber [9]. In 1993, Eldin and Senouci began innovating tyre waste in concrete [10]. Because of the potential of rubber used in concrete, researchers are carrying out many studies to improve the concrete characteristics so that it can work well as a rubberised concrete. The studies include selected rubber types and proper mixing procedures. Around 50% of natural resources are used in civil construction [11]. Reducing the use of natural resources in civil engineering including in concrete can therefore help to cause environmental advantages by partially replacing it with waste material.

Concrete is extravagantly used as a material of building because it is economical in price and available worldwide. Concrete ingredients basically consist of 70% of the aggregated natural resources. This material is crucial in the production of concrete, which affects the concrete properties. The mineral aggregate has continued to decline with the passage of time because of its extensive use [12-13]. It was very troubling that this material would be resource constraining because global demand has already exceeded 4.5 billion tonnes [14]. Reducing the natural resources used may therefore, help improve our environment. Moreover, the involvement of other ingredients with mineral aggregates alike can help to overcome these problems. Being aware of this problem allows researchers around the world to come up with many ideas and solutions. Also, many stakeholders take part in fixing this issue before it gets worse. These stakeholders agree that the idea of recycling can handle particularly non-degradable waste materials. The recycling process not only reduces the bulk of the waste and usage of natural resources, but it can also cause benefits from the previous waste by producing new, innovative material. Many researchers have successfully studied the innovation of non-degradable wastes [3, 8, 15]. This review paper focuses on ten years of journal papers that have considered rubberised concrete. It also focuses on the size, percentage and procedure of mixing of rubber that many studies have suggested. The gap of this critical review is that this paper shows the latest studies which are sufficiently relevant to address the issue. The paper also aims to show that waste rubber can be used in concrete as a partial substitute, and can also offer a lot of advantages from various viewpoints if the scale of waste rubber and methods are applied with caution.
2. Waste rubber

2.1. Composition of tyre rubber

A tyre is made up of natural rubber, synthetic rubber or a combination of natural and synthetic rubber surrounding a wheel [16]. Mostly tyre rubber is made using a combination of natural and synthetic rubber [16]. The tyre composition was added according to their suitability of use. The different compositions of tyres based on the various types of vehicles. It is showed from the previous studies that the highest ingredient percentage comes from rubber and carbon black has always been an essential material other than rubber itself [17].

Many researchers are studying the benefits of rubber in concrete to enhance concrete performance. Usually, the waste rubber of tyres is cut using machines in different sizes to be re-used in construction for different purposes due to the goal of reducing waste production on landfill and illegal dumping activities to prevent harm towards humans and the environment. Figure 2 shows the various sizes of waste tyres that have been processed to be used. Waste rubber can be divided into three categories, which are shredded / chipped rubber (13 – 76 mm), crumb rubber (0.425 – 4.75 mm) and ground rubber (0.075 – 0.425 mm) [18].

![Figure 2. Reprocess of waste tyre rubber [19]](image)

3. Rubberised concrete properties

3.1 Workability

Workability is an essential property of concrete mixtures revealing there feasibility. It does indeed have a significant effect on concrete's ultimate strength. Workability also much depends on the features of the raw material used in the design of concrete mixtures. With the increase in rubber content, the workability of a rubberised concrete tends to decrease [15,17,20-27]. Besides, the contrasting result showed that the presence of rubber in concrete mixtures could increase the workability [28,29]. The result variation was due to the variation in particle size [29]. It is shown in this study that the size and quantity of rubber are essential regarding the workability of concrete [29]. Other than this, the combination of powdered rubber and crumb rubber with appropriate admixture reveals good results compared to chipped rubber and plain concrete. Based on Yang et al. [17], the summary of the results show that concrete specimens prepared with larger particles of rubber exhibit better workability than those with finer ones, also supported Li et al. [22] and Rashid et al. [23].

At the same time, the use of various sizes of rubber particles in concrete as part of the fine aggregates influences the workability and the rubber aggregates of various sizes with continuous grading offer more excellent workability. However, the complete contrast result showed that the reduction of workability which the slump test result show 50% reduction compare to control due to increasing of particle size [20]. The larger rubber particles cause increased friction between the angular rubber particles. Besides, the pre-treatment of rubber also influences the workability of fresh concrete. This has already been studied by some of the researchers [28,30-34]. The treatment of rubber with 10% NaOH treatment for 120 minutes, water wash followed by drying caused decreases in workability [28,30]. While saturated 30 minute NaOH followed by water wash and drying also yielded the same results [33]. Furthermore, H2O2, CaCl2, KMNO4 and NaHSO4 also led to reduced fresh concrete workability [30]. However, the pre-treatment of H2SO4 caused an increase in workability by 95% H2SO4 in 1 minute, followed by water wash and drying [31-32].
3.2. Mechanical properties

Mechanical properties are an important indicator of the toughness of concrete to be used, either it follows the minimum requirement for a structural element or not. Some of the studies found out that rubber can contribute towards the reduction of compressive strength. However, the rate of reduction depends on the size of the rubber chunks used [35-37]. They also concluded that the replacement of coarse aggregates with chipped rubber showed worse compressive strength values with about 85% decrease (compared with controlled) while fine aggregate replacement with crumb rubber, 65% decrease (compared with controlled). If a comparison is made between crumb rubber and chipped rubber, chipped rubber results in higher losses in strength compared to crumb rubber. The reason is due to the physical characteristics of the rubber itself, which low water absorption is associated with low result in specific gravity. This characteristic causes less bonding of rubber with other concrete ingredients. Besides, the weak bonding between cement paste and rubber create void and trapped air between them. Although increasing rubber percentage may decrease the concrete strength, crumb rubber is better compared with other types of rubber [14]. The ability of rubber as a partial replacement for fine aggregate caused some studies have been conducted to affirm the statement [37-38].

Researchers also reported that compressive strength tends to decrease with a rise in the proportion of rubber content [14,21,35,36,39-41]. The content of rubber should be limited by the amount of 20% to 30%, and the rubber also should undergo pre-treatment and involvement of pozzolanic material [41]. Some of the researchers also agreed that 10% replacement of rubber (by volume) is the optimum result of mechanical properties [29,42]. While some of the researchers [43-44], they agreed that less than 20% and 25% replacement of crumb rubber by volume respectively gave better results for compressive strength. The decreasing trend in mechanical properties was related to the vastly lower rubber stiffness (< 5 MPa), the unequal distribution of the rubber aggregate, lightweight and the weak bonding between the rubber aggregate and the cement paste [29,45-47].

The pre-treatment of rubber also affects the compressive strength [30,48]. Correspondingly, NaOH can increase the mechanical properties of concrete [28,30-31,48-49]. In these two studies [50-51], they found that water soaking rubber aggregates for 24 hours would lead to a substantial improvement in the compressive strength after 28 days. They agreed that soaking rubber particles helps to remove the air trapped in rubber particles, thereby improving the bonding performance of rubber with cement. One study has studied the effect of sodium hydroxide, sulfuric acid, calcium hydroxide, and acetic acid solutions, treating crumb rubber on the mechanical properties of crumb rubber concrete [33]. With all the treatment methods, the authors noted an improvement in compressive strength after 28 days compared to that of untreated rubber concrete [33]. This is due to the increasing surface roughness of the rubber. From all of this pre-treatment, NaOH showed the best result of compressive strength. Besides, the involvement of pozzolanic materials such as silica fume, fly ash or RHA can also help in improving the strength of rubberized concrete [30,52-55]. For the result of tensile strength, most of the researchers found that the trends followed compressive strength result [3,8,54,56-57].

For the Modulus of Elasticity, the researcher noticed that with the increase in particle size, the elastic module tends to increase [58]. While some of the authors also agreed that the elastic modulus showed decreasing result when the rubber content was increasing [49,59]. Compared with natural aggregates for treated and untreated samples, the rubber aggregate presented an apparently low elastic modulus if compared with natural aggregate, which in accordance was obtained by Gupta et al. [21]. The reduction in the modulus was directly related to the partial substitution of rigid fine aggregates by rubber particles with low elastic modulus. It shows that the concrete's elastic modulus depends on the aggregate's elastic modulus [60]. However, the condition of modulus of elasticity for rubberized concrete with the involvement of silica fume was increased to 24.4%. The author agrees that the presence of silica caused it to fill the pores with silica between the aggregate and the cement paste [61].
3.3. Energy absorption

Energy absorption of concrete is related to the toughness of concrete [62]. The toughness of concrete means the capacity of energy production at the time of fracture. It was observed by identifying the condition of plastic and elastic properties at that time. In normal concrete, elastic energy capacities are higher than plastic energy capacities. However, many studies have shown that by adding the rubber as an ingredient in concrete to replace some portion of aggregate was helpful to twist the original condition of normal concrete [8, 21, 59-64]. The elastic energy capacities of concrete by the presence of rubber inside it, start to decrease, and plastic energy capacities start to increase [65]. The study also showed that the energy of fracture rose up to 20% level of replacement [63]. Besides, based on these author [59, 66-67], the replacement of crumb rubber in fine aggregate gave good results regarding energy absorption with the increasing percentage of rubber contain. Studies also reveal that waste rubber can be used as a sustainable material for developing concrete's good impact resistance and flexibility [21, 68]. Moreover, the studies [69-70] also showed that crumb rubber concrete's energy absorption capacity is better than normal concrete and the rubber content is more significant than the size of the rubber to improve the energy absorption.

4. Conclusion

This review paper has presented the findings of 70 studies published over the last ten years. This extensive review of research data has led to the following conclusions. Firstly, the workability of concrete. The involvement of rubber in concrete mix decreased the workability of concrete. Besides, the increasing of rubber contains caused reduction of concrete workability. It is also affected by the size of rubber. The larger the size of the rubber, the lesser will be the workability of concrete and the pre-treatment of rubber does not help in improving the workability of concrete. For the mechanical properties, the increasing of rubber replacement and size caused a reduction towards mechanical properties such as compressive strength, tensile strength and Modulus of Elasticity (MoE). However, the pre-treatment and pozzolanic material help in increasing the compressive strength result and tensile strength result. For the treatment, NaOH was suggested by many researchers as a pre-treatment of rubber which for the pre-treatment and as a concrete material. Crumb rubber is a suitable size to be partially replaced in fine aggregate. The result of MoE also tends to decrease with an increase in rubber content. Lastly, the result of energy absorption shows the increasing result with the increase of rubber percentage which the crumb rubber is suitable to be used to produce good energy absorption. Therefore, from the reviews, the replacement of crumb rubber in concrete suitable to be applied as energy absorber structure.

5. References

[1] Kaza S, Yao L, Bhada-Tata P, Van Woerden F 2018 What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 (Washington DC: World Bank Publications)
[2] Mashiri M S, Vinod J S, Sheikh M N, Tsang H H 2015 Shear strength and dilatancy behaviour of sand–tyre chip mixtures, Soils Found. 55 517–528
[3] Thomas B S, Gupta R C 2016 A comprehensive review on the applications of waste tire rubber in cement concrete, Renewable and Sustainable Energy Reviews. 54 1323–1333
[4] Mouri H 2016 Bridgestone’s View on Circular Economy, in Towards a Circular Economy: Corporate Management and Policy Pathways.ERIA, Research Project Report 2014-44, Jakarta pp. 31–42
[5] Mohajerani A, Burnett L, Smith J V, Markovski S, Rodwell G, Rahman M T, Kurmus H, Mirzababaei M, Arulrajah A, Horpibulsuk S, Maghool F 2020 Recycling waste rubber tyres in construction materials and associated environmental considerations: A review, Resources, Conservation & Recycling. 155 104679
[6] Bjegovic D, Lakusic S, Baricevic A, Serdar M, Haladin I 2013 Innovative use of waste tyres for sustainable concrete technology, International Advances in Cement and Concrete Technology 199 535-542
[7] Lindhjem H 2009 The Use of Economic Instruments in Nordic Environmental Policy 2006-2009 (Nordic: Council of Ministers) p 144
[8] Rashad A M 2016 A comprehensive overview about recycling rubber as fine aggregate replacement in traditional cementitious materials, *International Journal of Sustainable Built Environment*. 5 46–82

[9] Topcu I B and Unverdi A 2018 *Utilization of waste rubber in construction applications* Waste and Supplementary Cementitious Materials in Concrete (Cambridge: Woodhead Publishing Chapter 2) pp 51-77

[10] Guo H, Yu Y and Skitmore M 2017 Visualization technology-based construction safety management: A review, *Automation in Construction*. 73 135-144

[11] Erdem S, Gürbüz E, Uysal M 2018 Micro-mechanical analysis and X-ray computed tomography quantification of damage in concrete with industrial by-products and construction waste, *Journal of Cleaner Production*. 189 933-940

[12] Skrzypczak I, Kokoszk W, Ożóg L B, Kogut J, Slowik M 2017 Environmental aspects and renewable energy sources in the production of construction aggregate, *E3S Web of Conferences*. 22 00160

[13] Alexander M and Mindess S 2015 *Aggregates in Concrete* (CRC Press) p 253

[14] Mushunje K, Otieno M and Ballim Y 2018 A review of Waste Tyre Rubber as an Alternative Concrete Constituent Material, *MATEC Web of Conferences*. 199 11003

[15] Bisht K, Ramana P V 2017 Evaluation of mechanical and durability properties of crumb rubber concrete, *Construction and Building Materials*. 155 811–817

[16] Department of Environmental Affairs 2012 *Integrated Industry Waste Tyre Management Plan of the Recycling and Economic Development Initiative of South Africa* Retrieved on December 20, 2012 from https://www.environment.gov.za/content/resumption_redisa_plan

[17] Yang J, Ling T C (Bill), Ghataora G S and Dirar S 2015 Properties of concrete prepared with waste tyre rubber particles of uniform and varying sizes, *Journal of Cleaner Production*. 91 288-296

[18] Ganjian E, Khorami M, Maghsoudi A A 2009 Scrap-tyre-rubber replacement for aggregate and filler in concrete, *Constr Build Mater*. 23 1828–1836

[19] Rerubber 2017 *Crumb Rubber* Retrieved on July 28, 2017 from http://www.rerubber.com/crumb-rubber/

[20] Holmes N, Browne A and Montague C 2014 Acoustic properties of concrete panels with crumb rubber as a fine aggregate replacement, *Construction Building Material*. 73 195–204

[21] Gupta T, Chaudhary S and Sharma R K 2014 Assessment of mechanical and durability properties of concrete containing waste rubber tire as fine aggregate, *Construction Building Material* 73 562–574

[22] Li N, Long G, Ma C, Fu Q, Zeng X, Ma K, Xie Y and Luo B 2019 Properties of self- compacting concrete (SCC) with recycled tire rubber aggregate: a comprehensive study, *J. Cleaner Prod.* 236 117707

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

[24] Hossain F Z, Shahjalal M, Islam K, Tiznobaik M and Alam M S 2019 Mechanical properties of recycled aggregate concrete containing crumb rubber and polypropylene fiber, *Constr. Build. Mater.* 225 983–996

[25] Lv J, Du Q, Zhou T, He Z and Li K 2019 Fresh and mechanical properties of self- compacting rubber lightweight aggregate concrete and corresponding mortar, *Adv. Mater. Sci. Eng. Struct 2019* 1-14

[26] Aslani F, Ma G, Wan D L Y and Muselin G 2018 Development of high-performance self-compacting concrete using waste recycled concrete aggregates and rubber granules, *J. Cleaner Prod.* 182 553–566

[27] Stallings K A, Durham S A and Chorzea M G 2019 Effect of cement content and recycled rubber particle size on the performance of rubber-modified concrete, *Int. J. Sustain. Eng*. 12 189–200

[28] Mills Y O, Julie E and Reza H 2016 Assessment of the mechanical performance of crumb rubber concrete, *Construction and Building Materials* 125 175–183
Mohammadi I, Khabbaz H and Vessalas K 2014 In-depth assessment of Crumb Rubber Concrete (CRC) prepared by water-soaking treatment method for rigid pavements, Constr. Build. Mater. 71 456–471
[51] Mohammadi I and Khabbaz H 2015 Shrinkage performance of crumb rubber concrete (CRC) prepared by water-soaking treatment method for rigid pavements, *Cem. Concr. Compos.* 62 106–116

[52] Hadipramana J, Samad A A A, Ibrahim R, Mohamad N and Riza F V 2016 The energy absorption of modified foamed concrete with rice husk ash 11 7437-7442

[53] Xu W, Lo T Y and Memon S A 2012 Microstructure and reactivity of rich husk ash, *Construction and Building Materials.* 62 106–116

[54] Copetti C M, Borges P M, Squiavon J Z, da Silva S R and Andrade J J D O 2020 Evaluation of tire rubber surface pre-treatment and silica fume on physical-mechanical behaviour and microstructural properties of concrete. 256 120670

[55] Aslani F, Ma G, Yim Wan D L and Tran Le V X 2018 Experimental investigation into rubber granules and their effects on the fresh and hardened properties of self-compacting concrete, *Journal of Cleaner Production* 172 1835- 1847

[56] Youssf O, Julie E. Mills and Hassanli R 2016 Assessment of the mechanical performance of crumb rubber concrete, *Construction and Building Materials* 125 175–183

[57] Jokar F, Khorram M, Karimi G and Hataf N 2019 Experimental investigation of mechanical properties of crumbed rubber concrete containing natural zeolite, *Construction and Building Materials* 208 651–658

[58] Li L, Ruan S and Zeng L 2014 Mechanical properties and constitutive equations of concrete containing a low volume of tire rubber particles, *Constr. Build. Mater.* 70 291–308

[59] Atahan A O and Yücel A O 2012 Crumb rubber in concrete: Static and dynamic evaluation, *Construction and Building Materials* 36 617–622

[60] Onuaguluchi O and Panesar D K 2014 Hardened properties of concrete mixtures containing pre-coated crumb rubber and silica fume, *Journal of Cleaner Production* 82 125-131

[61] Gupta T, Chaudhary S and Sharma R K 2016 Mechanical and durability properties of waste rubber fiber concrete with and without silica fume, *Journal of Cleaner Production* 112 702-711

[62] Topcu, I B 2018 The Properties of Rubberized Concrete. *Cement and Concrete Research.* 25 304–310

[63] Roychand R, Rebecca J. Gravina, Zhuge Y, Ma X, Youssf O and Mills J E 2020 A comprehensive review on the mechanical properties of waste tire rubber concrete, *Construction and Building Materials.* 237 117651

[64] Najib N, Gergesa, Issa C A, Samer A and Fawaz 2018 Rubber concrete: Mechanical and dynamical properties, *Case Studies in Construction Materials* 9 1-13

[65] Guoqiang L, Su-Seng P, Samuel and Ibekwe I 2011 FRP tube encased rubberized concrete cylinders, *Mater. Struct.* 44 233–243

[66] Ozbay E, Lachemi M and Sevim U K 2011 Compressive strength, abrasion resistance and energy absorption capacity of rubberized concretes with and without slag, *Mater. Struct.* 44 1297–1307

[67] Ganesan N, Raj B and Shashikala A P 2013. Behavior of self-consoli- dating rubberized concrete beam-column joints, *ACI Mater. J.* 110 697–704

[68] Najim, Khalid B, Hall and Matthew R 2012 Mechanical and dynamic properties of self-compacting crumb rubber modified concrete, *Constr. Build. Mater.* 27 521–530

[69] Xu J, Yao Z, Yang G and Han Q 2020 Research on crumb rubber concrete: From a multi-scale review, *Construction and Building Materials.* 232 117282

[70] Issa C A and Salem G 2013 Utilization of recycled crumb rubber as fine aggregates in concrete mix design, *Constr. Build. Mater.* 42 48–52

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