Sustainable concrete with scrap tyre: Impact on strength and health

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Abstract. The increasing of scrap tyres is unknown to what extent these tyres are disposed of in a way that is environmentally friendly and legal. Therefore, one way should be worked out to reduce scrap tyres and preserving the environment. To relate the issue of achieving environmental sustainability with the construction industry, this study was carried out by adopting scrap tyres crumbs replacing coarse aggregates in the concrete mixture called as tyre crumbs concrete (TCC). This study aimed to investigate the compressive strength of TCC and the effect of its use as construction materials, to consumer health. The TCC mixtures were designed in various replacement of coarse aggregate with tyres crumbs of 5%, 10%, and 15% over coarse aggregate volume. All specimens were tested in both material strength and environmental laboratory to determine TCC structural strength and also the hazardous level of TCC to the life health through water quality test. The result of this study found that 10% of the scrap tyres replacement is the most optimum TCC mixture design in which the strength is similar to the control concrete. The environmental test on curing water also found the pH, BOD, and COD gave no harmful substances leaching from the cube specimens. In conclusion, the use of scrap tyres in concrete manufacturing can reach the sustainability of construction resource, environmentally and economically, in line with Sustainability Development Goal 2030, the agenda of the United Nations Development Program.

1. Introduction
Scrap tyres crisis at the West including Malaysia becomes serious when many of the waste sent to the landfill sites, only a small portion is sent to trader's collectors and recycling centers. A total of 29 million tonnes of rubber consumed in various industries where 986 thousand tonnes were consumed by Malaysia in 2018 and the volume trend is increasing year by year [1]. The tyre industry is one of the product sectors that consumed about 66 thousand tonnes of rubber. It can be concluded that, the same amount of tyres consume in 2018 had become end-of-life tyres in 2019. Malaysia construction industry nowadays has been extensively investigating the use of by-products to replace natural resources to support the world's aspiration to achieve Goal 9 in 2030 Sustainable Development Goals [2].

Rubber tyre made by rubber with black filler to enhance the strength properties of rubber vulcanize to achieve an average tensile strength of 20MPa and 70 hardness [3]. There are several types of carbon fillers such as N-200 ISAF (Intermediate Super Abrasion Furnace), N-300 HAF (High Abrasion Furnace), N-500 FEF (Fast Extruding Furnace) and N-660 GPF (General Purpose Furnace).
The use of crumb tyre in the concrete mixture has been growing in approval in some research studies that have been conducted. Among these previous studies, the crumb tyre is suitable to replace natural aggregates as it is comparable with the controlled concrete and its benefits in natural aggregate preservation. Based on previous studies some findings have been reported to optimize the use of crumb rubber in this research:

(a) Replacing 5%-20% natural sands with rubber decreased the compressive strength of concrete cylinders but good in dynamic performance as its high resilient nature [4]. Rubber concrete also possesses desirable properties such as lower density, higher impact resistance, and higher in toughness.

(b) An analytical study using the method of initial function (MIF) has been conducted to rubber aggregate concrete beam to determine its physomechanical properties. It was found that optimum rubber aggregate replacement can be up to 15% [5]. However, such concrete cannot be used as structural elements except other construction elements like partition walls, road barriers, pavements, and sidewalks.

(c) Rubber tyre with a maximum size of 20mm used to replace 50% of natural aggregates in concrete cube mixtures had given 4.1MPa compressive strength which lower than controlled, 19.03MPa[6]. However, the density reduced about 10% over the controlled cube. The flexural strength of the beam contained rubber tyre also decreased by 65%, thus, this rubberized concrete did not sustain bending.

(d) Analytical studies using Abaqus and laboratory test has been conducted for concrete contained 0% -20% crumb rubber over fine aggregate [7]. It was found that the water absorption of rubber concrete increased as the percentage of crumb rubber was increased. The results also showed the was no presence of corrosion in the specimens from the macro cell corrosion test. The study concluded that the rubberized concrete is suitable to be used in the area where there are chances of acid attack to be happened.

(e) The workability of tyre concrete mix is measured from the slump test. Research results by [8] have shown that the use of rubber crumbs with a maximum size of 25mm causing an increment in terms of workability. The increment is directly proportional to the increase in rubber crumbs content.

Among the results mentioned above, most of the research was conducted to determine the mechanical properties of TCC while no report is available on the effect of TCC on life health. Typically, tyres are made of rubber with various chemicals. Rubber exposed to heat and rain promotes a chemical reaction that may be harmful to health. Therefore, this is one of the matters to look into to further strengthen the use of scrap tyres in the construction industry.

2. Experimental Program

2.1. TCC mix design

The concrete mix design is based on the DOE basic procedures and method set out in the Building Research Establishment Report: ‘Design of Normal Concrete Mixes’ which is suitable for producing multi-purpose concrete [9]. The basic procedure is very important to be followed to achieve the correct workability of concrete mix, compression strength, and durability of the concrete cube as defined in British Standard. In this study, a concrete mix design has been aimed to achieve grade 30 concrete with a target mean strength of 46MPa on the 28th day. Other important requirements used in this design are 0.46 w/c ratio, while sand and coarse aggregate used were uncrushed and crushed, respectively. The size of additional material which is crumb rubbers from scrap tyre is 20mm. The grade 30 concrete mix was then divided into 4 different mixes according to 4 different crumb rubber content. The variation of crumb tyre content was 0% (control specimens), 5%, 10% and 15% out of coarse aggregate volume.

2.2. Specimens preparation

The dimension of TCC cube specimens produced for each concrete mixture was 100mm × 100mm × 100mm [10, 11]. Before casting, each concrete mixtures were tested for its workability through a
slump test [12]. The hardened TCC cubes then demoulded after 24 hours and placed in 3 different water tanks for the curing process until took out for compressive strength test on 7th, 14th and 28th day [13-15]. At the 28th day, curing water of concrete cubes has been taken to test on the quality of water in terms of pH value, chemical oxygen demand (COD) and biological oxygen demand (BOD) of the leachate.

3. Experimental work and result discussion

3.1. Workability
The workability of fresh concrete has been measured through a slump test. The procedures and values of the slump were recorded following the BS EN 12350-2 [12]. The standard slump value is between 10mm to 210mm. Each form of the slump has also been observed to classify slump types, either collapse, shear slump, or true slump. All slumps obtained were the true slump. Figure 1 shows the slump value of all mixes. It was observed that there was an increase in slump value as the crumb rubber content was increased. The largest slump is 180mm which is the slump of 15% crumb rubber content. The workability of this concrete mix was increased by 35% compared to the control concrete mix.

![Figure 1. Slump value of all concrete mixes.](image)

3.2. Compressive strength
The testing of compressive strength procedures was followed the EN12350-3 standards test method for cube specimens [15]. The ultimate load of each specimen was recorded as shown in Figure 2. It can be observed that compressive strength at 28 days for TCC with 5% rubber aggregate (TCC-5%) had higher strength compared to TCC-10% and TCC-15%, but its strength was lower than control cubes about 38%. However, the compressive strength of TCC achieved the design strength of 30MPa.

From the results, it can be seen that increasing the replacement of natural aggregate with tyre crumb up to 15% led to decrease the compressive strength development. The replacement with 10% to 15% showed the target design strength neither can be achieved. Furthermore, this study confirms the potential use of artificial aggregates from tyre crumb as construction materials limited to only 5% replacement with natural aggregates.

3.3. Water quality
For the effect on consumer health, the water leached at 28 days of curing stage was tested in the environmental laboratory. Water quality test has been carried out to determine pH, chemical oxygen demand (COD), and biological oxygen demand (BOD). The results obtained were then compared with National Water Quality Standards for Malaysia which was acquired in the "Environmental Quality Act
1974". According to the standards, several types of water have been classified, from Class I to Class V according to water use as shown in Table 1 [16].

![Figure 2. Compressive strength of concrete cubes of all concrete mixes.](image)

**Table 1. National Water Quality Standards for Malaysia [16].**

| Parameter | Unit | CLASS   |
|-----------|------|---------|
| pH        |      | I       | II       | III      | IV       | V       |
|           |      | 6.5-8.5 | 6-9      | 5-9      | 5-9      | -       |
| COD       | mg/l | 10      | 25       | 50       | 100      | >100    |
| BOD       | mg/l | 1       | 3        | 6        | 12       | >12     |

**Class I:** Conservative of the natural environment.
Water supply I- Practically no treatment necessary
Fishery- very sensitive aquatic species

**Class II:** Water supply II- conventional treatment
Fishery II- sensitive aquatic species
Recreational use body contact

**Class III:** Water supply III- Extensive treatment required
Fishery III- Common of economic value and tolerant
species; livestock drinking

**Class IV:** Irrigation

**Class V:** None of the above

The pH has been determined using a pH meter. It is found that the pH values from each concrete mix were in the range of 11.22 to 11.61 (Figure 3), therefore, it shown that the pH values for leaching water at 28 days for all TCC specimens were alkaline. According to the Portland Cement Association [17], the alkaline environment of concrete contributes to the protection of the reinforcement bar from corrosion. By comparing the results with the water quality standard, the results obtained were beyond the National Water Quality Standards for Malaysia for all water classes which is 9. Thus, this has shown good potential for TCC to be used in the construction industry.

BOD test was carried out to indicate the concentration of organic matter in leachate fluid. The average results obtained in Figure 4 were in the range of water quality standard Class I and II. The TCC-5% specimens had the lower BOD of 1.92mg/l which classified under water Class I followed by TCC-
10% and TCC-10% of (2.31mg/l-Class I) and TCC-15% (3.9mg/l-Class II), respectively. However, all BOD values for all specimens were larger than control specimens. This is an indication that the organic matter increased as the increasing of tyre crumbs content in a concrete mixture where a large amount of oxygen in the curing water, there will also be a lot of organisms’ present.

![Figure 3](image3.png)

**Figure 3.** pH value for TCC cube specimens.

![Figure 4](image4.png)

**Figure 4.** BOD content in TCC curing water.

COD is a very important parameter to assess to characterize the quality of water. When the COD level is higher or larger in oxidizable organic matter, it will reduce the degree of DO. The reduction of DO can lead to anaerobic conditions that can be harmful to aquatic life. According to the National Water Quality Standards for Malaysia, the minimum COD value 1 mg/L which under the Class I. However, the results obtained in Figure 5 shows the COD value for all curing water were in a range between -45mg/l to -1mg/l. All the COD values were negative and according to [18], the COD vial used is Low Range (LR) which is expected to obtain a reading in between 0 mg/L to 150 mg/L. Therefore, the results observed showed that COD results in this study cannot be relied upon.
4. Analysis of result

For further study, the compressive strength at 28 days to the types of specimens and BOD content to the types of specimens was analyzed as shown in Figure 6. From this analysis, two polynomial graphs developed for compressive strength and BOD with $R^2$ values were 0.9937 and 0.9546, respectively. From the best fitted graphs, it can be concluded that the optimum mix design for TCC was between 5% to 8% tyre crumb replacement. Therefore, a validation process was carried out by testing a new TCC mix with an 8% tyre crumbs replacement. The result showed that the concrete strength and BOD value for TCC-8% were 32.01MPa and 2.11mg/l, respectively. It can be concluded that 8% tyre crumbs replacement is the maximum amount that can replace natural aggregates to fulfill the desired strength and safe for the environment too.

5. Conclusion

Based on the results, some conclusion could be drawn as follows:

- The workability of fresh TCC increased when the tyre crumb replacement increased. The maximum slump was achieved by TCC-15% with 180mm, followed by TCC-10% and TCC-5% with 150mm and 147mm respectively.

![Figure 5. COD content in TCC curing water.](image1)

![Figure 6. The optimized design of TCC cube specimens.](image2)
• The TCC cube specimens containing various amount of tyre crumbs exhibited lower compressive strength after 28 days compared to control specimens. The maximum strength was achieved by TCC-5% with the strength value 35.78MPa. However, replacement of tyre crumb by 10% and above had not achieved the design strength of 30MPa at 28 days.
• The pH value of TCC cube specimens was 11.22 to 11.61 which all specimens characterized as alkaline. However, the results showed the higher tyre crumb replaced, the less alkaline it will become.
• The BOD content of TCC cubes specimens increased as tyre rubber replacement increased. The maximum BOD valued were detected for curing water of TCC-15% with 3.9mg/l. According to the National Water Quality Standards for Malaysia, this water was characterized under Class II which safe for conventional treatment use and suitable for recreational activities. However, it is sensitive to aquatic species.
• The optimum design for TCC cubes was 8% replacement and below. The results showed replacement of tyre crumb exceed 8% cannot achieve the design strength at 28 days.

As a summary, the best environmental parameter is BOD and by combining the BOD test and structural parameter which is compressive strength test compared with percentages of rubber tire replacement for 28 days, the optimum rubber tire replacement was obtained. For this research, the maximum design of rubber tire replacement is 8% which complying both structural and environmental tests.

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