Properties of Cement Mortar Containing Rubber Ash as Sand Replacement

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Abstract: Discarded scrap tyres have become one of the major environmental problems nowadays. There has been increasing public worry about the mining of natural resources in recent years. In order to minimize the consumption of natural resources, rubber ash has been postulated as a potential material for partial replacement of sand in concrete materials especially for applications which are subjected to impact and vibration such as road and bridge construction. Thus, it contributes to the development of the construction industry in a sustainable way. This paper mainly emphasizes on the use of rubber ash from waste tyres in cement mortar. 100mm cubic specimens were produced by adding rubber ash volume ratios of 0%, 3%, 5% and 7% as sand replacement in M30 quality cement mortar. A compressive stress test and a density test were conducted at the end of 7, 14, and 28 days. The result shows that 5% is the optimum value for sand replacement in the cement mortar. Therefore, rubber ash is acceptable to be used as sand replacement.

1. Introduction
Waste tyres cause major problems to the environment, due to the increasing volume of rubber waste in landfills from the disposal of used tyres [1-5]. EU states generate over three million tons of waste tyres each year and roughly 600 tons are stockpiled [5-7]. It is predicted that almost 1000 million tyres are discarded every year. From this amount more than 50% are discarded without further action. By the year 2030, the number of discarded tyres would increase to 1200 million tyres yearly [6-7]. Scrap vehicle tyres which are disposed of in landfills form one important part of solid waste. The tyres are bulky and 75% gap that a tire occupies is space and these gaps provide breeding ground for vermin, rats and mosquitoes. Stockpiled tyres have negative effects on health, the economy as well as the environment due to soil, water and air pollution [7]. Moreover, discarded tyres may cause fires especially during summer as it is difficult to be extinguished [8]. Generally speaking, the best way to get rid of waste tires is to reuse them [9-11].

The potential solutions to reduce the waste tyre rubber are to integrate it into cement concrete as partial replacement to natural aggregates. This practice could be environmentally friendly (as it aids to reduce the waste tires discarded and prevents environmental pollution) and more economical as some of the more expensive natural aggregates can be conserved [11-15]. The use of rubber in concrete has garnered much interest. Previous research has reported that the replacement of aggregates with waste tyres in concrete mixture leads to a significant increase in terms of toughness and ductility [12]. Studies on the use of waste tyres as aggregate replacement in concrete shows that concrete with...
increased strength and sound insulation can be obtained. Research has indicated that adding fibrous rubber to concrete improves shock wave abrasion, decreases heat conductivity and noise levels and increases resistance to acid rain [16][17-19].

Two different technologies can be used to obtain rubber aggregates from waste tyres: mechanical grinding at room temperature to produce chipped rubber replacing coarse aggregates and cryogenic grinding at a temperature below the glass transition temperature to produce crumb rubber replacing fine aggregates [14][20][21]. The use of rubber in concrete as an additive forms a composite and suitable to partially replace the natural aggregate. When the aggregates were replaced by crumb rubber, the compressive strength of concrete reduced significantly [15][22-25]. However, a large amount of energy under compressive and tensile loads can be absorbed by this rubberized concrete [23][25-27]. It is believed that the increase in impact resistance was derived from the enhanced ability of the material to absorb energy [26-29].

Rubberized concrete was suggested to be used under conditions where vibration damping is needed, such as in buildings as earthquake shockwave absorbers and in highway constructions as shock absorbers, [23][24][28-31]. The addition of shredded rubber to concrete helps to soften the concrete and produces greater plastic deformation on impact as well as lower deceleration forces [32][33]. Chou et al. [34] suggested that rubberized concrete such as concrete products, modified with tyre rubber as partially sand replacement, is suitable to be used in applications where mechanical properties are of secondary importance but high resistance to chloride ion penetration is required. This modification can save lives of passengers and at the same time reduce the amount of rubber which often end up in landfills or stockpiles.

Therefore, due to the lack of research on the use of rubber ash as sand replacement, this study emphasises on the strength of cement mortar with different percentages of rubber ash as sand replacement.

2. Experimental Work

2.1. Material

2.1.1. Cement. In this study, Type 1 Ordinary Portland Cement(OPC) was used. The physical properties of the cement have been obtained and presented in Table 1 and chemical analyses of the cement are presented in Table 2. Fig. 1 shows the scanning electron microscopy of the cement used in this research. The SEM result was displayed using 500 x magnifications showing that the minimum size of the cement was 3.57 µm.

| Table 1. Physical properties of cement used in this study |
| --- | --- | --- |
| Property | Unit | Type I cement |
| Specific gravity | - | 3.15 |
| Passing grain size | % | 78 |
| Median grain size | µm | 18 |
| Blaine specific surface | m²/kg | 300 |
| Initial setting time | Min | 145 |
| Final setting time | Min | 270 |
Table 2. Chemical analysis of cements used in this study

| Component (%) | Type I cement |
|---------------|---------------|
| SiO$_2$       | 21.2          |
| Al$_2$O$_3$   | 5.5           |
| Fe$_2$O$_3$   | 3.1           |
| CaO           | 63.7          |
| MgO           | 1.5           |
| SO$_3$        | 2.63          |
| Na$_2$O       | 0.18          |
| K$_2$O        | 0.71          |
| TiO$_2$       | -             |
| Cl$^-$        | -             |
| Zn            | -             |
| Loss on ignition | 0.96       |

2.1.2. Fine Aggregate. River sand was used as fine aggregates which has a maximum size of 4.75mm. Figure 2 shows the scanning electron microscopy (SEM) of the sand used in this research. The scanning electron microscopy (SEM) result was displayed using 500 x magnifications. The sand has irregular shape.

2.1.3. Rubber Ash. The rubber ash was taken from pyrolysis plant located at Gopeng, Perak. The maximum size of the rubber ash was 4.75mm. Figure 3 shows the scanning electron microscopy of the rubber ash displayed using 500 x magnifications in this research. The rubber ash has irregular round shapes compared to the sand only irregular shape. Shape of the rubber ash are suitable to be used as aggregates because the irregular shape is good for bonding and the the round shape is good for workability.

![Figure 1. SEM for cement at 500x magnification.](image-url)
2.2. Specimen Preparation

The cement mortar for this research was manually mixed not using mixer machine. Firstly, cement, sand and rubber ash was dry mixed for 3 minutes. After that, water was added into the mixture and mixed for another 3 minutes. The cement mortar mixture ratio was 1:2:0.55 by volume of cement, sand and water respectively. The rubber ash was mixed into the cement mortar mix as 0%, 3%, 5% and 7% by volume of sand as sand replacement.

| No | Mix % | Cement (cm$^3$) | Sand (cm$^3$) | Rubber Ash (cm$^3$) | Water (cm$^3$) |
|----|-------|-----------------|--------------|----------------------|----------------|
| 1. | 0     | 6000            | 12000        | 0                    | 3300           |
| 2. | 3     | 6000            | 11640        | 360                  | 3300           |
| 3. | 5     | 6000            | 11400        | 600                  | 3300           |
| 4. | 7     | 6000            | 11160        | 840                  | 3300           |

Table 3 shows the cement mortar mixture ratio used in the study. The compressive strength of the specimens (100 mm cubes) can be seen in Figure 4. Three cement mortar specimens were prepared and tested to obtain the average values for each test condition. Each specimen was casted in three
layers and compacted. After casting, all specimens were left for 24 hours before being demoulded and cured in a curing tank at 23±2°C for 7, 14 and 28 days.

2.3. Test Procedures
The compressive strength test for the cement mortar specimens was performed according to ASTM C109-02. The compression machine shown in Figure 5 has been used to measure the compressive strength of specimens. The rate of loading was 7kN/s. The loading rate remain constant along the testing program.

Figure 4. Concrete cube specimen

Figure 5. Compression machine
3. Results and Discussions

3.1. Density
The presence of rubber ash reduced the density of the cement mortar specimens. Figure 6 shows the density of the mortar specimens for 0%, 3%, 5% and 7% rubber ash at 7, 14 and 28 days. The 0% specimen indicated the highest density compared to the others and the density for the 7% specimen had the lowest density compared to other specimens at 28 days. The density of the cement mortar specimens had increased by duration.

The reduction of density for the cement mortar specimens compared to the 0% specimen at 7 days were 4.61%, 1.11% and 3.18% for 3%, 5% and 7% respectively. The reduction of the density for the cement mortar specimens compared to the 0% specimen at 14 days were 3.31%, 0.32% and 3.00% for 3%, 5% and 7% respectively. The reduction of the density for the cement mortar specimens compared to the 0% specimen at 28 days were 4.48%, 2.47% and 4.92% for 3%, 5% and 7% respectively. The reduction of density compared to the control specimen was attributed to the low specific gravity of rubber ash compared to sand. The result indicated that the 3% specimen had the lowest density as the gaps in the cement mortar specimen were not fully filled by the rubber ash. An increase in density from 3% to 5% occurred because the rubber ash acts as a filler in the cement mortar specimens. However, replacement of rubber ash beyond 5% reduces the density due to excessive rubber ash content in the cement mortar specimens.

3.2. Compressive Strength
Figure 7 shows the development of compressive strength with a curing period of 7, 14 and 28 days for hardened cement mortar containing 0%, 3%, 5%, and 7% rubber ash for sand replacement. The rate of compressive strength developed was relatively high between 7 and 14 days, followed by a slower rate between 14 and 28 days. The rapid development of compressive strength of cement mortar containing...
different percentages of rubber ash during the early stage of 7 days indicates rapid hydration during this period. The development of strength continues at the later stages.

The compressive strength of cement mortar specimens decreased with the addition of rubber in the cement mortar specimens. The percentage decrease in compressive strength at 7 days compared to the 0% rubber ash specimen was 10.25%, 8.56% and 25.68% for 3%, 5% and 7% rubber ash specimens respectively. The percentage decrease in compressive strength at 14 days compared to the 0% rubber ash specimen was 15.25%, 5.51% and 30.95% for 3%, 5% and 7% rubber ash specimens respectively. The percentage decrease in compressive strength at 28 days compared to the 0% rubber ash specimen was 6.67% and 17.33% for 3% and 7% respectively. However, at 28 days, the cement mortar with 5% rubber ash recorded an increase in compressive strength with a percentage of 1.72% compared to the 0% rubber ash specimen. The increase in compressive stress from 3% to 5% was due to the fine size of rubber ash that acts as gap fillers. However, the use of rubber ash beyond 5% decreases the compressive strength because of excessive rubber ash content in the cement mortar specimens.

![Figure 7. Compressive strength versus duration](image-url)
4. Conclusions

This study shows the results of the different percentages of rubber ash as sand replacement in cement mortar. Based on the outcomes of the analysis, the following inferences may be taken:

- The density of the cement mortar specimen decreased with the presence of rubber ash.
- The compressive strength of the cement mortar specimens decreased with the presence of rubber ash at the early stages. However, at 28 days only the specimen with 5% rubber ash showed an increase in compressive strength. The usage of rubber ash beyond 5% will reduce the compressive strength of the cement mortar.
- 5% can be considered as the optimum rubber ash content because only that amount increases the compressive strength of the cement mortar specimens.
- The presence of rubber ash in the cement mortar results in a longer setting time compared to control specimens because there was an increase in compressive strength between 14 days to 28 days.

As a recommendation for future work, a proper study on small range percentages of the rubber ash between 3%-7% such as 3.5%, 4.0%, 4.5%, 5%, 5.5%, 6%, and 6.5% could be performed. The curing time should also be extended to 90 days because the presence of rubber ash in cement mortar specimens results in a longer setting time.

Acknowledgement

The authors would like to thank UTHM fellowship and Grant Vot U523 and U572. This paper was partly sponsored by the Centre for Graduate Studies, UTHM.

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