Sustainable Utilisation of Quarry Dust Waste in Concrete: Strength Performance

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Abstract. Each year, a large amount of quarry dust (QD) waste is disposed into landfills. This waste material was obtained as a by-product during the production of aggregates through the crushing process of rocks at the quarry site. The increasing value of waste will have a significant impact on health and the environment. Reusing such wastes by including them into building materials is a practical answer for the pollution problem. Therefore, this research was to observe the possibility of quarry dust to be included in a concrete mix. The quarry dust has been used as a partial replacement for cement proportion at different levels of replacement (25%, 30% and 35%). Quarry dust was used as the main material in this project to measure the effectiveness of concrete performance. In this research, the quarry dust composition was determined by using X-Ray Fluorescence Spectrometer (XRF). From the x-ray fluorescent spectrometry test result, the quarry dust displays some similar characteristics with the Ordinary Portland Cement (OPC) where it comprises a high composition of Calcium Oxide (CaO). Research were done to determine the optimum percentage of quarry dust in concrete. The result shows that 25% of quarry dust and 75% of cement is the best percentage that can be used in concrete mixture to reach the standard strength. From an economic point of view, the proposed optimum concrete mix was found to be the most economical with the reducing of RM 33 per 1 m³ of the concrete mixture. The results indicated that the quarry dust waste could be utilised as cement replacement to produce durable and resilient concrete. These materials could be an alternative low-cost material for concrete and at the same time provide a new disposal method for the waste.

1. Introduction
One of the main objectives of sustainable waste management is to maximize the ability of its recycling and reusing. The current way of life, alongside the development of technology has led to an escalation in the amount and type of waste being produced, resulting in a waste disposal crisis [1]. The
productive use of waste material represents a way of alleviating some of the issues of waste management [2]. Quarry dust is well-known waste subject materials that will affect the environment (air pollution). Therefore, recycling this waste is very vital from environment and sustainability aspects. This lead to the saving of natural resources and resulting in a reduction in environmental pollution. Currently, Malaysia has taken a big initiative on developing the infrastructures to satisfy the requirement of globalization in the development global of homes and different systems that used concrete. The initiatives to exchange some percentage of the ingredients in concrete mixture really draws severe consideration of researchers and investigators. It is because our nature tools do not seem to be at all times lengthy-lasting and it is a need to produce a few new ideas on the way to create a concrete without reducing the natural tools. Recycle of waste product as partial replacement of cement in construction activities results in reducing the demand for extraction of natural raw materials as well as saving landfill space. Thus, utilization of quarry dust waste in concrete mixes minimises the necessity of natural resources and as a result leads to sustainable development.

Quarry dust has been used for varied activities within the construction industry similar to for road development and manufacture of structure materials similar to lightweight mixtures, bricks, tiles and autoclave blocks [3]. Cement being a major ingredient of concrete, its production contributes in damaging the environment, is a huge driver of climate change, responsible for 5% of man-made carbon dioxide (CO₂) reported in [4]. Type I OPC is the most common cement used in general concrete construction when there is no exposure to sulphates in soil and groundwater. From the statistic, nearly 60% of the cement utilised in construction nowadays is OPC [5]. The drop in the sources of natural sand and the requirement for reducing the cost of concrete production has resulted in poor quality sand sources supplied and thus increased need to identify substitute material to sand as fine aggregates and also cement in the production of concrete especially in green concrete [6]. Therefore, it is desirable to obtain low-cost, environmentally friendly substitutes for cement that are preferably by-products.

In the Peninsular of Malaysia there have also been many attempts to use quarry dust as a partial replacement, but only up to 50% on the lower grades concrete with different construction purposes. This may be expected to bring out a reduce the usage of cement, but also will cut down the cost of construction with economical concrete production. The choice of utilizing the waste product/by-product as a replacement and substitution for cement and natural river sand has been supported in the previous research, [7] and [8] showing that up to 20% of sand has been effectively replaced by quarry dust in traditional concrete. [9] used this waste as the main construction material for the base layer of flexible pavement and observed its satisfactory performance under field conditions. Therefore, this study is aimed at the determination of the effect of quarry dust replacement of cement with by-products on strength of concrete. The effect of partial replacement for cement proportion at different levels of replacement (25%, 30% and 35%) on concrete strength was evaluated.

2. Materials and Methods
Concrete is the product that has been mixed by cement, fine aggregates and coarse aggregates with water. The common used is the proportion of 1:2:4 mixtures where cement to fine aggregates to coarse aggregates respectively. This research was conducted in the laboratory to determine the behavior of the concrete in term of mechanical strength as well as the workability properties. By referring to the literature review, the partial ratio of quarry dust (as shown in figure 1) for this project was 25%, 30% and 35% respectively for each set of sample cubes. This partial ratio replacement of quarry dust for cement percentage was aimed to determine the optimum percentage of the quarry dust that can be used in the concrete mix.

The tests that have been carried out for this project were the slump test, cube test, curing test and compressive strength test. The other test that involved in order to determine the characteristics of the quarry dust is x-ray fluorescence (XRF) test. XRF spectrometer is an x-ray instrument used for routine, slightly non-damaging chemical analyses of rocks, minerals, sediments and fluids. It works on wavelength-dispersive spectroscopic concepts. The XRF is in line with [10]. The mechanical
properties of hardened concrete were tested through the compressive strength test with cubes 100 mm × 100 mm × 100 mm mould. A total of 36 concrete cubes have been tested in this study. The cubes were tested at the age of 4 days, 7 days, 14 days and 28 days after the wet curing process at the curing tank in accordance to procedures in [11]. The fresh properties of the green concrete are determined through the flow slump test for the best workability, it is done in accordance with [12] for sampling at the laboratory. Testing on the compressive strength test is based on [13].

![Figure 1. Quarry dust.](image)

3. Results and Discussions
This section discusses the test results on the mechanical properties of the concrete. The test results for this research including the X-ray fluorescent, slump and compressive strength test.

3.1. Sieve Analysis
Sievign analysis is performed before any of the tests is conducted. The sieving stage is the important part in order to make sure the size of the quarry dust that has been used was the same as the size of the cement. The aggregates were also being sieved to make sure the size of the aggregates were equal and same. Table 1 shows the size of the materials used in this study.

| Materials         | Size   |
|-------------------|--------|
| Cement            | 60 µm  |
| Quarry dust       | 60 µm  |
| Coarse aggregates | <19 mm |
| Fine aggregates   | 600 µm |

3.2. X-ray fluorescent
The XRF test is conducted after the sample of quarry dust was collected at the quarry site. From the XRF result, the quarry dust shows the presence of calcium, aluminium and silica. A comparison that shows the chemical compound difference between OPC and quarry dust has been presented in table 2. The result shows the similarities between Ordinary Portland Cement (OPC) and quarry dust.
Table 2. The comparison result of OPC and quarry dust.

| Compound | OPC (%) | Quarry Dust (%) |
|----------|---------|-----------------|
| Al₂O₃    | 3.1     | 2.7             |
| SiO₂     | 14.1    | 9.27            |
| K₂O      | 1.26    | 1.44            |
| CaO      | 72.13   | 81.85           |
| TiO₂     | 0.34    | 0.55            |
| V₂O₅     | 0.064   | 0.070           |
| Cr₂O₃    | 0.036   | 0.046           |
| MnO      | 0.17    | 0.041           |
| Fe₂O₃    | 4.24    | 2.03            |
| CuO      | 0.032   | 0.050           |
| SrO      | 0.054   | 0.16            |
| ZrO₂     | 0.021   | 0.025           |
| RuO₂     | 0.19    | 0.37            |

The main components of the cement are aluminium, silica and calcium and these three components have been found in quarry dust. The percentages of quarry dust and cement are not really different from each other. For aluminium, the percentage is 3.1% for cement and 2.7% for quarry dust. The difference is just 0.4% only. Then, for silica, the percentage is 14.1% for cement and 9.27% for quarry dust with the difference of 4.83% only. Lastly, for calcium, the percentage is 72.13% for cement and 81.85% of quarry dust with 9.7% difference as can be seen in figure 2.

3.3. Slump test

Figure 3 shows the results of the slump for all mixes. The slump recorded for mixes made of 25%, 30% and 35% are ranging from 79 mm, 82 mm and 89 mm respectively. It can be seen that without the addition of quarry dust, the slump value for control concrete is 76 mm, however, with the addition of quarry dust resulted in a higher slump. It is also interesting to note that the workability in terms of the slump was improving with a higher replacement level of quarry dust. The result shows that the water in this concrete mixture is higher and the bond between the materials in the concrete is not strong enough because of the presence of the water [14].
3.4. Compressive strength

As stated early, the cube test was done in this research to obtain the compressive strength of the concrete specimens. Compressive strength of concrete can be defined as the maximum measured resistance of concrete to axial loading. The compression test is the most common test used to test the hardened concrete specimens with different percentage of quarry dust replacement can be indicating through the compression test. The specimens were being tested with three different curing periods, namely 7 days, 14 days and 28 days. The details of the test results on different concrete mixes were shown in figure 4. The test results on the compressive strength for concrete (25% quarry dust) shows as early strength of 19.8 MPa gain at 7 days age curing, which is quite similar with control concrete (19.9 MPa). By comparing the strength of 3 different concrete mixes, the higher combination of by-products, materials show lesser in compressive strength compare to the other concrete mixes. However, the strength gain will be greater after the 28 days up to the long time period.

The compressive strength decreased after 35% replacement because as the dust particles go beyond 35%, flaky particles or higher fines increase water demand which results in higher water-cement ratio and segregation of concrete leads to non-uniform distribution of cement paste [15]. This consequently leads to a reduction in compressive strength. As the replacement of the cement with quarry dust increases, the workability of the concrete is increasing due to the absorption of the water by the quarry dust. From this, it is seen that use of 25% of quarry dust as cement replacement enhances the concrete compressive strength when compared to other mixes. The trend is the same for all ages of curing. These test results agree with the test result of compressive strength for concrete modified with quarry dust as cement replacement done [14].
3.5. Cost analysis of concrete mixes
The significance of this project is to reduce the waste materials and also to reduce cost. The values of 25% quarry dust replacement in concrete were calculated by multiplying the weight (for 1 m³) of concrete-making materials to the per-unit price for the respective material. Nowadays, the market price for 50 kg of cement is equals to RM 19.25. A total of 350 kg of cement will be used for 1 m³ of concrete which equal to RM 134.35. For 75% of cement (25% of quarry dust replacement), the price is reduced to RM 101.10. So, it can save around RM 33 for 1 m³ of concrete mix. The free availability of quarry dust waste is one of the major factors in the reduction of the material cost.

4. Conclusions
From the results and discussion, the following conclusions can be drawn:

i. The main components of the quarry dust are aluminium, silica and calcium and these three components have been found in cement. The percentages of quarry dust and cement are not really different from each other.

ii. The workability in terms of the slump was improving with a higher replacement level of quarry dust.

iii. Up to 25% replacement level of quarry dust to cement, a good quality concrete can be achieved. As compared to the control specimens, a higher replacement level of quarry dust to the cement content in the concrete mixes results in lower compressive strength.

iv. Proposed optimum concrete mix (25% quarry dust and 75% cement) was found to be the most economical with the reducing of RM 33 per 1 m³ of the concrete mixture.

Overall, the results indicated that the quarry dust waste can be utilised as partial cement replacement to produce resilient and durable concrete. The use of quarry dust in concrete will reduce carbon emission which in turn reduced cement consumption. The higher durability characteristics concrete mixes coupled with the lower ecological and economic burden can enhance the overall sustainability index of the utilisation of quarry dust as partial cement replacement.

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