INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 16 No. 1 (2024) 213-221
https://publisher.uthm.edu.my/ojs/index.php/ijie

# Morphological Characteristics and Mechanical Properties of Quarry Dust Waste as Sand Replacement in Mortar

**Nur Fatin Amira M. Yosri[1], Aidah Jumahat[1,2]*, Ummu Raihanah Hashim[1,2], Mohd Norhasri Mohd Sidek[1,2], N. A. Haris[3]**

[1] *School of Mechanical Engineering, College of Engineering,*
*Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA.*
[2] *Institute for Infrastructure Engineering and Sustainable Management (IIESM),*
*Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA.*
[3] *Department of Solid and Structures, Faculty of Science and Engineering,*
*The University of Manchester, Manchester, M13 9PL, UNITED KINGDOM*

*Corresponding Author: aidahjumahat@uitm.edu.my
DOI: https://doi.org/10.30880/ijie.2024.16.01.017

**Article Info**

Received: 1 December 2023
Accepted: 17 April 2023
Available online: 22 May 2024

**Keywords**

Cement mortar, granite dust, sand replacement, SEM, XRF, water absorption, compressive strength

## Abstract

The generation of industrial waste has been steadily increasing, necessitating sustainable waste management strategies. Quarry dust, a by-product of the aggregate production process obtained from crushing rocks in rubble crusher units, contributes to this waste stream. This study proposes using fine quarry dust waste, ranging from 50 to 100 µm, as an additive or replacement in mortar to mitigate environmental and health hazards caused by this kind of waste. However, studies on the usage of very fine quarry dust waste (about 50-100µm particle sizes) as a partial sand replacement in mortar production is very limited. Therefore, this paper presents an experimental investigation on the effects of incorporating quarry dust waste as a sand replacement, with variations of 0%, 5%, 10%, 15%, 20%, 25%, and 30%, with a water-cement ratio of 0.5 to enhance mortar strength. The micro-structural analysis and compression tests were performed to evaluate the mortar samples. XRF analysis confirmed that silica oxide ($SiO_2$) was the predominant element present in quarry dust waste. The compression tests were conducted on 50 mm x 50 mm x 50 mm mortar cubes. The tests were performed at 3, 7, 14, and 28-day intervals. The results revealed that, incorporating 25% quarry dust waste as a sand replacement produced the highest compressive strength of about 37 MPa on the 28th day curing duration. Hence, using this material as an environment-friendly sand replacement offers a promising solution for producing high-strength mortar. This finding highlights the potential of quarry dust waste as a supplemental cementitious material and emphasizes its viability in reducing the environmental impact associated with industrial waste.

## 1. Introduction

The Malaysian economy has significantly grown year after year, driven by successful supply and demand in various industries. The country is globally renowned for its natural resources, particularly its tropical rainforests, which cover approximately 59% to 70% of its land. These forests provide significant opportunities in the construction industry, notably in sand mining and cement production. However, the continuous use of natural resources has adversely impacted the environment, leading to sustainability issues that cannot be ignored. This continuous exploitation has notably affected mortar manufacturing, necessitating significant improvements in raw materials used in the construction industry [1]. Consequently, the dynamics of supply and demand will inevitably come into play. Due to high demand and limited supply, the costs of producing mortar and concrete, which require sand and cement, are likely to soar. The environmental impact of this practice is evident, as extensive mining of natural resources has led to landslides, soil erosion, and flooding in the affected areas [2]. Mortar, an anisotropic composite material and a vital construction element, consists mainly of cement, sand, and water. The type of mortar used can be classified based on the required strength for the application, with the selection being guided by the proportions or properties listed in ASTM C270 [3].

Sand, comprising finely divided rock and mineral particles, varies in composition depending on local rock sources and conditions. It is categorized by grain size, being finer than gravel but coarser than silt, with diameters ranging from 0.074 to 4.75 mm as indicated in Table 1. Sand, a non-renewable natural resource, plays a crucial role in the production of concrete and mortar, contributing significantly to building construction and infrastructure. However, not all types of sand are suitable for these purposes. The physical and chemical qualities of sand, as stated in the Indian Standard, have been the subject of various studies, including those by Bakar et al. [4]. Table 2 shows the chemical properties of quarry dust and natural sand. According to previous research, data from the Unit of Minerals & Geosciences of Malaysia indicates a significant increase in sand mining operations, from 24,471 million tonnes in 2008 to 34,341 million tonnes in 2015. Consequently, the high demand for sand has led to the depletion of this natural resource. Sand mining operations not only result in sand depletion but also harm marine ecosystems, water quality, and cause turbidity due to erosion of shorelines and riverbanks [5].

**Table 1** *The physical properties of quarry (granite) dust and natural sand [1]*

| Property | Quarry Dust | Natural Sand | Test Method |
|---|---|---|---|
| Specific gravity | 2.54-2.60 | 2.60 | IS2386(Part III)-1963 |
| Bulk density (kg/m3) | 1720-1810 | 1460 | |
| Absorption (%) | 1.20-1.50 | Nil | |
| Moisture content (%) | Nil | 1.50 | |
| Fine particles less than 0.075 mm (%) | 12-15 | 6 | |
| Sieve analysis | Zone-II | Zone-II | IS 383-1970 |

**Table 2** *The typical chemical properties of quarry (granite) dust and natural sand [1]*

| Constituents | Quarry Dust (%) | Natural Sand (%) | Test Method |
|---|---|---|---|
| $SiO_2$ | 62.48 | 80.78 | IS 4032-1968 |
| $Al_2O_3$ | 18.72 | 10.52 | |
| $Fe_2O_3$ | 6.54 | 1.75 | |
| CaO | 4.83 | 3.21 | |
| MgO | 2.56 | 0.77 | |
| $Na_2O$ | Nil | 1.37 | |
| $K_2O$ | 3.18 | 1.23 | |
| $TiO_2$ | 1.21 | Nil | |
| LOI | 0.48 | 0.37 | |

Quarry dust or granite dust, a by-product of aggregate production from crushing rocks, presents environmental challenges due to disposal difficulties [6], [7]. This waste product, accounting for approximately 200 million tonnes annually, is primarily composed of excess fines generated during pulverization, washing, and screening processes in quarries [7]. As a result, the disposal of quarry dust in landfills has adverse environmental impacts. Previous research has demonstrated the feasibility and benefits of using quarry dust as a partial substitute for sand, addressing environmental concerns. Utilizing waste materials like quarry dust can reduce energy, time, natural resources, and potential health hazards, leading to cost savings. Quarry dust's effective micro-filling capacity and pozzolanic activity contribute to enhanced durability and strength when mixed with fine aggregate [8]. The fineness of Granite dust is an important element in terms of its strength. The finer Granite dust will contribute more strength to the mortar compared to the course Granite dust. Based on previous research, it's been established that using GD can enhance the strength of concrete compared to concrete made with an equal quantity of river sand [9]-[12]. The bonding of fine aggregate, which fills the spaces left by the coarse aggregate, is crucial for the strength of concrete [9]. Therefore, further research into using quarry dust as a partial sand replacement is crucial to improve mortar strength, reduce sand demand in the construction industry, and mitigate environmental issues associated with waste materials in landfills. By substituting sand with quarry dust waste in mortar, the negative environmental impacts of excessive waste accumulation can be minimized, leading to an improved overall environment.

## 2. Methodology

Materials used in the production of mortar specimens with quarry dust waste as a partial sand replacement are quarry dust, sand, cement, and water. All the materials are prepared accordingly based on the mixed design form and discussed in detail as accordingly.

### 2.1 Preparation of Raw Materials

The quarry dust waste was obtained from Jabatan Kerja Raya (JKR), Kelantan, Malaysia. The collected quarry dust was dried for 24 hours at temperature of 100°C in the oven. This stage was performed to eliminate moisture in the raw quarry dust obtained from the site. Subsequently, the dried quarry dust underwent a sieving process with a 212 µm sieve to remove larger particles and any residual materials. The ordinary portland cement (OPC) utilized in this research was supplied by Tasek Corporation Berhad in hermetically sealed packaging. The chosen cement adheres to the standards of BS EN 197-1 [13], demonstrating a moderate rate of hardening suitable for diverse applications. The fine aggregate employed in this study is sourced from natural river sand that was sifted to pass through a 2 mm sieve. Special care was taken to ensure its cleanliness, as impurities could undermine the bond between aggregate and paste. The water employed originates from a tap source and is regarded as suitable due to its cleanliness. This tap water's quality aligns with the specifications outlined by the Public Work Department of Malaysia, in line with the criteria outlined in BS EN 1008 [14] for concrete work.

### 2.2 Mix Proportion

In this study, a set of mortar mixes was prepared to determine the maximum strength of different weight percentages of quarry dust as a partial sand replacement, these are 0 wt.% (control), 5 wt.% (M5GD), 10 wt.% (M10GD), 15 wt.% (M15QD), 20 wt.% (M20GD), 25 wt.% (M25GD) and 30 wt.% (M30GD). The mortar mixes design of experiment is tabulated in Table 3.

**Table 3** *The details of mix proportions*

| Mixture | Sand (kg/m$^3$) | Cement (kg/m$^3$) | Quarry Dust (kg/m$^3$) | Water (kg/m$^3$) | No. of Sample |
|---|---|---|---|---|---|
| Control | 1600 | 533.33 | 0 | 266.67 | 12 |
| M5GD | 1520 | 533.33 | 80 | 266.67 | 12 |
| M10GD | 1440 | 533.33 | 160 | 266.67 | 12 |
| M15GD | 1360 | 533.33 | 240 | 266.67 | 12 |
| M20GD | 1280 | 533.33 | 320 | 266.67 | 12 |
| M25GD | 1200 | 533.33 | 400 | 266.67 | 12 |
| M30GD | 1120 | 533.33 | 480 | 266.67 | 12 |

### 2.3 Specimens Fabrication

To ensure high quality of concrete, the mixing procedure was executed utilizing a concrete pan mixer. Before usage, the concrete pan mixer underwent cleaning process by wiping it with a damp cloth. The mixing process adhered to the guidelines stipulated in BS 1881-125 [15]. The components employed in the mortar mixtures were measured based on their specific weight as determined in the design mix.

A series of mortar mixes were cast at the size of 50 mm x 50 mm x 50 mm. The mixes had different amounts of quarry dust as sand replacement. The water-cement ratio was fixed at 0.5. The mortar mixes were poured into the mould and compacted manually using hand and placed it over a vibratory table to completely fill the moulds with minimum gap. As per the guidelines set by British Standards (BS), demoulding of the mortar cube samples from the moulds takes place 24 hours after casting, followed by a curing period in water for specific durations of 3, 7, 14, and 28 days. The mortar mixtures were cured in a water tank after 24 hours to ensure that the specimens had ample time to harden on days 3, 7, 14, and 28 before the compression test. The purpose of the curing process is to enhance the hydration process of cement in developing strength over time. The fabricated samples are shown in Fig. 1.

(a) (b)

**Fig. 1** *Sample preparation (a) Curing process; (b) Mortar cube specimens*

## 2.4 Test Procedures

This research investigated the chemical and morphological properties of materials, using Scanning Electron Microscopy (SEM) and X-Ray Fluorescence (XRF), water absorption evaluation along with mechanical testing; compression test.

### 2.4.1 Characterisation of Raw Materials

The research involved a detailed examination of the morphological and chemical properties of three types of materials: quarry dust, sand, and cement. These analyses were conducted using two primary methods: scanning electron microscopy (SEM) and x-ray fluorescence (XRF).

Scanning electron microscopy (SEM) was employed to closely observe the morphology of the cementitious materials. A Hitachi SU3500 scanning microscope was used for this purpose. This model is notable for its high resolution and precision in imaging fine details of material surfaces. It operated with an accelerating voltage of 15 kV, as shown in Fig. 2(a), which is optimal for producing clear images of cementitious materials. The field of view ranged from 10 to 11.5 mm, providing a comprehensive overview of the material's surface structure. The samples were magnified 1000 times, allowing for an in-depth examination of the microscopic features that could influence the material's properties and behaviour.

The chemical analysis of the cementitious materials was performed using x-ray fluorescence (XRF). This technique is highly effective for determining the elemental composition of materials. The XRF analysis was conducted in limestone-limestone mode, which is particularly suited for identifying and quantifying individual elements in the raw material compositions. This mode is beneficial for analyzing materials like cement, which often contain a complex mix of elements. Fig. 2(b) illustrates the XRF device used in the study, a SI TITAN Handheld XRF Spectrometer. This device is known for its portability and accuracy in identifying the highest composition of each element in the material samples.

(a) (b)

**Fig. 2** *Equipments for materials characterisation: (a) SEM: Hitachi SU3500; and (b) XRF: SI TITAN Handheld XRF Spectrometer*

### 2.4.2 Water Absorption Test

One of the most important properties of a good quality mortar or concrete is low permeability, especially one resistant to freezing and thawing. A mortar with low permeability resists ingress of water and is not as susceptible to freezing and thawing. Water enters pores in the cement paste and even in the aggregate. The 50 mm x 50 mm x 50 mm mortar cubes were prepared for water absorption test. This test is important for determining the durability and resistance to water of the mortar, and also helps to ensure that it will perform as expected in its intended environment. Water absorption is defined as the rate of water absorption when an aggregate is immersed in water. It is calculated by measuring the growth in mass of an oven-dried sample after 24 hours in water. BS EN 1097-6 [16] specifies the standard process. The rate of absorption influences the binding between the aggregate and the cement paste. BS EN 1097-6 [16] specifies the procedure for determining aggregate water absorption using Eq. (1).

$$\text{Water absorption: } \frac{(\mathrm{A} - \mathrm{B})}{\mathrm{B}} \times 1 \tag{1}$$

where $A$ is mass in saturated surface dry (SSD) condition, and $B$ is mass after dried in oven.

### 2.4.3 Compression Test

Compressive strength is a parameter used to measure the quality of hardened concrete. The 50 mm x 50 mm x 50 mm cubes were tested for compression once the necessary curing period was completed at the rate of 0.9 kN/min. Fig. 3 shows the compression test done in accordance with BS EN 12390-3 [17] using a 1000 kN UTM machine.

**Fig. 3** *1000kN Universal Testing Machine for compression test*

## 3. Results and Discussion

### 3.1. Characteristics of Raw Materials

Fig. 4 shows the SEM micrographs of sand and quarry dust having almost similar shape and edge. Sand has more homogeneous particles and a clear surface. Similar to limestone filer (LF) grains, these particles have an angular shape and a rough surface and are abundant at diameters of 10 m and below. Quarry dust's angular appearance affected the flow properties of concrete or mortar due to increased friction. The particles within the red circles have irregular, angular shapes. This is common with crushed materials like sand and granite dust, which tend to fracture along planes of weakness in the crystal structure during the crushing process, leading to angular geometries. These characteristics can impact the material's performance in concrete or mortar. For example, angular particles may enhance mechanical interlock in mortar, which can potentially improve strength. However, they could also increase the water demand due to a higher surface area compared to more rounded particles. Understanding the size and shape of these particles is crucial because it affects the packing density, workability, and strength of the resulting cementitious mixtures. Small, angular particles can fill voids between larger particles, potentially leading to a denser, less permeable material, but might also require more water to achieve the desired workability [10].

The XRF analysis was conducted on sand, cement, and quarry dust to determine the concentrated chemical composition of each material. The analysis revealed that silica oxide ($SiO_2$) is the predominant element in quarry dust, comprising 79.504% of its composition. This high $SiO_2$ content highlights the importance of silica in the waste material. $SiO_2$ in quarry dust is vital for enhancing the performance of mortar and concrete, with its pozzolanic properties contributing to increased strength and durability through the reaction with calcium hydroxide during hydration. This reaction not only enhances the mechanical properties of the material but also reduces permeability, improving resistance to water penetration. Additionally, silica improves workability by acting as a filler, promoting a more cohesive mixture.

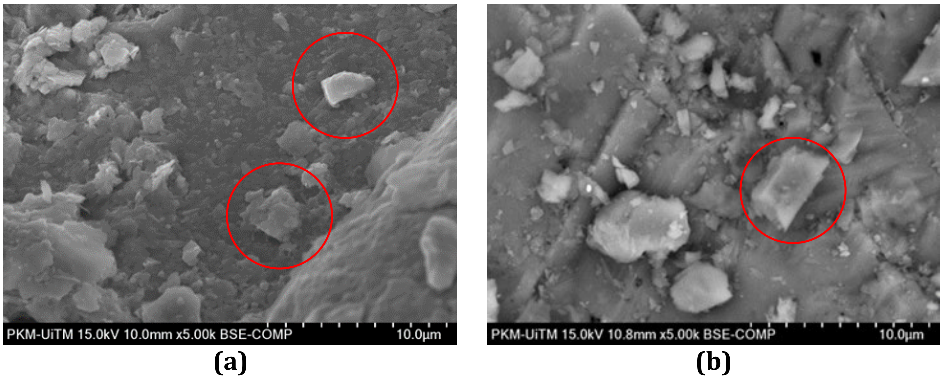

**Fig. 4** *SEM micrographs of (a) sand; and (b) quarry dust*

Aluminium oxide ($Al_2O_3$) was found to be the second most abundant element, making a significant contribution to the overall composition. The presence of $Al_2O_3$ in quarry dust aids in improving the performance of mortar and concrete in various ways. It acts as a secondary pozzolan, reacting with the calcium hydroxide formed during cement hydration to produce additional binding materials, which increases strength and durability. Moreover, $Al_2O_3$ can affect the setting time of concrete, helping to control the curing process, and can enhance the workability and cohesion of concrete mixes. These qualities render $Al_2O_3$ a valuable component in quarry dust, optimizing the performance and longevity of mortar and concrete structures. Magnesium oxide (MgO) was detected at levels below the limit of detection (<LOD), indicating its negligible presence in the quarry dust studied, which suggests that magnesium is only present in trace amounts.

**Table 4** *Chemical compositions of sand, cement and quarry dust*

| Chemical Compositions | Sand | Cement | Quarry dust |
|---|---|---|---|
| SiO | 89.168 | 16.136 | 79.504 |
| $Al_2O_3$ | 5.423 | 2.172 | 10.889 |
| Fe2O3 | 0.586 | 2.505 | 1.672 |
| CaO | 0.566 | 71.783 | 1.966 |
| MgO | 1.422 | 4.054 | <LOD |
| $K_2O$ | 1.748 | 0.315 | 5.600 |
| $SO_3$ | 0.564 | 2.871 | 0.067 |
| $TiO_2$ | 0.467 | 0.130 | 0.094 |

## 3.2. Water Absorption Properties

The graph depicted in Fig. 5 illustrates that water absorption in quarry dust mortar decreases with an increasing amount of quarry dust. This reduction could be attributed to the presence of phosphorous (V) oxide in quarry dust, which is known to be an effective drying and dehydrating agent. However, the water absorption of quarry dust mortar increases with a 30% quarry dust replacement on days 3, 7, 14, and 28. This increase may result from the size and distribution of quarry dust particles. Because the quarry dust used has a finer particle size than sand, it may affect the particle packing arrangement within the mortar matrix. Inadequate particle packing can lead to increased porosity, creating more pathways for water to be absorbed by the mortar. Additionally, the larger surface area of quarry dust particles compared to sand necessitates more water during mixing. This higher water requirement can result in a more porous mortar, as excessive water may disrupt proper particle hydration, leading to a less dense and more porous concrete matrix. Porosity refers to the volume of voids or open spaces within the mortar matrix. Higher porosity facilitates faster water penetration, which increases the mortar's water absorption. An increase in water absorption can adversely affect the strength of the mortar or concrete.

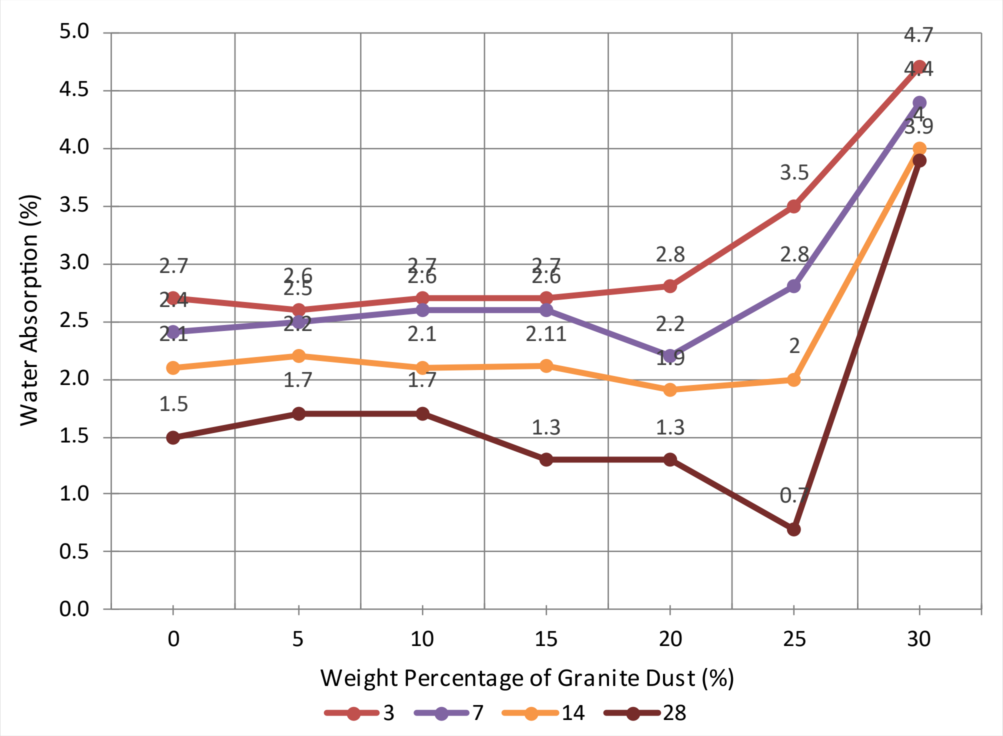

**Fig. 5** *Percentage of water absorption for granite dust (%)*

## 3.3. Compressive Strength

This study focused on assessing the solidified state of various mortar mixtures through compressive strength testing. The goal was to formulate mortar compositions with an integrated approach involving quarry dust as a partial substitute for sand, thereby contributing to the creation of high-strength mortar. To achieve this, it was essential to identify the optimal proportion of quarry dust. Initial attempts involved creating trial mixes of 50mm mortar cubes where quarry dust served as a partial replacement for sand at varying ratios: 0%, 5%, 10%, 15%, 20%, 25% and 30%. The aim was to pinpoint the ideal granite dust percentage. The results are tabulated in Table 3, showing the compressive strength data acquired over curing periods of 3, 7, 14, and 28 days.

**Table 5** *Compressive strength of mortar on the effect of different percentages of granite dust*

| **Weight percentage of Granite dust (%)** | **Average of stress by days (MPa)** | | | |
|---|---|---|---|---|
| | **3** | **7** | **14** | **28** |
| 0 | 12.7 | 18.14 | 21.6 | 25.02 |
| 5 | 11.55 | 17.71 | 21.97 | 24.82 |
| 10 | 13.08 | 18.8 | 22.63 | 25.95 |
| 15 | 11.74 | 17.5 | 22.01 | 27.68 |
| 20 | 17.04 | 21.96 | 25.53 | 28.46 |
| 25 | 17.21 | 25.16 | 31.2 | 37.74 |
| 30 | 4.82 | 7.91 | 11.26 | 12.31 |

Fig. 6 shows that the optimal proportion of quarry dust in mortar as a partial sand replacement is 25%. This proportion yielded the highest strength, reaching 37.74 MPa on day 28, which surpassed other proportions such as 20% at 28.46 MPa. The increase in strength observed may be due to the quarry dust filling the voids between sand particles, resulting in a denser and better-bonded specimen, known as the filler effect. Quarry dust has a higher specific surface area because of its finer structure; consequently, when water is added to the mixture, it takes longer to wet the particles, reducing workability as the content of granite dust powder increases. Previous research reported a significant increase in concrete compressive strength, roughly 20% higher than that of standard concrete. This improvement was attributed to the integration of tiny particles of powdered limestone filler within the voids between aggregates.

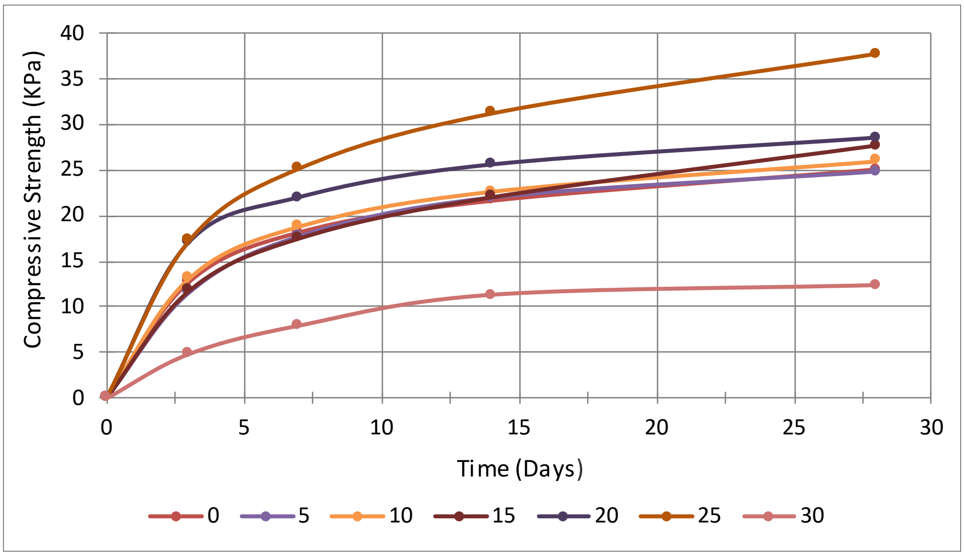

**Fig 6** *Compressive strength of mortar on the effect of different percentages of granite dust*

However, the lower replacement percentages which is 5%, 10% and 15%, the compressive strength remains relatively consistent with the control specimens (0%) due to a balanced interaction between the added granite dust particles and the existing sand particles. This interaction enhances certain properties of the mortar without compromising overall strength. Simultaneously, the observed similarities in compressive strength values between the replacement percentages and the control specimens at 7 and 14 days suggest the crucial role of curing time. During the curing process, hydration reactions continue, leading to further development of strength and mechanical properties. Over time, the differences in compressive strength between the replacement percentages and the control become less pronounced as the mortar matures, emphasizing the importance of considering both mechanical interactions and curing time in understanding the behaviour of mortar samples with varying percentages of granite dust replacement.

According to this study, the presence of quarry dust leads to higher compressive strength by occupying gaps within the concrete matrix. As quarry dust fills in the voids of concrete's ingredients, the result is denser and stronger concrete with increased compressive strength. Additionally, secondary cementitious compounds such as calcium silicate hydrates (CSH) are formed due to the pozzolanic reaction with quarry dust, which enhances the binding properties of the cement paste. The combination of micro-filling and the pozzolanic reaction of quarry dust contributes to the increase in strength. However, as the proportion of quarry dust increases, strength diminishes due to impaired flowability, resulting in larger voids in the cured concrete. On the contrary, the lowest compressive strength on day 28 was observed with 30% replacement, followed by those with 5%, 0%, and 10% quarry dust replacements. The decline in compressive strength with a 30% replacement of quarry dust could be attributed to the excess quarry dust in the mix after void saturation, which hinders the inter-particle bonding between cement particles and aggregates.

## 2. Conclusion

Based on a comprehensive investigation on both, microstructural aspects and the mechanical strength of mortars with quarry dust as a partial sand replacement, it can be deduced that the findings not only enhance the performance of the mortar but also addresses critical environmental issues associated with sand extraction, thereby promoting sustainability. Sophisticated techniques such as SEM and XRF analysis are utilized to assess the material's composition, and particularly the functionality of quarry dust. The analysis results show a substantial presence of silica oxide ($SiO_2$) in the quarry dust, accounting for as much as 79.504% of its composition. This high concentration of silica is crucial in influencing the mortar's strength development. The study finds that a composition with 25% quarry dust yields the most promising outcomes for enhancing mortar strength as a partial sand replacement. This discovery deduced a delicate balance between incorporating granite dust and achieving optimal strength. By adopting this approach, the study not only enhances mortar performance but also presents a substantial potential to mitigate environmental impacts. The reduction in the use of natural river sand, along with the environmental benefits of incorporating quarry dust, contributes to a more sustainable construction practice that is in line with the global movement toward eco-friendly solutions. Further investigations are warranted to explore the long-term durability and economic feasibility of using quarry dust waste as construction materials.

## Acknowledgements

The authors would like to thank Universiti Teknologi MARA (UiTM) for the research support. This research work is financially supported by the Global Research Reputation (GRR) Grant no: 600-RMC 5/3/GRR (008/2020).

## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

*The authors confirm contribution to the paper as follows:* ***study conception and design:*** *Nur Fatin Amira M. Yosri, Aidah Jumahat;* ***data collection:*** *Nur Fatin Amira M. Yosri;* ***analysis and interpretation of results:*** *Nur Fatin Amira M. Yosri, Aidah Jumahat, Ummu Raihanah Hashim, Mohd Norhasri Mohd Sidek, N. A. Haris;* ***draft manuscript preparation:*** *Nur Fatin Amira M. Yosri, Ummu Raihanah Hashim. All authors reviewed the results and approved the final version of the manuscript.*

## References

[1] Hamid, N. J. A., Kadir, A. A., Kamil, N. A. F. M., & Hassan, M. I. H. (2018). Overview on the utilization of quarry dust as a replacement material in construction industry. International Journal of Integrated Engineering, 10(2), 112-117.

[2] Gavriletea, M. D. (2017). Environmental impacts of sand exploitation. Analysis of sand market. Sustainability, 9(7), 1118.

[3] Mollo, L. (2015). Influence of cement/sand ratio on behavior of cement mortar. Journal of Engineering, Design and Technology, 13(1), 23–36. https://doi.org/10.1108/jedt-07-2012-0031

[4] Abdull Bakar, A. Z., & Ahmad Jeni, M. L. (2021). A review on potential of granite dust waste as an aggregate in concrete production. Progress in Engineering Application and Technology, 2(2), 184–194.

[5] Sundaralingam, K., Peiris, A. & Sathiparan, N. (2021). Manufactured sand as river sand replacement for masonry binding mortar. Moratuwa Engineering Research Conference (MERCon), Moratuwa, Sri Lanka, pp. 403-408, https://ieeexplore.ieee.org/document/9525718

[6] Etim, R. K., Ekpo, D. E., Attah, I. C., & Onyelowe, K. C. (2021). Effect of micro sized granite dust particle on the compaction and strength properties of cement stabilized lateritic soil. Cleaner Materials, 2, 100023. https://doi.org/10.1016/j.clema.2021.100023

[7] Kadir, A. A., Hassan, M. K., Sarani, N. A., Rahim, A. S. A., & Ismail, N. (2017). Physical and mechanical properties of granite dust waste incorporated into a fired clay brick. AIP Conference Proceedings, 1835, 020040. https://doi.org/10.1063/1.4981862

[8] Rahim, N. Z., Awang, A. Z., Sam, A. M., Ma, C. K., Chin, C. L., & Hassan, W. W. (2021). Compressive strength of concrete containing high volume of granite waste. PERINTIS eJournal, 11(2), 84-105.

[9] Khan, N., & Chandrakar, R. (2017). An Experimental study on uses of Granite Dust to replace sand in concrete. International Research Journal of Engineering and Technology, 4(11), 1215-1217.

[10] Bahoria, B. V., Parbat, D. K., Nagarnaik, P. B., & Waghe, U. P. (2017). Effect of characterization properties on compressive strength of concrete containing quarry dust and waste plastic as fine aggregate. International Journal of Civil Engineering and Technology, 8(3), 1-9.

[11] Aliyu, I., Sulaiman, T. A., Mohammed, A., & Kaura, J. M. (2020). Effect of sulphuric acid on the compressive strength of concrete with quarry dust as partial replacement of fine aggregate. FUDMA Journal of Sciences, 4(1), 553-559.

[12] AL-Kharabsheh, B. N., Moafak Arbili, M., Majdi, A., Ahmad, J., Deifalla, A. F., Hakamy, A., & Majed Alqawasmeh, H. (2022). Feasibility study on concrete made with substitution of quarry dust: A review. Sustainability, 14(22), 15304.

[13] BS EN 197-1 (2000). Cement. Composition, Specifications and conformity Criteria for common cements. British Standards Institution.

[14] BS EN 1008 (2002). Mixing Water for Concrete. Specification for Sampling, Testing and Assessing the Suitability of Water, Including Water Recovered from Processes in the Concrete Industry, As Mixing Water for Concrete. British Standards Institution.

[15] BS 1881-125 (2013). Testing concrete. Methods for mixing and sampling fresh concrete in the laboratory. British Standards Institution.

[16] BS EN 1097-6 (2013). Tests for mechanical and physical properties of aggregates - Part 6: Determination of particle density and water absorption. British Standards Institution.

[17] BS EN 12390-3 (2009). Testing hardened concrete Compressive strength of test specimens. British Standards Institution.