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The Potential of Using Quarry Dust as Sand Replacement Material in Production of Cement Sand Block

Wan Shi Ying[1], Rafikullah Deraman*

[1]Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: Sand is an essential natural source that has been used commonly in the construction industry in Malaysia. With the rapid development of construction projects around the world, sand depletion had become a critical global issue arise in the world. The amount of sand decreasing while the price is increasing due to the high demand for this resource in construction projects. Quarry dust is a fine particle which spread in the atmosphere that will cause air pollution. Moreover, disposal of quarry dust is one of the most critical problems facing the quarrying industry. Thus, the purpose of this study is to examine the effect of quarry dust as partial sand replacement material in cement sand blocks production in terms of physical, mechanical, and thermal properties. The mix proportion of cement sand block used is 1(Cement):6(Sand) and the water-cement ratio is 0.6. The percentages used for quarry dust as sand replacement in the production of cement sand blocks vary from 0%, 5.0%. 10.0%, and 15.0%. A total of 60 units of solid cement sand blocks size of 400mm x 200mm x 100mm were produced. All the specimens were tested with sieve analysis, X-ray Diffraction (XRD), specific gravity, density, compressive strength, water absorption, and thermal conductivity. The result indicates that the optimum percentage of quarry dust as partial sand replacement block is at 15.0% as it showed the highest compressive strength value, 5.7 MPa >3.45MPa (ASTM C129-11), water absorption, 179 kg/m^3 < 240 kg/m^3 (ASTM C90-11a), density, 1913 kg/m^3 in medium weight range of 1680-2000 kg/m^3 (ASTM C129-11 for density), and thermal conductivity, 1.27 W/mK between range of 0.1 - 1.5 W/mK (BS 6073-2). These findings proved that quarry dust is a potential material that can be used as an alternative to sand in the production of cement sand blocks. As consequence using quarry dust can reduce the use of sand, reduce costs, and as well as reduce construction waste materials. Moreover, the use of quarry dust in the production of cement sand blocks can contribute to the production of environmentally friendly building materials that can create a sustainable built environment.

Keywords: Quarry Dust, Partial Sand Replacement Material, Cement Sand Block, Thermal Conductivity

Corresponding author: rafikullah@uthm.edu.my

1. Introduction

The rapid development of the construction sector in Malaysia due to world globalization. The construction materials produced by the quarrying sector is increased over the year. As reported by the Department of Statistics Malaysia (DOSM), the breaking and crushing of the stone and gravel industry contributed a gross output value of RM2,386.5 million with a 33.5% contribution [1]. Malaysia had exported 6,664,339,138 kg of aggregates to the world in 2019. With the high demand for construction materials for the local development and overseas market, a lot of construction waste produced when crushing the stone in the quarry sector. Sand is an essential natural source and has been used as material for the construction field in Malaysia for a long time since this country started development. Rapid construction development in Malaysia had increased the demand for river sand as this is an important source of construction material. The main source of sand in Malaysia is river mining all around the country.

Based on the United Nations Commodity Trade Statistics Database (COMTRADE), sand exported from Malaysia to the world in 2019 was 1,291,599,812 kg for US$32,182,791 equivalent to RM129,294,362.84 compared to the sand exported in 2018 was 1,693,640,785 kg for US$9,444,439 equivalent to RM 37,943,033.68 [2]. This amount shows that the demand for sand in the world increased over the year but the amount of sand in our country had dropped significantly. Sand depletion occurred due to excessive mining of sand to supply high demand. This will reduce the natural resources and affect the ecosystem badly. This causes the sand to become a very costly material due to high demand in the construction field.

Quarry dust is a type of construction waste produced when exploding the mountain to crush the aggregates. This dust formed as waste and will cause air pollution if not properly managed. Quarry dust can be used in the construction industry to reduce the use of natural resources. Researchers reported that quarry dust can be used as sand replacement in the production of concrete to reduce the mining of sand [3]. This will reduce the increment of the factory to grinding the aggregate which will help in reducing pollution to the environment. Based on that, reusing waste materials as replacement materials in the building materials production is possible to reduce environmental pollution.

2. Literature Review

In Malaysia, the crushing of the stone and gravel industry is one of the main sectors that giving profit to the country. When crushing the gravel, a big quantity of quarry dust is produced (Figure 1). The amount produced depends on the type of rock, how much fragmentation is used by blasting, and the type of crushing [4]. After rock mining and production, the quarry dust can be defined as the residue or tailing material that forms less than 4.75 mm of fine particulates. The quarry dust has a rough surface texture and an angular shape due to the crushed nature of the aggregate [5].

Figure 1: Quarry dust.

Quarry dust is a unique material as it is a non-porous material, readily usable, and comparatively low cost than sand. It is a fine particle which spread in the atmosphere that will cause air pollution [6].

Moreover, disposal of quarry dust is one of the most critical problems facing the quarrying industry [7]. Quarry dust should be used in the construction industry to reduce the use of natural resources [8]. The insufficient place of waste disposal growing environmental concerns, the disposal of the dust becomes extremely costly [9]. Quarry dust had been used in the road pavement to improve physical, mechanical, and swelling properties of soil subgrade and subbase [10].Quarry dust is also used as building materials or making materials such as bricks and tiles in the construction process. The dust was found to be appropriate for those practices. The dust required to manage properly to avoid pollution of the environment occurs [4].

Malaysia facing a problem with the spaces for landfills disposal especially from industrial disposal. The nature of the dust renders it challenging to dispose of acceptably and economically and the eventual accumulation in an unprotected environment has brought on a negative impact on the environment and human health [11]. Besides, research on investigating replacement material as sand substitutes has become an important issue in the construction sector to reduce the usage of the sand. Quarry dust is a by-product and the cost is lesser than sand. Typically quarry dust had been used for different percentages of replacement materials in cement sand mixtures. A study focusing on the use of quarry dust in the production of cement sand blocks is limited. Table 1 presents previous studies on sand replacement materials with quarry dust.

Table 1: Summary of previous studies on the use of quarry dust in building materials

Researcher(s)	Usage	Water-Cement Ratio/ Mix Ratio	Mixing percentage (%)	Properties			
				Density (kg/m^3)	Compressive Strength (MPA)	Water Absorption (%)	Thermal Conductivity (W/mK)
[8]	Concrete Mix	-	0, 20, 30, 40 & 50	-	31.03 – 32.98	-	-
[12]	Concrete Mix	0.55	0, 20, 30, 40 & 50	2480 - 2530	29.60 - 31.60	2.50 – 4.50	-
[13]	Concrete Mix	0.5 – 0.9	0	-	23.12 – 33.00	-	-
		0.5 – 0.9	10	-	22.86 – 34.46	-	-
		0.5 – 0.9	20	-	22.65 – 35.21	-	-
		0.5 – 0.9	30, 40 & 50	-	-	-	-
[14]	Sandcrete Mix	- Mix Ratio: 1: 6	0, 10, 20, 30, 40, & 100	-	5.23	3.20	-
[15]	Concrete Mix	0.70	30, 40 & 50	-	22.70 – 24.50	-	-
[16]	Concrete Mix	0.45	0, 20, 25 & 30	-	37.00 - 38.00	-	-
		0.50	0, 20, 25 & 30	-	31.00 – 35.00	-	-
[17]	Fired Clay Brick	-	0, 10, 20 & 30	1879.2	18.06	-	-
[18]	Concrete brick Expand Polystyrene (EPS)	0.50	0, 20, 30, 40 & 50	1435.71	13.50 - 28.00	4.37 -6.95	-

3. Materials and Methods

The raw material used in the production of cement sand blocks are Ordinary Portland cement (OPC), sand, and water. Meanwhile, quarry dust was used as sand replacement material in this study. The following sub-section has discussed the collection of raw materials and processes applied to produce cement sand blocks.

3. 1 Raw materials preparation

3.1.1 Cement

Ordinary Portland cement is the common type of cement used as a construction material. The cement was kept in the laboratory and stored in good condition to ensure the characteristic of cement in good condition. The cement was bought by faculty and kept in the Faculty of Civil Engineering and Built Environment (FKAAB) laboratory for the usage of research. The standard of Portland Cement used in this project is MS 522: Part 12003 [19].

3.1.2 Sand

The standard size of sand which is 4.75 mm in diameter is used in this study, complied with the standard requirement. The sand must be clean in making specimens because the impurities in the sand such as silt or organic matter will weaken the strength of specimens. The sand was bought by faculty and stored in the FKAAB laboratory.

3.1.3 Water

Water is used as the binder to bind the cement and sand together to form a cement sand block. The amount of water used in the production of cement sand block was determined by the water-cement ratio. The water was taken from the pipe at the FKAAB laboratory.

3.1.4 Quarry Dust

The quarry dust has a rough surface texture and an angular shape due to the crushed nature of the aggregate [5]. The waste was collected from the quarry factory in Johor Bahru, Johore. For the sand replacement material in the production of cement sand block, the size of quarry dust used in this research was 4.75mm which similar to the size of sand. The quarry dust was undergoing sieve analysis to obtain the 4.75mm size. The collected quarry dust was washed and screened before carried out mixing to ensure no other substances in the samples.

3.2 Design Mix

The design mix was following the design method in BS 5628-3 [20]. The percentage of quarry dust used in this study varied from 0%, 5.0%, 10.0%, and 15.0%. The mix proportion of cement sand block used is 1(Cement):6(Sand) and water-cement ratio used was 0.6. The water-cement ratio used is based on the trial mix result. Table 2 shows the actual design mix of specimen.

Table 2: Design mix of raw material

Percentage of replacement (%)	Cement (kg)	Sand (kg)	Quarry Dust (kg)	Water Cement Ratio	Water (kg)
0.0	1.80	10.82	0	0.60	1.08
5.0	1.80	10.21	0.61	0.60	1.08
10.0	1.80	9.59	1.23	0.60	1.08
15.0	1.80	9.00	1.82	0.60	1.08

3.3 Curing Process

In this study, the curing method used is by covering the surface of the blocks with gunny bags. The blocks are placed in the FKAAB laboratory to protect them from direct sunshine and rainfall. The exposed surface is prevented from drying out and covering the blocks by the wet gunny bag. The gunny bags are periodically wetted and the wetting interval depends on the rate of evaporation. The wetting gunny bag is to enhance the strength of the blocks [19]. Care should be taken that the surfaces of cement sand blocks are not dry out throughout the curing process.

4. Results and Discussion

4.1 Material gradation and characterization

These tests were carried out to determine the characteristics and grading of sand and quarry dust. The result obtained from the testing were elaborated and analyzed.

4.1.1 Particle Size

Sieve analysis test is to ensure the particle size of quarry dust is equivalent to the particle size of sand used in the laboratory. The particle size distribution of sand and quarry dust can be obtained from the percentage of the mass of the quarry dust and sand that passes through the sieve size.

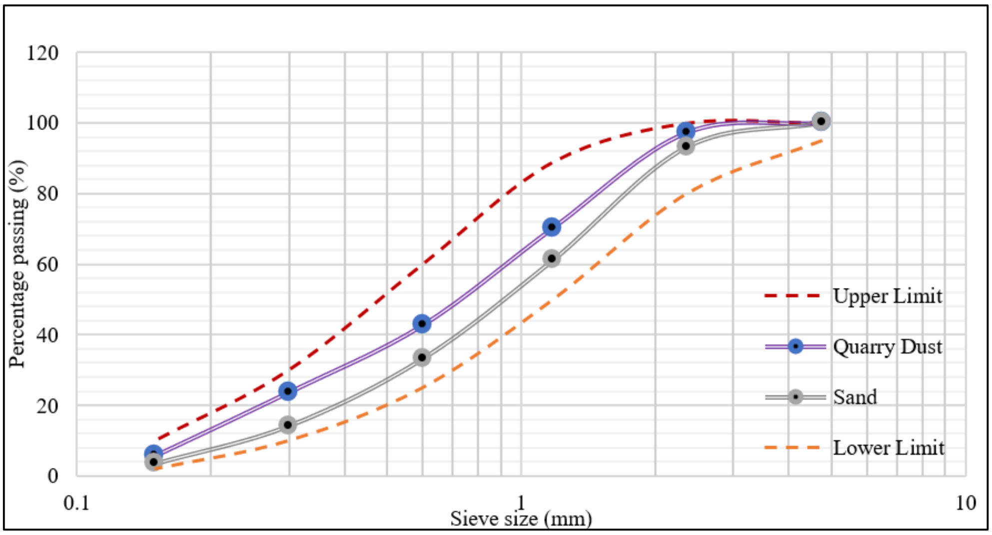

Figure 2: Semi-log graph of the particle size distribution for sand and quarry dust.

Based on the result obtained in Figure 2, the particle size used for sand and quarry dust has complied with the standard requirement in ASTM C144 [21]. The sizes of quarry dust lie between the maximum and minimum particle sizes stated in the standard and passing completely through a 4.75mm sieve.

4.1.2 Chemical Properties

X-ray Diffraction (XRD) test was performed to identify the chemical composition or mineral that present in the quarry dust and sand in this study. It is important to ensure the quarry dust has similar properties to sand.

Table 3: Chemical composition of sand and quarry dust by using XRD analysis.

Chemical Compound	Types of materials	
	Sand	Quarry Dust
Silicon oxide (SiO_2)	Present	Present
Aluminium oxide (Al_2O_3)	Present	Present
Iron oxide (Fe_2O_3)	Present	Not detected

Calcium oxide (CaO)	Present	Present
Chromium oxide (Cr_2O_3)	Present	Not detected
Titanium oxide (TiO_2)	Present	Not detected
Potassium oxide (K_2O)	Present	Not detected
Magnesium oxide (MgO)	Present	Present
Manganese oxide (MnO_2)	Present	Present
Sodium oxide (Na_2O)	Present	Present

Table 3 shows the chemical composition of sand and quarry dust by using XRD analysis. The main chemical compound contains in the quarry dust are silicon oxide (SiO_2) and aluminum oxide (Al_2O_3) that have a high peak in the XRD analysis. The presence of a high concentration of SiO_2 in quarry dust able to provide high compressive strength in the cement sand block. The result of XRD analysis indicated that quarry dust is suitable to use as the partial sand replacement material as it contains a similar chemical composition with sand. based on a high concentration of SiO_2 because it will provide compressive strength to the cement block.

4.1.3 Specific Gravity

From the result obtained, the specific gravity of quarry dust is 2.54 and it is categorized as the soils with some organic matter. Sand has a specific gravity of 2.65. Quarry dust is a material that compactible as the partial sand replacement material as the specific gravity of quarry dust is similar to the sand.

4.2 Physical and mechanical testing

The purpose of the testing is to identify the compressive strength, water absorption, density, and thermal conductivity of the cement sand block with partial replacement by quarry dust. The percentage replacement of sand by quarry dust is 5.0%, 10.0%, and 15.0%.

4.2.1 Compressive Strength Test

A compressive strength test is a strength testing to measure the maximum load that can be withstood by the material before failure. The compressive strength of the specimens is shown in Figure 3.

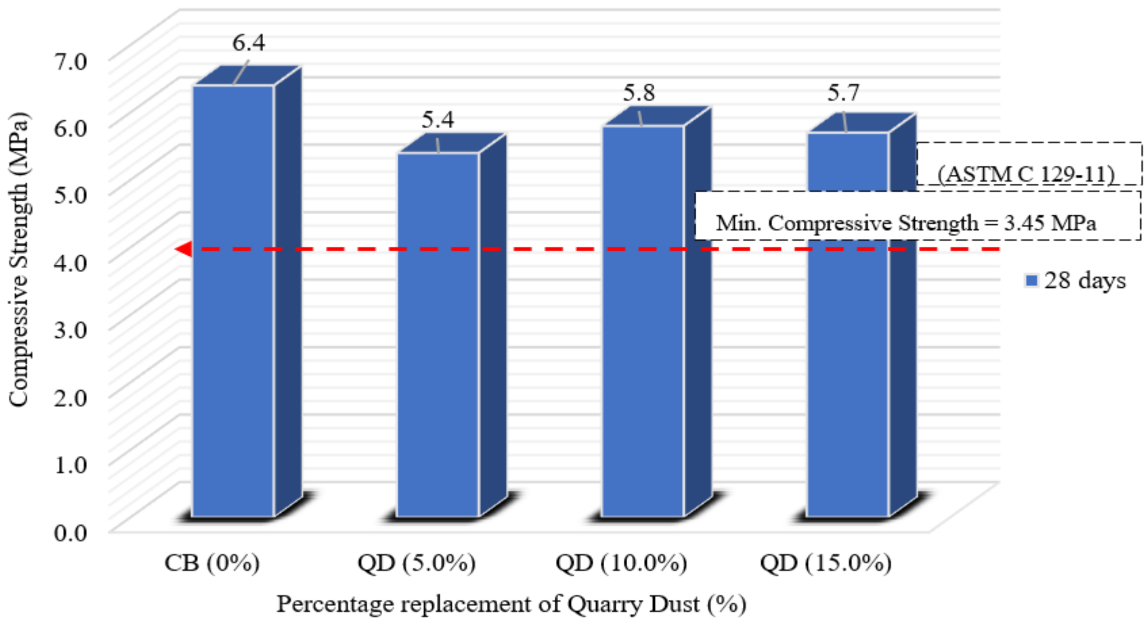

Figure 3: Histogram graph of compressive strength

Based on the result obtained in Figure 3, the highest compressive strength among the 3 different percentages of quarry dust replacement specimens was 5.8 MPa (10.0% Quarry Dust) while the lowest value was 5.4 MPa (5.0% Quarry Dust). Based on ASTM C 129, the minimum compressive strength value required for a non-load-bearing wall masonry unit is 3.45 MPa [22]. Based on the minimum requirement, as shown in the histogram graph, all the percentage of quarry dust replacement has met the minimum standard requirement value. It shows that quarry dust has a similar silica content as the sand that suitable to be used as the replacement materials for sand. The silica content SiO_2 can react with the presence of $Ca(OH)_2$ in cement sand block to form secondary calcium silicate hydrate and make it chemically stable and structurally dense [23]. The strength reduction occurred when the percentage of quarry dust increased to a certain percentage.

4.2.2 Water absorption test

Water absorption is the testing to determine the amount of water that can be absorbed by the material after immersed in the water. The result of the water absorption test with quarry dust replacement cement sand block is shown in Figure 4.

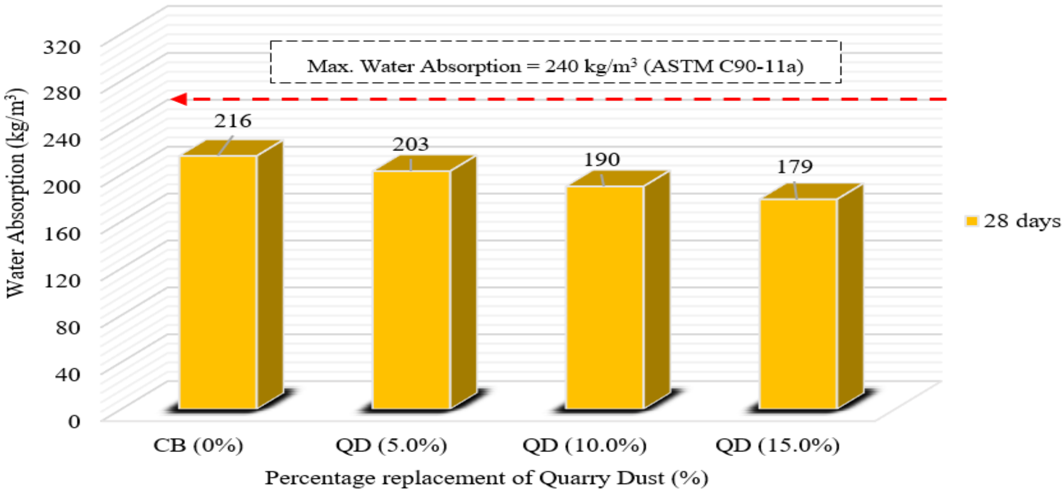

Figure 4: Histogram graph of water absorption

Based on the graph in Figure 4, the highest water absorption value of cement sand block was 5.0% quarry dust replacement block with 216 kg/m^3 meanwhile the lowest water absorption value was 15.0% quarry dust replacement block with values of 179 kg/m^3. According to the ASTM C 90-11a, the maximum allowable value of water absorption for solid blocks is 240 kg/m^3. All mix percentages of the cement sand blocks do not beyond the limit of the standard requirement. The water absorption of the blocks with different percentages of quarry dust is decreasing gradually. The reaction between calcium oxide (CaO) with water to produce the calcium silicate hydrate (CSH), which filled the empty spaces between particles in blocks and making it impervious [24]. This condition prevented water absorption into the blocks. The blocks with more quarry dust unable to absorb more water because there are only a little void in the blocks and the quarry dust had filled the voids with fine dust instead of water.

4.2.3 Thermal Conductivity

The thermal conductivity test is to identify the thermal insulation of the quarry dust in the cement sand block. The k-value for all different percentages of quarry dust replacement blocks is shown in Figure 5.

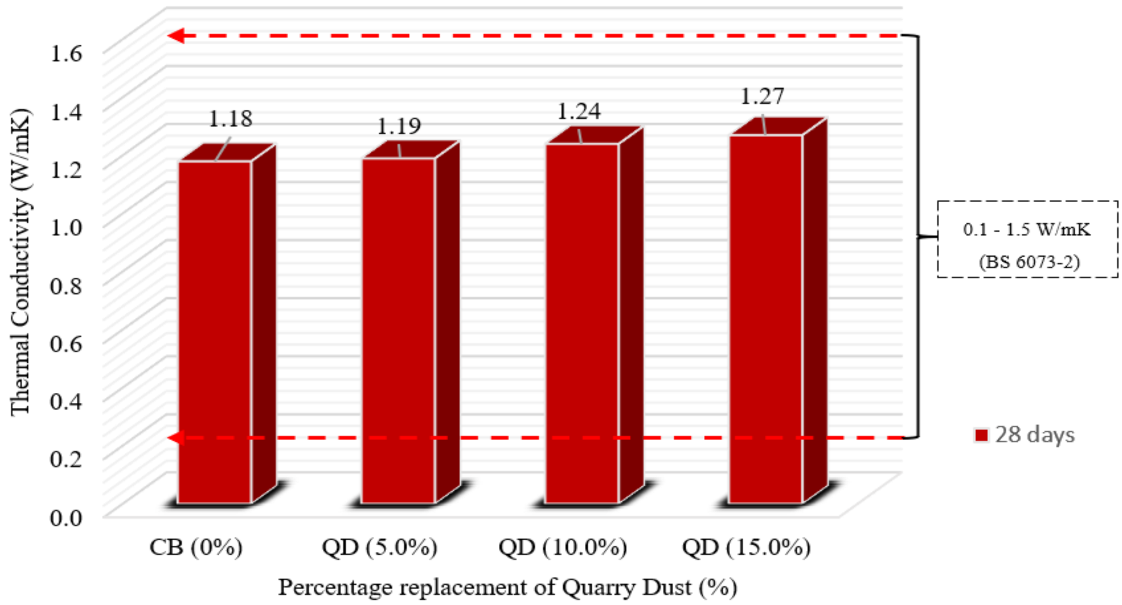

Figure 5: Histogram graph of density

The highest value for thermal conductivity of cement sand block was 1.27 W/mK (15.0% Quarry Dust) while the lowest thermal conductivity value was 1.19 W/mK (5.0% Quarry Dust). Based on the requirement in standard BS 6073-2, the thermal conductivity of concrete solid blocks was the range from 0.10 to 1.5 W/mK [25]. All the mix percentages have met the standard thermal conductivity of solid blocks. Thermal values were increases with the increase of quarry dust in the blocks. The quarry dust in the blocks has a low number of pores in the blocks that cause the heat to flow fast from one medium to another medium. The porosity plays the most important role in determining the value of thermal conductivity. The higher percentage of the quarry dust reduces the porosity in the blocks and there is less amount of air able to be trapped in the quarry dust. Thus, a high percentage of quarry dust will have a high value of thermal conductivity.

4.2.4 Density

The density of the different percentages of quarry dust replacement blocks is shown in Figure 6.

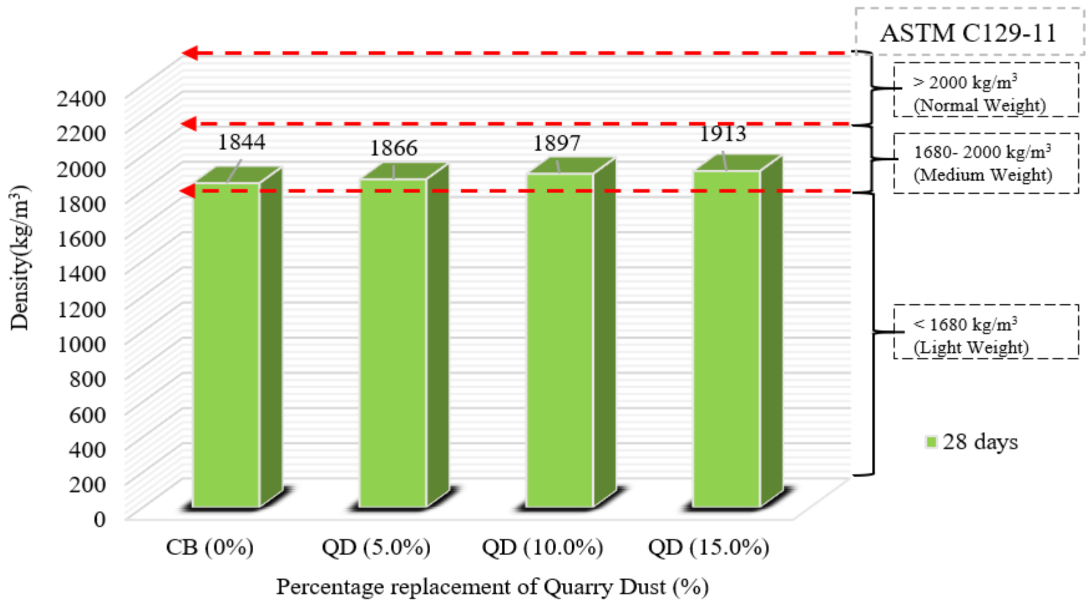

Figure 6: Histogram graph of thermal conductivity

Based on the figure, the density of the blocks varies by the different percentages of quarry dust replaced in the blocks. According to the standard in the ASTM C129-11 [22], all blocks has located in the range of medium-weight blocks (1680 to 2000 kg/m^3). The highest density of the blocks was 1913 kg/m^3 (15.0% Quarry Dust) and the lowest density among the cement sand blocks was 1866 kg/m^3 (5.0% Quarry Dust). The increase in the percentage of quarry dust in the blocks will reduce the pores in the blocks and the blocks will become denser. There were a little number of pores in the blocks and cause the blocks to become denser as the specific gravity of quarry dust is similar to the sand. Therefore, the replacement of sand by quarry dust will cause the blocks to become denser than the control blocks.

4.2.5 Relationship between compressive strength against water absorption

Figure 7 shows the relationship between compressive strength and water absorption.

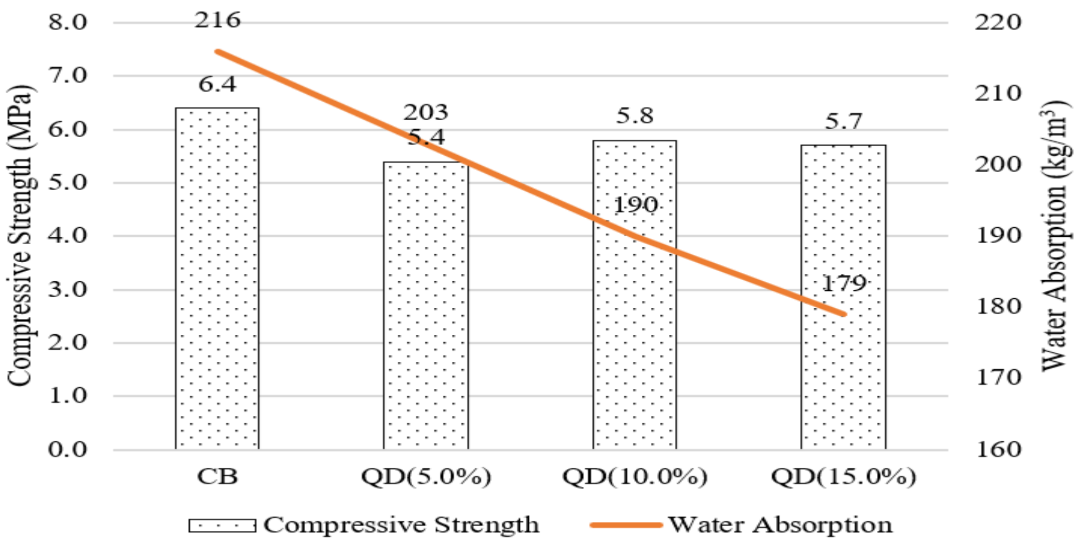

Figure 7: Compressive strength and water absorption

From the graph shown in Figure 7, it shows that the relationship between the compressive strength of the cement sand blocks and the water absorption of the cement sand block is the water absorption correlated inversely with compressive strength when more percentage of quarry dust was added to the blocks. The water absorption decreases while the compressive strength increases. The reason was there were only little pores in the blocks when the increase of the percentage of quarry dust. The lower porosity of the blocks had blocked the water to enter the blocks and this increase the block strength.

4.2.6 Relationship between compressive strength and thermal conductivity

Figure 8 shows the relationship between compressive strength value and thermal conductivity. The relationship between the compressive strength of cement sand block with the thermal conductivity of the blocks is a positive linear correlation which shows that the compressive strength increases linearly with the thermal conductivity. The compressive strength increases while the thermal conductivity of the blocks also increases. The reason this occurred is due to the porous in the blocks are being filled by the quarry dust and there are only little pores in the blocks. The bonding between the blocks becomes stronger but for thermal conductivity, there are no pores for heat to improve the thermal insulation value.

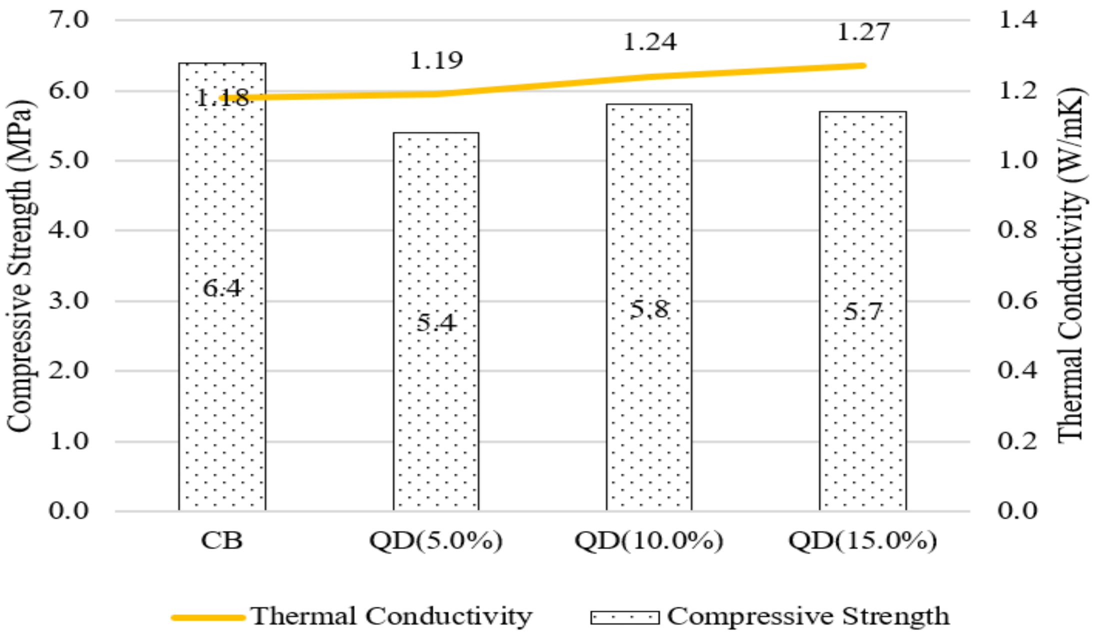

Figure 8: Compressive Strength versus Thermal Conductivity

4.2.7 Relationship between thermal conductivity and water absorption

Figure 9 shows that the relationship between thermal conductivity and water absorption for cement sand blocks.

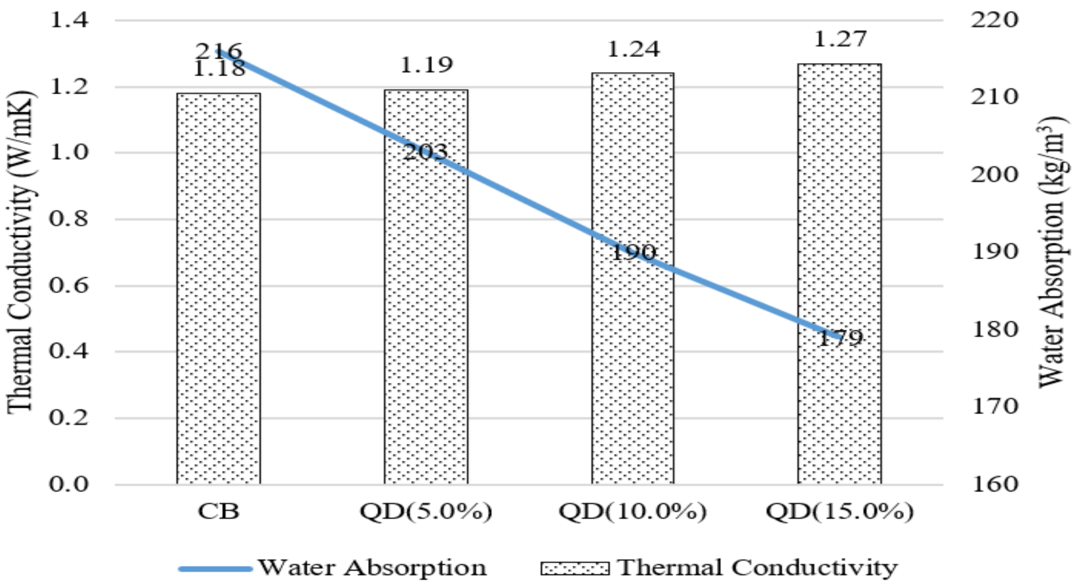

Figure 9: Thermal conductivity versus water absorption

From Figure 9, the graph shows the relationship between the thermal conductivity and water absorption of the block samples is a negative linear correlation which indicated that the thermal conductivity increases when the water absorption decreases. This occurred due to the specific gravity of the quarry dust is like the sand and the quarry dust has created fewer voids in the blocks as the size of the quarry dust very fine. When more percentage of quarry dust replaced in the blocks causes lesser voids inside the blocks. When the decrease in the number of voids will increase the thermal conductivity value of the blocks.

5. Conclusion

From the result of the analysis, it can be concluded that the quarry dust suitable and potential to be used as the sand replacement material in the construction field. The optimum percentage of quarry dust as sand replacement material is 15.0% as it complied with all standard requirements in terms of compressive strength, water absorption, density, and thermal conductivity. Therefore, the use of quarry dust as the sand replacement material in the production of cement sand blocks is suitable and able to reduce the waste generated and reduce the pollution that occurred.

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