

Physical Properties of Concrete Roof Tiles Containing Recycled Wood-wool and Quarry Dust as Partial Sand Replacement

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Abstract

Concrete roof tile is an important building material that highly demanding in construction sector. The production of wood-wool concrete roof tiles (WWCRT) become an alternative in generating sustainable material development and have its potential to be in demanding market. WWCRT was a prototype of flat roof contained grinded wood wool (CWWP) and quarry dust as partial sand replacement with the addition of perlite and SP. The aim of this study is to investigate the physical properties of WWCRT mortar and to identify the optimum proportion of replacement material, water-cement ratio and mix proportion of roof tile. The tests conducted were water absorption of prism-shape mortar and water permeability of WWCRT mortar. The results showed that the B15 of WWCRT mix with 15% and 10% proportion of CWWP and QD respectively achieved the lowest water absorption rate which is 9.9% and this is the optimum percentage in producing a low-density roof mortar as its density of 28-day of curing is 1567 kg/m³. For water permeability rate by uncoated WWCRT, B15 showed the lowest rate as the water seeping in 1-hour test only up to 38 mm depth. The increase time taken in minutes, the higher permeability rate achieved at the end of 1-hour test. The increasing time also leads to the slower flow rate of water seeped through the WWCRT. WWCRT with surface coating enhanced the performance of this test as all coated roof batches resulted nearly null of water permeability rate. Therefore, the proportion of CWWP and QD affected the physical behaviour of mortar.

1. Introduction

The green and sustainable construction became the main aim of this innovative roof tiles. As mentioned by Jaafar (2017), sustainable construction known as building a healthy built environment based on ecological principles and responsibly preserving it through efficient resource used. The approach of this study in replacing sand with CWWP and quarry dust (QD) at certain specified percentage become a way in promoting green environment in Malaysian construction sector. This study mainly observed the physical properties of WWCRT containing CWWP and QD with an addition of perlite. This WWCRT aligned with the typical roof tiles in Malaysia in terms of its dimension without the consideration of joints of roof connections design. By the WWCRT innovative design, it focused more in evaluating the potentiality of CWWP and QD in its implementation as a

mortar for roof tiles without considering the detailed shape of market roof that come with the roof connection system design.

As CWWP and QD were the variable parameters in the proportion of mix design, this composite mortar also had an addition of 5% perlite and 2% superplasticizer (SP) as constant parameter. The qualities of perlites in being insulating, light, non-organic, fireproof, and pest-proof become its most well-known benefits. Perlite is commonly utilized in the industry to create lightweight, user-friendly joint compositions. Perlite also improves bonding properties and provides improved uniformity. However, from the past research, Maxineasa et al. (2022) mentioned that expanded perlite (EP) deteriorates concrete's physical and mechanical characteristics because of its strong capacity to absorb water. Therefore, it is anticipated that applying a polymer coating to the EP would greatly minimize the amount of water absorption, enhancing its mechanical and physical qualities.

Patthanavarit et al. (2021) had examined the physical and mechanical characteristics of cement mortar that contains expanded perlite as a sand replacement. This past study concluded that higher expanded perlite content enhanced water absorption, which slightly decreased with higher compressive force. The optimal expanded perlite content according to the experimental findings is 10% of weight. The final assumption of the proportionally linear relationship between EP content and absorbed water encouraged to implement further research in this scope of study in order to find the suitability of EP application in cement mortar which more specifically for roof tiles. For SP application in cement mortar, in general Kumar et al., (1989) had studied the potential of SP and concluded that this addition material increased the workability of mixture while decreasing the demand of water content.

According to Maier (2021), the incompatibility of cement and wood become the main limitation research. As wood acted as a moisture absorber and cement required a particular amount of humidity to activate and increase its strength, the concrete production may significantly lose mechanical strength. A wood- wool cement board (WWCB) is one of the examples of advanced wood-cement composites by Ahmad et al. (2011). The conventional particleboard of cement has varied in term of its density and porosity compared to the WWCB. According to the findings, the optimum mix ratio is three parts cement to two parts wood wool by weight. The water absorption result and swelling were more than those allowed by German Standard which defined a maximum water absorption value of 22% and a maximum thickness swelling value of 0.84%.

Meanwhile, wood-wool in sand mortar research by Taoukil et al. (2012) demonstrated that the mortar's ability to absorb water is significantly increased when wood wool was added. Numerous studies demonstrated the importance of using a proper mix of materials and further research into ratios was still necessary. Therefore, this proposed study became one of the beginnings in searching the best optimum proportional ratio of mixture related to the woodwool-based product and quarry dust with the addition of perlite and SP in mortar.

The used of CWWP material in this study came from the leftover wood-wool composite panel (WWCP) which is a wood-based product made from renewable resource that is lightweight, easy to make, has a lower embodied carbon emission, and is frequently used in construction to replace less environmentally friendly materials like regular concrete roof tiles and other masonry components. Meanwhile, quarry dust is a by-product of the crushing process during quarrying activities. After analyzing and referred to past study, the water-cement ratio used was 0.60 and the cement-aggregate ratio was 1:4. The physical properties on the roof mortar that be observed are water absorption and water permeability. Both tests would be conducted according to the ASTM C140-11a, ASTM C90-16a, ASTM C1492-03 and MS 797: Pt.1: 1892. All the samples with different mix proportion of CWWP and QD underwent an analysis data through these tests to observe the physical properties behaviour of roof mortar and determine the optimum range of proportion for all materials involved in producing the most effective performance of cement composite for the concrete roof tiles.

2. Methodology

The line of action has been taken in producing roof mortar with the partial sand replacement by CWWP and QD with the addition of perlite and superplasticizer. The collection of materials for this WWCRT were Ordinary Portland Cement, sands, wood-wool panel, quarry dust and perlites.

2.1 Preparation of materials

The residue panel in the production of wood-wool cement composite panel (WWCP) by Noh *et al.* (2016) which its intention in developing new prefabricated wall been used by converting it to CWWP material. The collected WWCP being cut, crushed and grinded used mills grinder machine at the laboratory to get the finest particles of the wood wool. Figure 1 below shows the process in preparing the CWWP material.



Fig. 1 The process of CWWP preparation a) Cut CWWP; b) Crushed CWWP; c) Process of CWWP grinding; d) Finest particles of CWWP

The quarry dust been collected from a factory in Minyak Beku, Johore known as BP Lian Huat Granite Quarry Sdn. Bhd. The collected quarry dust and sands from laboratory has been settled in a tray in the open air for 24 hours to dry and get rid of any excess moisture in the materials prior to sieving process. The obtained quarry dust passed through sieve no.8 with diameter of 2.36mm and retained on sieve no.200 with diameter of 0.075mm which is the same size as sand according to ASTM E11 been used in the design mix. Expanded perlites that had been used in this study had been bought from a supplier known as Temperlite Insulation Sdn Bhd. The type of perlites used was Type C: Construction Grad with its particle's sizes within 0.074 mm to 2.2mm. For OPC, to guarantee that the OPC cement had the qualities of being in good condition, it been kept in the lab and stored properly.

2.2 Preparation of molds

A total of 40 specimens being produced as the sample testing consisted of 30 samples of prism for water absorption test and 10 samples of flat roof for water permeability test. The mold for prism samples been provided by the laboratory with its dimension is 160mm x 40mm x 40mm according to the BS EN 1015-11:1999. Meanwhile, the mold of flat roof samples was created prior to the design mix preparation of all 40 samples at the Makmal Teknologi Perakayuan, UTHM. The dimension of flat roof mold referred to the standard roof tiles available in the market which is 420mm x 330mm x 25mm. Figure 2 shows the flat roof mold that had been cast.

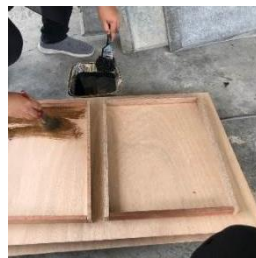


Fig. 2 The casted flat roof mold

2.3 Proportion of design mix

This study variable parameters are the percentage of the fine aggregate consisting of sands, CWWP and QD. A total of 5 different design mixes have been prepared with the specified proportion including the control sample as shown in Table 1 below. There are 30 samples of prism, 5 samples of flat roof without coating and 5 samples of flat roof with coating would be prepared for the physical testing.

Table 1 The proportion of design mix by percentage

Fine Aggregates	The percentage of replacement (%)					a/c ratio	w/c ratio
	B00	B01	B15	B30	B45		
Sand	100	100	75	50	25	1:4	0.60
CWWP	0	0	15	30	45		
QD	0	0	10	20	30		
Perlites	0	5	5	5	5		
SP	0	0	2	2	2		

The procedure in determining density for sand, CWWP and QD been executed in order to compute the weight proportion values for mix designs by volume method. Each material been placed into a 100 x 100 x 100 (mm) cube mold and the weight of material been computed. The density of every material of CWWP, QD and sands been identified by the equation (1) below. Table 2 shows the design properties value that been used for calculating the required weight of each material in each mix design.

$$\text{Density (kg/m}^3\text{)} = \left[\frac{\text{Weight of material (kg)}}{\text{Volume of cube (m}^3\text{)}} \right] \quad (1)$$

Table 2 Design Properties

Properties	Values
Water-cement ratio (w/c)	: 0.60
Aggregate-cement ratio (a/c)	: 1: 4
Proportion of perlite (%)	: 5
Proportion of SP (%)	: 2
Prism Dimension (mm)	: 160x40x40
Prism Vol. plus 30% (m ³)	: 0.0003
Nos. of Prism:	: 6 per batch
Total Prism Vol. (mm ³)	: 0.002
Flat Roof Dimension (mm)	: 420x330x25
Flat Roof Vol. plus 30% (m ³)	: 0.0045
Nos. of Flat Roof	: 2 per batch
Total of Flat Roof Vol. (m ³)	: 0.009
Density of Cement (kg/ m ³)	: 1440
Density of Sand (kg/ m ³)	: 1560
Density of CWWP (kg/ m ³):	: 850
Density of QD (kg/ m ³):	: 1600

The weight of each batch been computed by volume method. The mass of replacement for each batch been shown in Table 3.

Table 3 Equation formulas of weight material computation

Fine Aggregates	The mass of replacement (kg)					Cement (kg)	Water (kg)
	B00	B01	B15	B30	B45		
Sand	14.04	14.04	10.53	7.02	3.51		
CWWP	0	0	1.15	2.30	3.45		
QD	0	0	1.44	2.88	4.32	3.15	1.89
Perlites	0	0.01	0.01	0.01	0.01		
SP	0	0	0.06	0.06	0.06		

The first stage been performed by mixing all the constitute materials which are sands, CWWP, QD, and Perlites according to specified proportion of each batch. Then, about 1.89 kg of water been poured in the mixture following by 0.06 kg of SP. Prior to the process of pouring mix into the molds, the mixture underwent a mini-slump cone test in order to evaluate the workability of mortar pastes. This test been performed according to ASTM C-143. The dimensions and performance of the miniature cone test shown in Figure 3.

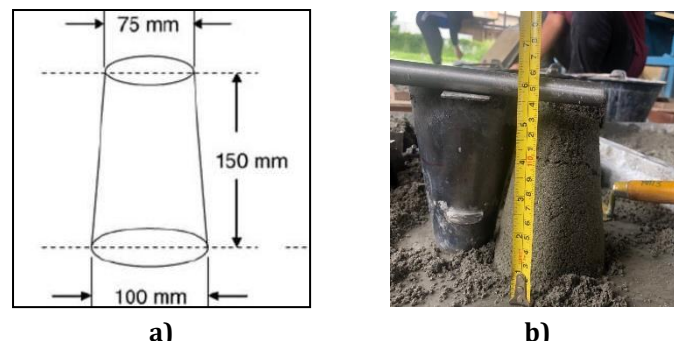


Fig. 3 The mini-slump cone test a) Dimension of cone; b) The performance of mini-slump test

For prism samples, the prism molds been coated with grease prior to the pouring of mixture into the molds. The fresh mixed design being compacted adequately in the mold by 25 blows for each of 3 layers. For flat roof samples, the wooden molds been coated with grease prior to the mixture been pouring into the mold. The fresh mixed design being poured into the mold in 2 layers of the pastes. The first layer of freshly paste would be compacted adequately by small steel bar. In between the two layers, the 380 mm length of fibre mesh been placed. The second layer of pastes was compacted again until the top surface of flat roof achieved smooth textures. This process is represented in Figure 4 below. All freshly casted sample being settled in an open air for about 24 hours before the samples been unmoulded. The curing methods used for both prism and flat roof samples was water immersion method The prism and flat roof samples been cured in water tank for 7 days and 28 days according to the ASTM C1314-07.

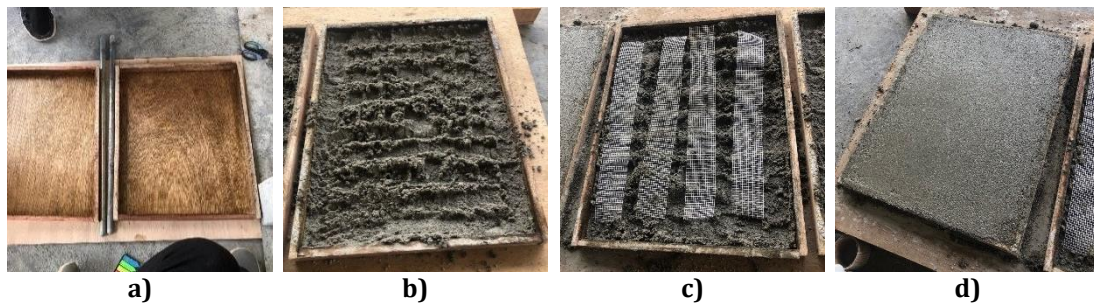


Fig. 4 Process in casting flat roof samples a) Greased mold; b) First compacted layer of sample; c) 380mm Fibre Mesh ; d) Texture of top surface

2.4 Water Absorption Test

A total of 30 samples of prism without coating been used for this test according to the ASTM C140-11a and C90-16a. After the prisms had been cured in the water tanks for 7 days and 28 days, the prisms were kept dried in an oven with temperature $105\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ for 24 hours. After 24 hours, the samples been weighted to compute W_d data. The prisms then been immersed in the water for another 24 hours. The weight of the samples after this immersion been recorded as W_s . The samples have been ensured to be clear with any dripping water by wiping up the sample with any fabric cloth. The process of this test been shown in Figure 5 and the water absorption data has been computed by using equation (2) below.

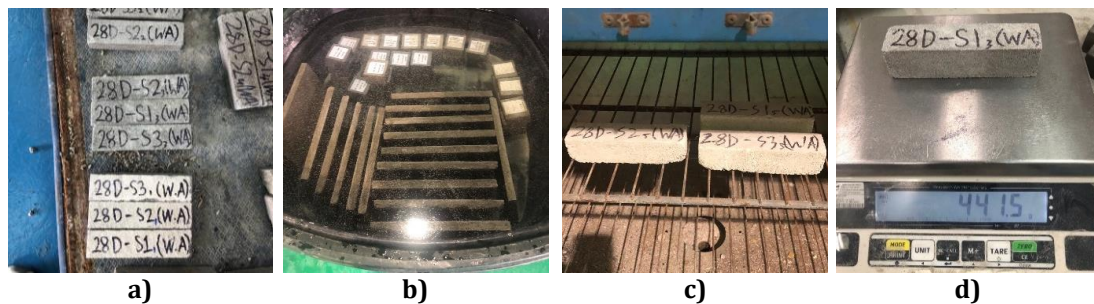


Fig.5 Process in water absorption test a) Prism samples; b) Water immersion for wet weight data; c) Dried process for dry weight data; d) Weighting process

$$\text{Water Absorption, \%} = [(W_s - W_d)/W_d] \times 100 \quad (2)$$

where:

W_s = Saturated Weight of Specimen (kg)

W_d = Immersed Weight of Specimen (kg)

2.5 Water Permeability Test

A total of 5 samples of flat roof without coating and 5 samples with waterproof coating been used for this test according to ASTM C1492-03 and MS 797: Pt.1: 1892. For WWCRT with no coating, the top surface was cleared from any coating and been tested in original condition of its top surface. Meanwhile, for the coated WWCRT, the top surface of flat roof been applied a layer of waterproof coating. The acrylic plates been used as a box barrier for the ponding water on the top surface of WWCRT. The connection between the acrylic plates has been sealed by silicone to prevent the leaking of water around the edge of the flat roof. This preparation of apparatus on the WWCRT with coating and no coating been shown in Figure 6 below.

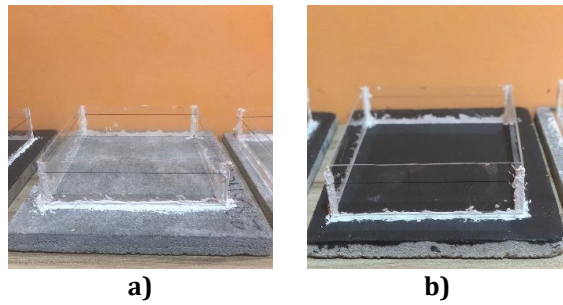


Fig. 6 The apparatus for water permeability test
a) No-coated flat roof; b) Coated flat roof

A 50 mm constant head of water has been ponded in the acrylic box by referred to the lines been marked at the acrylic plates. The cumulative depth of water penetration been recorded at 10-mins time interval for 1-hour duration of test. The WWCRT samples been ensured to be placed on top of two plank of woods cover in order to give some space in allowing the permeable water that seeped through into the samples being free drained through the underside of samples. This process been shown in Figure 7 below.

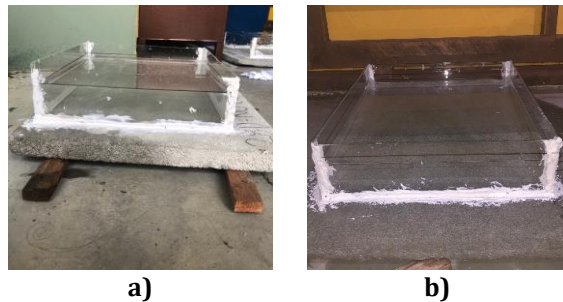


Fig. 7 The execution of water permeability test a)
The ponded water in the acrylic box; b) The
cover of plank woods

3. Result and Discussion

The result obtained from these tests has been analyzed and discussed. The water absorption results have been correlated with its density computed. Prior to the test analysis, curve of sieve distribution was also analyzed.

3.1 Sieve Analysis Distribution Curve

The curve in Figure 8 represents the cumulative quantity of materials that passed on each. The upper and lower limit of the fine aggregate was referred to ASTM C-33.

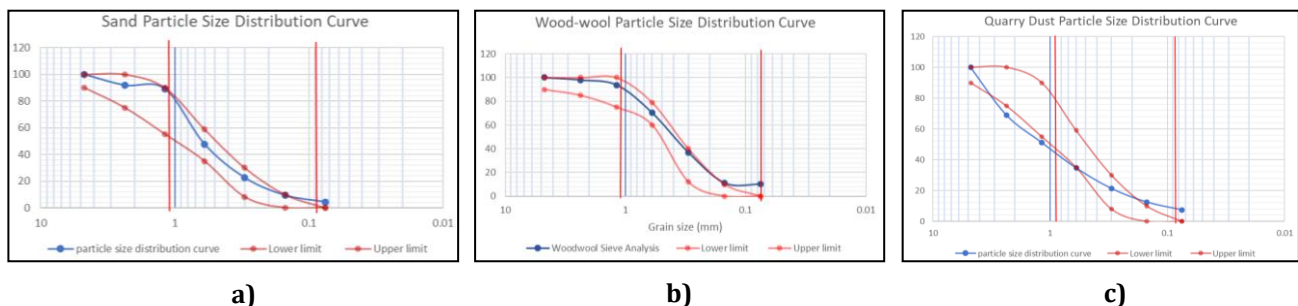


Fig. 8 Sieve Analysis Distribution Curve a) Sand; b) CWWP; c) Quarry Dust

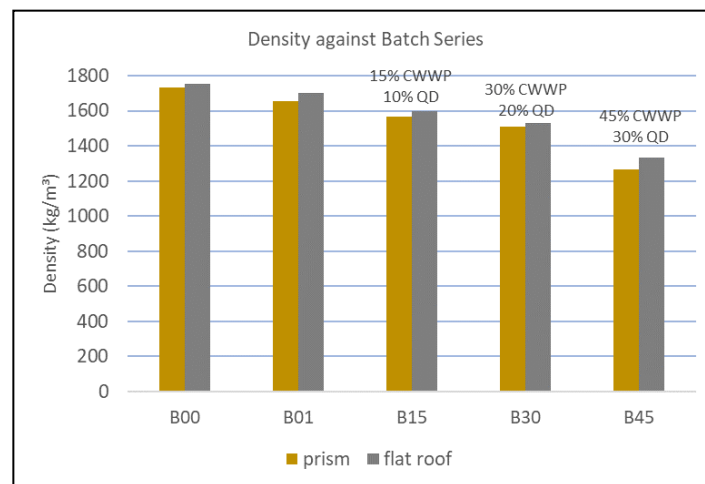
Table 5 *The materials zone classification*

Fine Aggregates	Zone Classification
Sand	Zone II
CWWP	Zone III
QD	Zone II

Each material of sand, CWWP and QD been classified under particular zone. According to Table 5, Zone I represent the aggregate in a coarsest condition meanwhile Zone IV represents the finest sand condition.

3.2 Density Test

The density for both prism and flat roof samples been identified after 28 days curing. The density values were computed using the formula mass divided by volume. This computation provides a value that indicates the quantity of mass contained in a given specific volume of a sample as shown in Figure 9.

**Fig. 9** *Density against Batch Series*

By evaluating the results based on the material proportion of each mix design, the density of samples decreased with the increasing proportion of CWWP and QD. The replacement of sands using CWWP and QD in B15, B30 and B45 makes significant changes throughout the density values. Among these three batches, the highest replacement proportion of CWWP and QD in the mixture, which is 45% and 30% respectively in B45, created the lowest density of samples both for prism and flat roof. Batch B15 which contained 15% CWWP and 10% QD, the smallest proportion in replacing the sands created the highest density for both samples. Meanwhile, both B00 and B01 did not contain CWWP and QD as to represent the changes due to the existence of perlite addition only in the mixture. B00 design was a mixture without perlite, meanwhile B01 design was a mixture with the addition of 5% perlites. The occurrence of perlite would decrease the density of sample as density of B01 was lower than the density of B00.

Next, by evaluating the results based on the design shape of prisms and flat roof, each single batch shows the flat roof sample had lower density than prism samples. For prism samples, the highest density throughout all the batches is 1789 kg/m³ by batch B00 without perlites, CWWP and QD, meanwhile the lowest density is 1511 kg/m³ by batch B45 contained 45% of CWWP, 30% of quarry dust and 5% of perlites. Meanwhile, for flat roofs the highest density throughout all the batches is 1756 kg/m³ by batch B00, meanwhile the lowest density is 1411 kg/m³ by batch B45.

According to the ASTM C90 which under the jurisdiction on concrete masonry units and related units with the physical of sample requirement referred to the ASTM C140, all the prism samples containing CWWP and QD classified as lightweight density sample as the density values less than 1680kg/m³. Meanwhile, flat roof samples with CWWP and QD also been classified as lightweight density sample based on ASTM C1492 as it less than 1680kg/m³. Table 6 below shows the density achieved by both samples after 28-days of curing.

Table 6 The density of each mix design

Batches	Density (kg/ m ³)	
	Prism	Flat Roof
B00	1733	1756
B01	1656	1700
B15	1567	1600
B30	1511	1533
B45	1267	1333

3.3 Water Absorption Test

After 7 days and 28 days of curing the prism samples in the immersed water, all samples underwent a water absorption test to evaluate the durability of samples.

3.3.1 Water Absorption at 7-days and 28-days aged of curing

Both data of water absorption behavior at 7-days and 28-days aged of curing been analyzed by visualized into graph as shown in Figure 10 below.

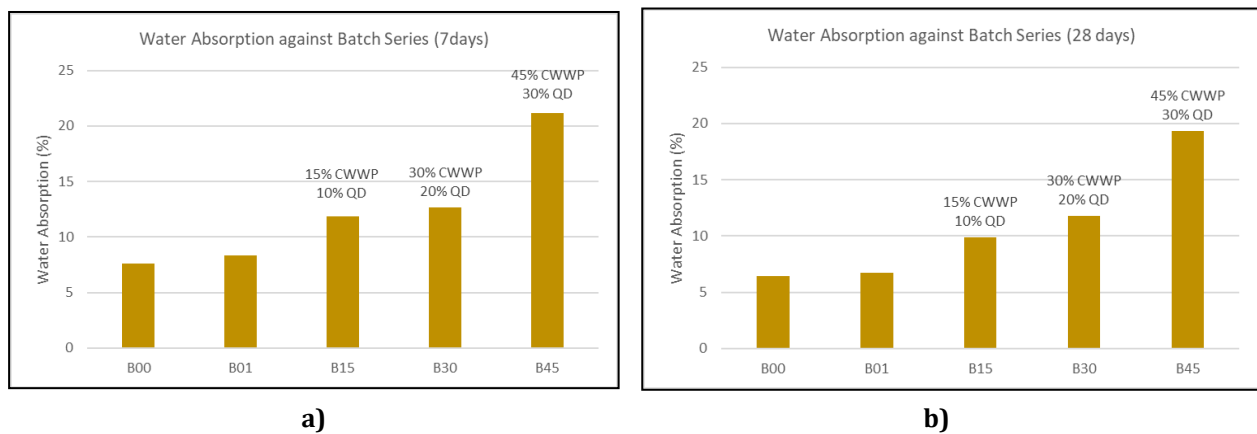


Fig. 10 Water Absorption against Batch Series a) 7-days aged of curing; (b) 28-days aged of curing

The addition of CWWP and QD in replacing sands was directly proportional to the percentage of water absorption. Batch B15, B30 and B45 contained CWWP and QD with the addition of 5% perlites and 2% SP. The data for these batches showed that the higher proportion of CWWP and QD replacement, the higher water absorption behavior of the samples. The main stem for the increasing potentiality of samples in absorbing water is most likely due to the nature properties of the woodwool itself. Wool fibers captured humidity from the atmosphere and absorbed large volumes of liquid when submerged in it. Water will begin to seep into wood as it encounters it, primarily through hydrophilic hemicellulose. Therefore, the originality of wood-wool behavior itself attracted more water bonds seeped into the mortar samples. This changes also due to the quarry dust properties as the greater content of fine quarry dust results in the increment of water demand for the mixed mortars. As batch B00 was mix control sample consisting of sands, cement and water only compared to the B01 which had the addition of 5% of perlites, this chart indicated that the perlites addition made the sample more porous and easily absorbed water.

3.3.2 The comparison of water absorption test between 7 and 28 days of aged

The water absorption behavior between 7 days and 28 days aged of samples appeared to have insignificant changes in data between them. This slight difference needs to be compared and analyzed in order to understand the comprehensive theory behind that which becomes the main principle that causes the correlation between water absorption and the samples' structures.

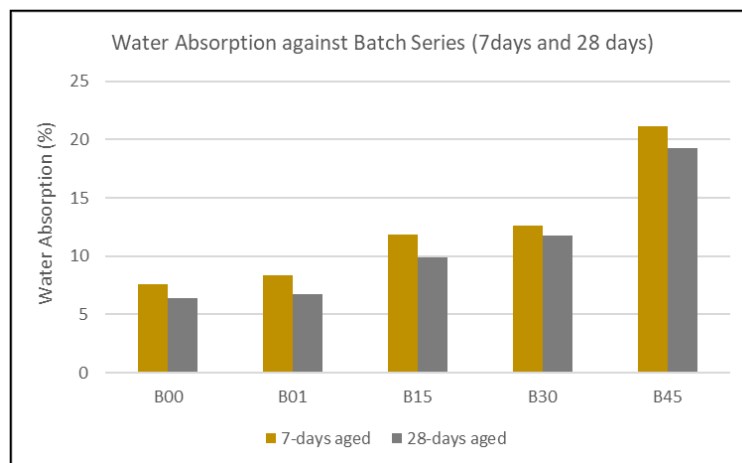


Fig. 11 Comparison of Water Absorption against Batch Series

According to Figure 11 above, the water absorption behaviour at 7 days aged of samples is much higher than the water absorption behaviour at 28 days aged of samples. For 7 days aged of samples, the highest water can be absorbed into the samples reached up to 21.1% by B45, meanwhile about 19.3% water absorbed for samples of aged 28-days. Curing is the process of keeping concrete damp after placing so that its intended properties can mature properly. A chemical reaction known as hydration took place right after the mixing of Portland cement and water. Basically, this reaction of chemicals occurred once the primary constituents in cement form into hydrates or hydration products after they chemically bond with molecules of water. At the 7-days aged of curing, the samples approximately achieved 60% of its complete hydration process only if the samples were properly cured with adequate amount of water or moisture to ensure the hydration process continuously happened until its fully cured.

The occurrence of this chemical hydration explained its contribution to the significant difference of water absorption behaviour at 7-days aged of curing as it was greater compared to the 28-days aged of curing. At 7-days of curing, the samples absorbed much more water than 28 days as the samples were still in the on-going hydration process. During this period where the mortar was in the most freshly mixed condition, the samples would consume a great amount of water to form its paste structure and glues all the materials together which consisted of fine aggregates and cement. By this adequate of water that allows the continuous hydration process to be happened, this process would allow the mortar to harden and eventually becomes sturdy and solids at the end of days of curing.

At 28-days aged of curing, approximately the mortar should achieve 98% complete of its hydration process. The mortar at this phase would absorb less amount of water compared to the amount of water absorbed at the early age of curing days. In this stage, the mortar nearly completed its chemical reaction of water bonding with the cement to become hydrate product and eventually achieved the desired properties of its ultimate durability, strength, resistance to thawing and freezing cycles, watertight tension, abrasion resistance, volumetric stability. This process of hydration and the amount of water needed for the mortar hardened and bonding between its aggregates explained the changes behaviour of water absorption at both curing phase during 7-days and 28-days aged.

3.3.3 The relationship between density and water absorption behavior

The behavior of samples in terms of its water absorption may correlate with the density achieved by all curing mortar. These two parameters would be evaluated through several analysis and theoretical reasons. Figure 12 below shows the visual representation of the water absorption behavior and its density for both 7-days and 28-days aged of curing samples.

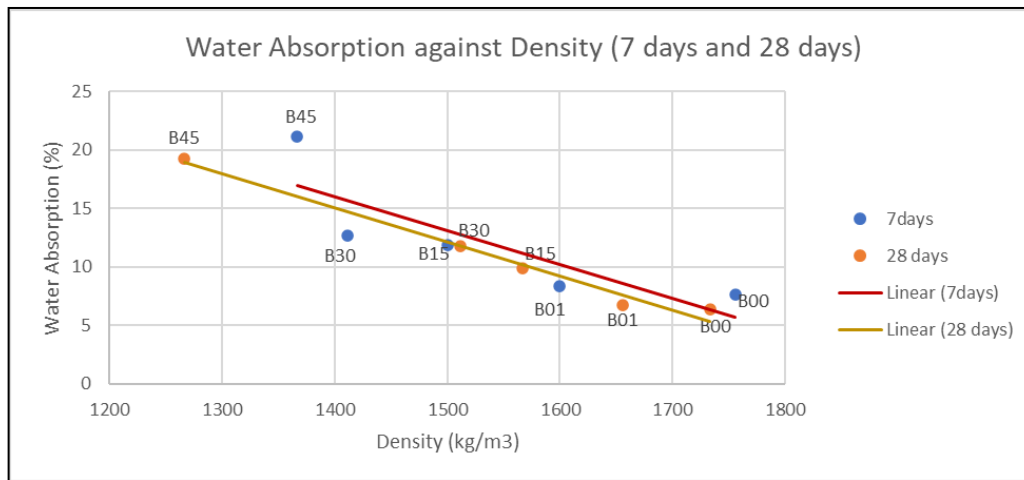


Fig. 12 Water Absorption against Density at 7-days and 28-days

The density of samples was inversely proportional to the water absorption behaviour. The higher density of certain samples achieved, the lower potential of the samples to absorb water. For 7-days aged of curing, the mix B01 where have perlites addition in the mixture absorbed higher water than B00 mixture of no perlites, as density of B01 was lower than B00. Batch B01 absorbs 8.3% of water with its density of 1600 kg/m³ meanwhile B00 only absorbs 7.6% of water with its higher density which is 1756 kg/m³. Batch B15, B30 and B45 also represent the same relationship which is the density values are inversely proportional to the water absorption behaviour. By the occurrence of wood-wool and quarry dust in these mixtures, the higher replacement of this materials, the lighter density could be achieved by the samples. Therefore, batch B45, where the highest replacement of sands by CWWP and quarry dust in it have the greatest rate of water absorption as this batch's samples conquered the lowest density among these three mixed designs. The existence of CWWP and QD in B15 obviously changes this correlation with B01 which is this batch had no CWWP and QD in it. The properties of CWWP and QD in the mixture reduced the density of samples and simultaneously attracts higher water to be absorbed into the samples. The same cases also applied to the samples aged of 28-days curing as it represented the same correlation as 7 days of curing which is inversely proportional relationship.

This data also highlighted the correlation between density of samples and the period of curing. For B00 and B45, the longer the day of curing, the lower density of samples achieved. In contrast with the B01, B15 and B30, the period of days been cured was directly proportional to the density achieved. These non-uniform results may be due to the different mold of samples between these two evaluation days of curing 7-days and 28-days. By all these evaluations, the optimum proportion of mix design contained of replacement materials that contributed the most effectiveness results was batch B15 as its give the lowest water absorption rate at the same its density, 1567 kg/m³ still classified under the lightweight type of sample according to ASTM C-90 and C1492.

3.4 Water Permeability Test

The flat roof samples that had been cured for 28 days underwent water permeability test in order to evaluate the potential of permeable mortar in draining the water that ponding above the top of its top layer by its properties of saturated hydraulic conductivity. Figure 13 below shows the results of water permeability behavior for the flat roof samples with no coating.

Fig. 13 Cumulative Flow Rate against Cumulative Time (No Coating)

The relationship of cumulative depth of absorbed water is directly proportional to the cumulative 10-mins time interval of 1-hour water permeability test. For mix control batch of B00, the depth of water absorbed through the top surface of the sample was about 5mm in the first 10 minutes of the test. In comparison to the batch B01 where this sample consisted of 5% of perlites material in it, the depth of water been absorbed through the top surface of the sample during the first 10 minutes much slower as the ponding water only absorbs 3 mm in that first time interval. For both batches, the ponding water keep absorbed throughout the 1-hour duration of test. The highest permeability rate of water in a 1-hour evaluation was achieved by batch B00 as the water penetrated up until 15mm in 1 hour. This increasing rate may be due to the effect from the non-occurrence of perlites in the mixture.

The relationship of cumulative flow rate is inversely proportional to the cumulative 10-mins time interval of 1-hour water permeability test. For mix control batch of B00, the flow rate of water penetrated through the top surface of the sample was $4 \times 10^{-3} \text{ m}^3/\text{s}$ at the first 10 minutes of the test. In comparison to the batch B01 where this sample consisted of 5% of perlites material in it, the flow rate of water been penetrated through the top surface of the sample during the first 10 minutes much slower as the water penetrated $2.4 \times 10^{-3} \text{ m}^3/\text{s}$ in that first time interval. For both batches, the ponding water keep penetrated throughout the 1-hour duration of test. As the time increase, the flow rate of water penetrated keep slower through the samples This decreasing rate may be due to the samples condition as the samples been fully saturated as its nearly end of test and eventually affect the capacity of water that the sample able to absorb.

For batch B15, B30 and B45, the higher proportions of CWWP and QD in replacing the sands, the higher rate of water permeability achieved by the flat roof samples at the end of 1-hour duration of test. At the initial phase of the ponded water been penetrated, during the first 10 minutes, the B45 was fastest in terms of its potential of water permeable through the surface compared to B15 and B30. Batch B45 penetrated about 35mm of ponded water at the first of time interval, meanwhile the rate of water permeability for B30 and B15 were smaller which are 18mm and 15mm respectively. For batch B15, B30 and B45, the increasing time decreased the flow rate of water. Among these 3 batches, B45 achieved the fastest flow rate at the last time interval of test which are $6.7 \times 10^{-3} \text{ m}^3/\text{s}$ compared to B15 and B30 which are $5.1 \times 10^{-3} \text{ m}^3/\text{s}$ and $6.1 \times 10^{-3} \text{ m}^3/\text{s}$ respectively. In order to evaluate the effect of wood-wool existence in the mixture, B01 and B15 become a crucial role in these terms of perspective. Once the wood-wool was included in the B15 mixture, the rate of water permeability significantly changes as the CWWP material boosted up this permeable rate compared to mix control of B01. Figure 14 shows the wet area and bubble of water appeared underside of the roof samples as there was a seeping water during the 1-hour test.



Fig. 14 Seeping water at underside of sample

Fig. 15 *Cumulative Flow Rate against Cumulative (With Coating)*

Figure 15 above shows the WWCRT samples with coating been applied as the exposed layer on the top surface of the flat roof samples. The water permeability rates of this WWCRT are nearly null as the top layer has been protected by waterproof roof coating. After some observations, the small changes in the cumulative depth of penetrated water were due to the improper sealing of silicone in between the joints of connecting plates of acrylic box during the test. This error can be ensured as there was some bubble of waters drips from the edge of the acrylic joints through detailed observation. The dropping of ponded water about 1 mm was not affected by the structures of WWCRT as there are no dripping or draining water underside of the flat roof as its stay still in dried condition and no signs of water occurrence as shown in Figure 16.



Fig. 16 *Permeability test for coating roof*

By all these perspectives of evaluation in terms of its water permeability parameter, the optimum proportion of mix design contained of replacement materials that contributed the most effectiveness results was batch B15 as it gives the lowest water permeability rate. However, the performance of WWCRT was much better with the top surface of the samples been coated by waterproofing roof pavers coating.

4. Conclusion

Several recommendations been outlined based on the observations through several insufficient of key elements, errors, and deficiencies in planning this research. The selection of various materials that to be combined with woodwool-based mortar or any fibrous-based mortar can be reduced to prevent the complication of analysing the effectiveness of too many materials in one mix design. Next, fo the preparation of wooden moulds, any study associated with the samples that in function as load-bearing structures or masonry flat unit like walls, slabs or roof pavers, the formation of the moulds should allow the mortar pastes to be poured vertically into the moulds. By this approach, the exposed surface's smoothness and compaction quality can be increased as the mould of samples been settled in position that vertically straight. Last, the cement-aggregate ratio can be increased to form more stabilizes proportion between these two components. The a/c ratio can be utilized to 1:2 or 1:3 ratio. This approach due to the observation during the mixing batch in this study where the cement used seems less and not really stabilized with aggregates proportion that may contributed the extra porous of the sample's structures.

After the test evaluation, several conclusions have also been outlined. The optimum proportion of WWCRT mix design is by batch B15 consisting of 15% of CWWP, 10% of quarry dust, 75% of sands with the addition of 5% perlites and 2% SP. B15 had the lowest proportion of CWWP and QD and this is the optimum values for WWCRT achieving a low density. The increment rate of water absorption contributed by the increasing proportion of CWWP and QD in mix design The WWCRT gives its best performance by null water permeability rate with the application of waterproof roof coating on the exposed surface of roof paver. All specified proportions of mix design containing CWWP AND QD which are B15, B30 and B45 classified under the lightweight density of hardened mortar. The existence of perlites contributed to the increment of water absorption rate, reduction in water permeability rate and reduction in density of hardened mortar. The addition of SP helped in the flowability of mortar containing wood-based absorbent water.

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Conflict of Interest

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

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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