Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Production of Washed Bottom Ash as Sand Replacement Material in Concrete Paving Block

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ARTICLE INFO

Article history:
Received 7 November 2022
Received in revised form 29 November 2022
Accepted 26 December 2022
Available online 17 January 2023

ABSTRACT

Concrete Paving Block (CPB) is made by mixing sand, gravel, cement, and water and is used in non-traffic and traffic areas. The CPB is proposed in a variety of shapes, sizes, colours, and materials. The demand for the CPB is increased in line by increasing in residential houses and building construction, and infrastructure activity. The advantages of CPB when compared with the rigid and flexible pavement is a more beautiful and interactive surface, fast-paced production without high technology equipment or skilled worker, and also creating a balanced humidity. Nowadays, concrete using waste materials such as cement, sand, or gravel replacement becomes more popular which supported the sustainable development requirement and goal. The replacement activity of concrete ingredients for promoting waste material with low carbon content in CPB is also part of the sustainable development programme which reduced the environmental impact of the waste material or production of natural concrete ingredients and cost production. With the intention of the issue, the CPB using bottom ash (BA) which is washed to reduce the carbon content is produced and tested for skid resistance, water absorption, and mechanical behaviour. The chemical and physical behaviour of WBA is conducted and shown the suitability to replace sand in CPB. The compressive strength of WBA with 100% of sand replacement in CPB illustrates the maximum load and compressive strength of approximately 1198.35 kN and 30.73 MPa and is appropriately used for paving blocks.

Keywords:
Washed bottom ash; Sand replacement material; Concrete; Paving block; Sustainable development

1. Introduction

A paving block or paver block is recognised as an unreinforced material block made of concrete that combined ingredients between sand, gravel, cement, and water to form a concrete mix. The paving block is utilised as road surfacing for the vehicle or hard standing for parking heavy vehicles or garden pavement decorative. Normally, a paving block is made of clay, concrete, special concrete, or other composite materials. The paving block is formed in solid or with a hole and designed in a variety of patterns, shapes, dimensions, and thicknesses. Patel and Singh [1] mentioned that the

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https://doi.org/10.37934/araset.29.2.236250

concrete paving block (CPB) is categorised as an attractive engineering application and economical option to replace the flexible and rigid pavements which appropriately used for commercial, municipal, and industrial areas. CPB is produced in a variety of shapes either plain straight face or curved face which is still been studied or completely commercialist in the construction industry. The CPB demand increased with the increase in human population, construction activity, and infrastructure programmes or budgets for developing countries. Simultaneously, the amount of waste product also increased fast and uncontrolled. Therefore, the waste product is utilised in concrete technology and other concrete application especially paving blocks.

Nowadays, normal concrete is shifted from ingredient traditional material to waste material which supports the sustainable development programme in a paving block. The utilisation of the low carbon material also became more popular in proposing the CPB either replaced the sand or gravel or cement with waste material. The concrete ingredient traditional replacement is studied to solve the environmental problem which produced from the waste material. Concrete is a versatile, durable, and strong material and becoming popular in the construction industry. The production of cement for concrete is also produced by carbon dioxide (CO_2) emissions in the world and in develop countries. There are two ways of producing CO_2 in cement production when the heating process of limestone and sand mixture in the kiln above 1000^0C and secondly when the chemical process of cement by breaking the limestone. Additionally, energy consumption is highly increased when manufacturing the concrete ingredient traditional material. Reddy [2] have reported that to minimise carbon emission and environmental problem, several requirements must be followed when utilising new building material such as material energy intensity, impact on the environment, ability to recycle, safe disposal, and natural resources of raw material usage. Cement is classified as high-energy consumption material and is produced at 187 x 10^6 tonnes in India, while sand is produced at 75 x 10^6 GJ in India [2]. D'Alessandro *et al.,* [3] have mentioned that the environmental problem existed when building materials is using of natural materials, consuming high-energy, waste production, and greenhouse gases emission. Fayaz *et al.,* [4] have noted that sand is scarce due to the Indian government imposing harsh restrictions on the sand quarrying at the river which causes construction activities to be affected. The sand quarrying activities at the river is normally produced environmental damage and river erosion [4]. Besides, sand mining activities also created a lot of problems such as riverbeds becoming deeper, riverbanks collapsing, vegetation losses on the riverbank, and, the aquatic life and agriculture sector interrupted [5].

Srividya and Rajkumar [6] have mentioned due to high processing temperatures, the production of cement is responsible for 7% of worldwide CO_2 emissions. Greenhouse gases especially CO_2, Nitrous oxide (N_2O), and Methane (CH_4) is affected by environmental problem and released when manufacturing activities concrete is started [7]. From the study by Jimenez *et al.,* [7] cement contributed a large percentage of 85.6%, and aggregate with leading to 14.3% of CO_2 emissions. They have also separated the aggregate into three categories, recycled coarse aggregate, normal coarse aggregate, and fine aggregate that have been used in concrete manufacturing which contributed to CO_2 emissions of 39%, 42%, and 19%, respectively. The CO_2 emission is reduced when the percentage of recycled coarse aggregate is utilised in the concrete manufacturing process. Mainly, the CO_2 emission from aggregate has occurred from excavation, blasting, and transportation activity which is produced from electricity. CO_2 is functioned to stimulate the early strength of the concrete and the carbonation process in concrete is performed by a reaction between CO_2 and calcium hydroxide to form calcium carbonates. This carbonation process is causing the steel bar in reinforced concrete to become rust.

There is a lot of research to replace or substitute cement or sand or gravel in concrete. Lightweight aggregate which is normally used as waste materials as sand or gravel replacement in concrete, can minimise the self-weight of the structure, reduce the transportation cost and subsequently minimise total construction costs. Lightweight aggregate is classified as low-embodied-carbon composite material which is also categorised as energy efficient and saving [3]. Some of the research using waste materials in CPB is analysed. Thus, many researchers studied on sand replacement, gravel replacement, and cement replacement in CPB as shown in Table 1. Other than cement and sand replacement, the CPB is also made of gravel replacement and added with fibre such as polypropylene, steel, nylon, etc. Normally, the addition of fibre either waste material or new material is not promoted to low carbon material but only focussed on upgrading the concrete strength. Here are some examples of the study on gravel replacement and fibre addition in CPB. Evangelista *et al.,* [8] have studied the production of the CPB by using electric arc furnace aggregate as coarse aggregate replacement and proposed their workflow of the study as shown in Figure 1. They just focussed on two testing, compressive strength test, and water absorption. Additionally, Kumar and Rao [9] reported that glass fibre is added in CPB with 0.1% to 0.4% by cement weight and lastly found 0.2% of glass fibre is the best solution to promote better strength.

Table 1
The previous study of the concrete paving block by sand, gravel, or cement replacement

Author & Year	Waste Material in CPB	Remarks
Sand Replacement		
Jankovic *et al.,* [10]	Crushed brick with 25%, 32.5%, 50%, 60%, 65% and 100% replacement	Testing: Density, weather resistance, compressive strength, tensile strength, flexural strength, abrasion strength, water absorption, freeze/thaw test Shape and dimension: Rectangular shape with the size 100 mm x 200 mm x 60 mm
Ling and Poon [11]	Recycled cathode ray tube (CRT) funnel glass with 50% and 100% replacement.	Testing: Compressive strength, water absorption, drying shrinkage Shape and dimension: No information
Penteado *et al.,* [12]	Porcelain tile, porous tile, and stoneware tile (Brazilian ceramic tile industry) with 5%, 10%, 15%, 20%, 25%, and 30% replacement.	Testing: Compressive strength, flexural strength, water absorption, Shape and dimension: Rectangular shape with the size of 200 mm x 100 mm x 60 mm
Olofinnade *et al.,* [13]	Crushed waste furnace steel slag with 20%, 40%, 60%, 80%, and 100% replacement.	Testing: Water absorption, tensile strength, compressive strength Shape and dimension: H-shaped, cross-section area = 0.032 m^2 and 60 mm of thickness.
Liu *et al.,* [14]	Drinking water treatment sludge with 5%, 10%, 15%, and 20% replacement	Testing: Water absorption, abrasion resistance, sulfate attack, compressive strength, metal leachability. Shape and dimension: Rectangular shape with 115 mm x 115 mm x 50 mm
Al-Kheetan [15]	Pre-treated wheat straw fibres with 5% and 10% replacement	Testing: Compressive strength, tensile strength, water absorption Shape and dimension: No information
Kumar and Vasanthi [16]	Eggshell powder 10%, 20%, 30%, 40% and 50% replacement	Testing: Compressive strength, flexural strength, tensile strength, abrasion resistance, water absorption. Shape and dimension: Square shape with 225 mm x 225 mm x 35 mm.
Da Silva *et al.,* [17]	Recycled tire rubber (crumb rubber) with 10%, 20%, 30%, 40%, and 50% replacement	Testing: Compressive strength, flexural strength, abrasion resistance, impact resistance, water absorption

		Shape and dimension: Tactile square shape with 200 mm x 200 mm x 60 mm
Gravel Replacement		
Indhiradevi *et al.,* [18]	Palm shell with 20%-40% replacement and coconut shell with 20%-40% replacement	Testing: Compressive strength, water absorption Shape and dimension: No information
Sweta *et al.,* [19]	Waste plastic with 2.5%, 5%, and 7.5% replacement	Testing: Compressive strength Shape and dimension: No information
Binu *et al.,* [20]	Recycled hospital plastic waste with 5%, 10%, 15%, and 20% replacement	Testing: Compressive strength Shape and dimension: Rectangular shape with 200 mm x 175 mm x 60 mm.
Cement Replacement		
Atici and Ersoy [21]	Fly ash with 10%-20% replacement and blast-furnace slag with 30%-40% replacement.	Testing: Compressive strength, tensile strength, flexural strength, rebound hardness, abrasion resistance. Shape and dimension: No information
Limbachiya *et al.,* [22]	Ground granulated blast furnace slag (GGBS) with 25%-80% replacement and Silica fume with 3.75%-15% replacement (blend).	Testing: Tensile strength, compressive strength, durability, water absorption, abrasion resistance, freeze/ thaw resistance, skid resistance Shape and dimension: Rectangular shape with 190 mm x 100 mm x 75 mm
Anusha and Dineshkumar [23]	Sugarcane bagasse ash with 5%, 10%, 15%, 20%, 25%, and 30% replacement.	Testing: Compressive strength, tensile strength, flexural, water absorption Shape and dimension: Rectangular shape with 200 mm x 100 mm x 80 mm
Djamaluddin *et al.,* [24]	Processed waste tea ash with 10%, 20%, 30%, 40%, and 60% replacement.	Testing: Compressive strength, flexural strength, water absorption, acid attack resistance Shape and dimension: Rectangular shape with 200 mm x 100 mm x 70 mm

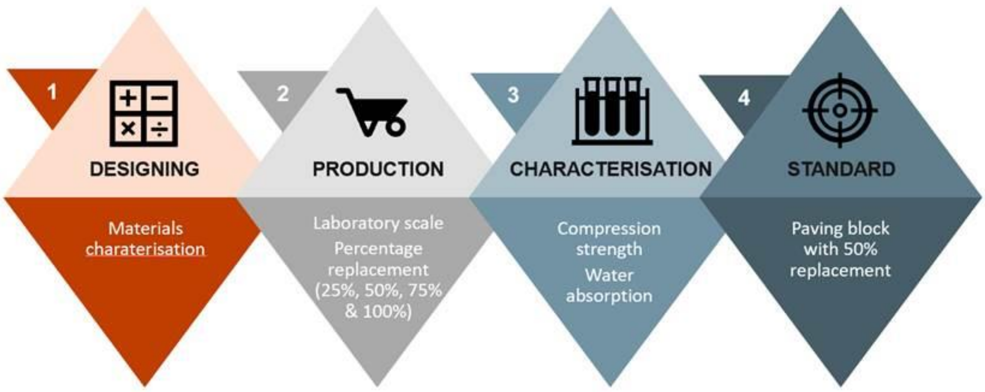


Fig. 1. The workflow of the CPB experimental

From Table 1, there is no information other than the shape of the rectangular and square. This is because the shape is easy to lay in various directions and conditions when compared with other shapes. Besides, no information on the CPB utilised washed or treated bottom ash as sand or gravel, or cement replacement. The majority of the previous study are used waste material in CPB in partial percentage or less than 50% and few of the previous study are replaced waste material in full percentage. This is because the waste materials are classified as high in water absorption compared with the traditional concrete ingredient. Normally, all previous study is tested the compressive strength of the CPB rather than used for heavy-duty or light-duty paving purposes.

Bottom ash (BA) is a by-product of coal-fired electric power plants which physically is a lightweight, granular and porous material with a coarse surface. The bottom side of the furnace or boiler kiln is where BA is collected, and the precipitator process is where another waste product, often known as fly ash, is collected. Figure 2 depicts an adapted version of the BA and fly ash process which was improvised from NETL [25]. The overall proportion of BA waste products is typically higher than that of fly ash, and occasionally the BA is discharged at the closest location for storage or recycling. If the BA is not kept properly, adverse consequences on the environment, including air pollution, water pollution, and groundwater contamination, as well as adverse effects on human health, including an increased risk of cancer and respiratory disorders, will occur. As a result, BA is suggested for the 3R (Reduce, Reuse, and Recycle) process and is used as a structural fill material, a material for making concrete, and a road base. For promoting lightweight concrete, BA with a similar sand particle size is often used to substitute sand in concrete. There is no information available on the prior study on the use of washed or treated BA in CPB. Singh and Siddique [26] reported that the BA with 100% of sand replacement in concrete is suitable for paving and hollow block application due to low workability mixes which clarified not a critical issue.

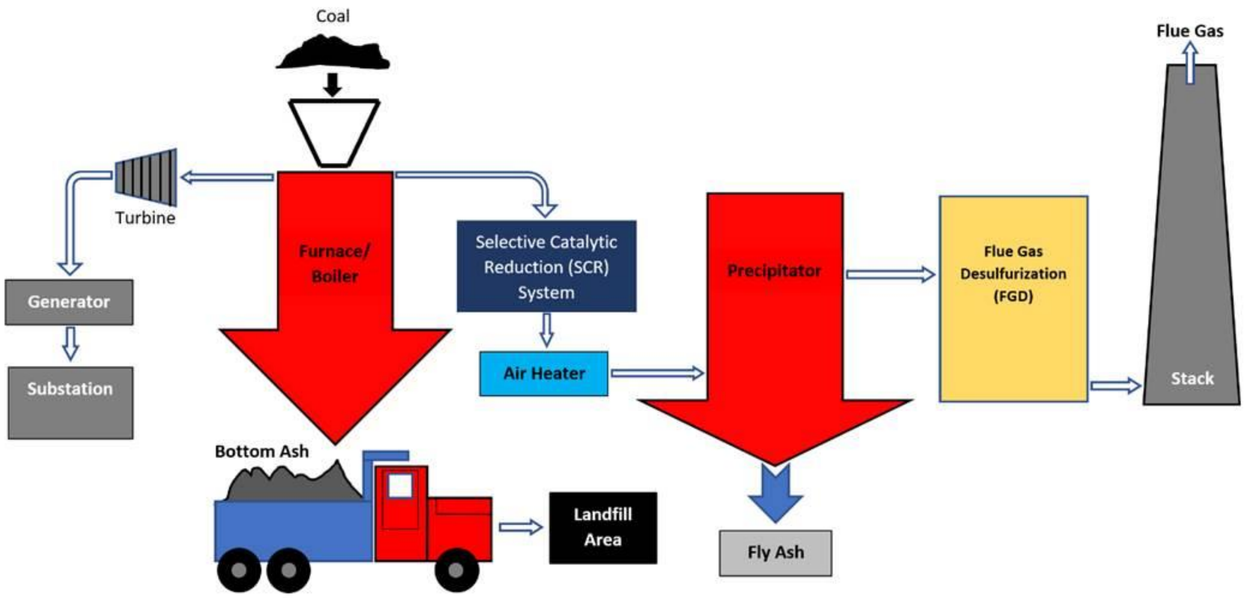


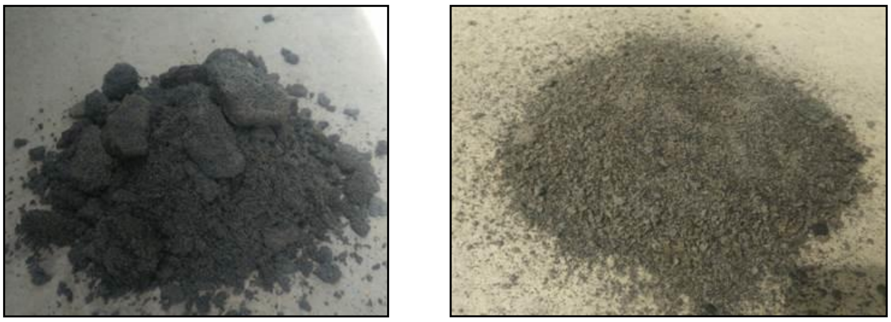
Fig. 2. Illustration of BA and fly ash production from coal-fired electric power plants

Normally, the paving block is tested for its mechanical behaviour (compressive, tensile, and flexural strength), water absorption, and skid resistance. Agyeman *et al*., [27] have mentioned that low water absorption properties and low compressive strength is recommended for non-traffic purposes such as walkways, landscapes, and footpaths. The main objective is to determine the mechanical and physical behaviour of BA after being washed as a sand replacement to form a CPB.

2. Material Preparation and Experimental Activity

The material for concrete paving block (CPB) and experimental activity which split into chemical and physical behaviour is explained broadly and lastly, CPB is tested for mechanical behaviour relationship. The material used in the study for concreting is Portland cement, sand, gravel, tap water, and washed bottom ash (WBA). Sand is replaced in the study by using WBA in partial and full percentages. Gravel with a passing sieve pan of 20 mm and sand with a passing sieve pan of 5 mm are utilised. The superplasticiser is also utilised in the concrete mix for workability and strength purposes.

The bottom ash is collected from the landfill area of coal-fired electric power plants in Malaysia, and the origin of coal is bought from Indonesia. The pH reading of the bottom ash is noted approximately 9.76. The discharging method of bottom ash is detected by circulating water and caused free from chloride and salt. The BA is treated by fully submerging them in a water tank using tap water for 72 hours to reduce the carbon content and is acknowledged as WBA. The comparison between BA and WBA is illustrated in Figure 3 and shows that BA darker colour compared with WBA. This is because the content of carbon is high compared with WBA. The carbon and other impurities which could be affected to the concrete are floating on the water. Then, they are collected and stored in the tank before further application. The WBA is obtained and dried at room temperature for 48 hours. WBA is checked and ensured that free from other waste material, soil, or material deleterious to the concrete mix.



(a) (b)

Fig. 3. The colour of (a) bottom ash and (b) washed bottom ash

The WBA is sieved with a sieve pan size of 5 mm and all WBA with passing 5 mm is collected. The sieve analysis process is carried out to determine the suitability of WBA to replace sand. Next, WBA is taken in a small amount for checking their chemical composition by using Inductively Coupled Plasma spectrometry. The design mix of the CPB is prepared and reported to have a density of cement, 410 kg/m^3; gravel, 1120 kg/m^3; sand, 690 kg/m^3 and water, 222 kg/m^3. Water-cement ratio of the design mix is 0.54. The drum mixer is used for the mixing process of the concrete. WBA is replaced by the weight of the sand with 50% and 100% for determining the strength behaviour of the CPB.

The concrete ingredient and WBA are mixed and then, placed into CPB mould. The CPB mould is selected and bought from the hardware supplier. The size and shape of the CPB are shown in Figure 4. The thickness of CPB is 50 mm and the cross-section area of CPB is 0.039 m^2. The shape of the CPB is known as hexagonal and mimics the maple leaf shape. The shape selection is suitable for contacting CPB each other and is easy to interlock them together strongly. The WBA CPB is allowed and let dry at room temperature for 24 hours and then, placed in a water curing tank for 28 days.

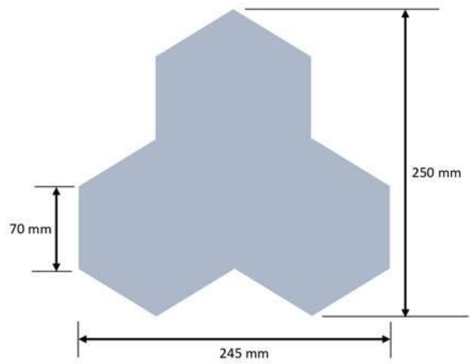


Fig. 4. The shape and dimension of the concrete paving block

The experimental activity of the CPB in the study is focused on strength behaviour, water absorption, water suction, and skid resistance. There are three specimens of CPB; WBA with 50% of sand replacement (WBA50CPB), WBA with 100% of sand replacement (WBA100CPB), and normal CPB without sand replacement (NCPB). The total specimens of CPB are nine units; three units of NCPB, three units of WBA50CPB, and three units of WBA100CPB. The average result of the strength behaviour is recorded and analysed.

The skid resistance test is important to be carried out to determine the condition of the concrete surface when the force of the tyre or shoe is applied. The specimens of the CPB are tested for skid resistance after curing for 28 days and only focussed on WBA50CPB and WBA100CPB specimens. The road accident or road slipperiness is happened due to a lack of road friction when the skid resistance condition is classified as low. Then, the water absorption test is conducted after the specimen is submerged in tap water for 28 days. Al-Kheetan [15] conducted the water absorption test being cured in the water for 7 and 28 days. The water absorption and suction test are to check the rate of absorption of water by using the mass and time of the CPB when contacted with water. Rathee and Singh [28] reported that the water absorption test is important to determine the direct durability property of concrete for long-term behaviour. Lastly, the strength behaviour of the CPB is tested for its compression behaviour after 28 days of curing. The strength of the CPB is important to determine the capability of concrete to sustain the heavy load from the vehicle or only used for low load.

3. Result and Discussion

3.1 Sieve Analysis of WBA

The result of the sieve analysis test for WBA is shown in Figure 5 with passing lower and upper zone which is suitable for replacing the sand. The highest and lowest percentage of the WBA retained in the sieve pan is 150 µm and < 36 µm, respectively. Singh and Siddique [29] reported that the bottom ash contained 17.19% when passing through a sieve pan 150 µm and was categorised as lighter and brittle material when compared with sand.

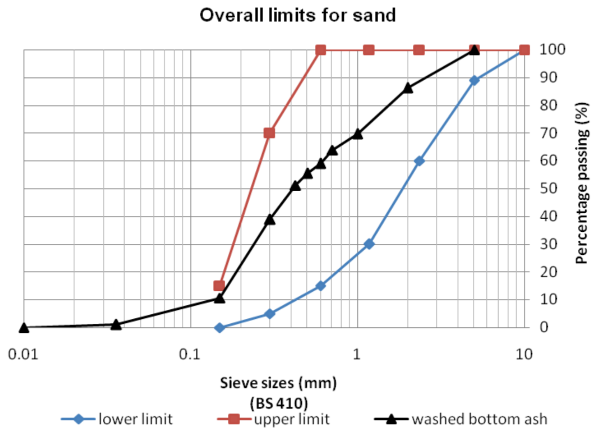


Fig. 5. The result of the sieve analysis test of WBA

3.2 Chemical Composition of WBA

The chemical composition of the WBA is tabulated in Table 2 and compared with the previous study. The highest chemical composition between WBA and BA are Silicon Dioxide, Aluminum Oxide, and Iron Oxide. The percentage difference in Silicon Dioxide between WBA with BA from the study of Singh and Siddique [29], Aggarwal and Siddique [30], and Caprai *et al.,* [31] is 13.27%, 5.12%, and 30.29%, respectively. The percentage difference of Aluminum Oxide of 27.40% and 24.28% are reported when comparing WBA with BA from the previous study by Singh and Siddique [29] and Aggarwal and Siddique [30], respectively. Lastly, the percentage difference between Iron Oxide of WBA and BA of Singh and Siddique [29] is 29.45%, the WBA and BA of Aggarwal and Siddique [30] are 0.82% and the WBA and BA of Caprai *et al.,* [31] is 16.85%. Normally, the most important chemical composition or major composition in concrete is Silicon Dioxide, Aluminum Oxide, and Iron Oxide, and the total of them is 91.8%. The total of Silicon Dioxide, Aluminum Oxide, and Iron Oxide of BA of Singh and Siddique [29] is 74.21% and the BA of Aggarwal and Siddique [30] is 87.90%. The process of washing BA before the mixing process is successful because the total major chemical composition is more than 80%. The total of Silicon Dioxide, Aluminum Oxide, and Iron Oxide of coal bottom ash is 92.42% from the previous study by Nathe and Patil [32], and the percentage difference between WBA is 0.67%.

Table 2
The chemical composition of washed bottom ash and bottom ash from the previous study

Chemical Composition	Washed Bottom Ash Weight (%)	Bottom Ash [29]	Bottom Ash [30]	Bottom Ash [31]
Silicon Dioxide, SiO_2	54.80	47.53	57.76	38.20
Aluminum Oxide, Al_2O_3	28.50	20.69	21.58	7.32
Iron Oxide, Fe_2O_3	8.49	5.99	8.56	10.21
Titanium Dioxide, TiO_2	2.71	-	-	1.25
Magnesium Oxide, MgO	0.35	0.82	1.19	2.22
Calcium Oxide, CaO	4.20	4.17	1.58	19.47
Sodium Oxide, Na_2O	0.08	0.33	0.14	3.35
Potassium Oxide, K_2O	0.45	0.76	1.08	1.24
Phosphorus Pentoxide, P_2O_5	0.28	-	-	1.37
Sulfur Trioxide, SO_3	-	1.00	0.02	2.25
Chlorine, Cl	-	-	0.01	0.98
Loss of Ignition (LOI) at 1000^0C	2.46	0.89	5.80	9.70

3.3 Skid Resistance of CPB

The skid resistance test in the study is split into 2 categories for the wet and dry conditions with the assumption of the length of the surface of tyre contact to the concrete surface is 150 mm. Every category is obtained from three locations and reported in the average result. The result of the skid resistance is tabulated in Table 3. From the result, the CPB has a potential for slipping which is categorised as a low condition and classified to have an outstanding skid resistance surface. The skid resistance is decreased when the percentage of WBA increased. The percentage difference between the WBA50CPB and WBA100CPB for the dry condition is 3.33% and for the wet condition is 2.70%. Fwa [33] stated that the wet condition of pavement has much less skid resistance than dry condition pavement and normally, the standard skid resistance tests should be conducted on the wet condition of the pavement. Furthermore, the percentage difference between these two conditions of WBA50CPB is 17.78% and WBA100CPB is 17.24%. Sadek *et al.,* [34] have mentioned that the skid resistance value slightly decreased with an increasing percentage of cement replacement with waste material. The presence of the waste material affected the water absorption and also influenced the skid resistance value. From the code of practice of BS EN1338:2003, the requirement for a skid resistance value is more than 45. The result of the skid resistance value of the CPB with full sand replacement by using 6 mm recycled clay bricks is 98 and by using 6 mm recycled concrete aggregate taken from the demolished concrete slab is 98 [35]. The percentage difference in the skid resistance value between the WBA100CPB specimen and recycled clay bricks and recycled concrete aggregate is 11.22%.

Table 3
The result of the skid resistance of the CPB for wet and dry conditions

Specimens	Dry Condition	Web Condition
WBA50CPB	90	74
WBA100CPB	87	72

3.4 Water Absorption of CPB

Water absorption of WBA CPB by mass and time is analysed and discussed. The water absorption of the WBA100CPB specimen under mass is 10.46% and under time is 42.43 minutes. The water absorption value is increased with increasing the amount of WBA as sand replacement. Factors that affect the water absorption in the concrete such as size and shape of the aggregate, the porosity of the aggregate, admixtures, temperature surrounding, and mixing time. WBA which is classified porous surface tends to absorb water in a high percentage and affected the water absorption value. Muthusamy *et al.*, [36] reported that the proportion of water absorbed by the concrete steadily increases when more bottom ash is added to the mix since more empty pores are available and more quickly absorb water. Shah *et al.*, [37] reported that the increment of the air void could affect the workability and water absorption capacity of the concrete. Gencel *et al.*, [38] mentioned about water absorption is not a common metric for assessing concrete quality but high-quality concrete has water absorption of less than 10%. Djamaluddin *et al.*, [24] reported that the maximum value of water absorption is 8% for pedestrian CPB application and 10% for CPB garden application accordingly to the code of practice of SNI 03-0691. Thus, the value of water absorption of CPB made by WBA is classified as acceptable for both applications.

3.5 Compressive Strength of CPB

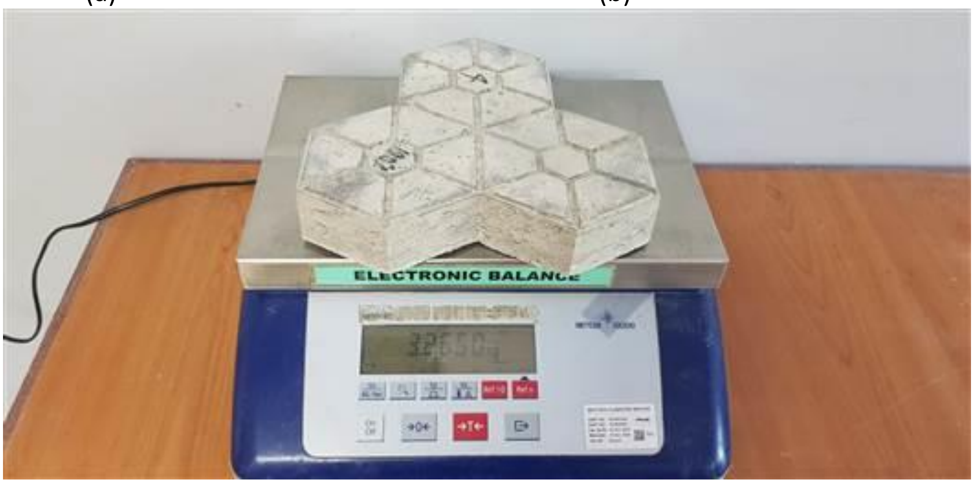
The maximum load and compressive strength value of the CPB either made by normal or WBA which replaced the sand in concrete is tabulated in Table 4. The mass of the NCPB is 4.35 kg, WBA50CPB is 3.85 kg and WBA100CPB is 3.27 kg as shown in Figure 6. The percentage difference of the mass between NCPB with WBA50CPB and WBA100CPB is 11.49% and 24.83%, respectively. Whilst as the percentage difference in the mass of the specimen of WBA50CPB and WBA100CPB is 15.06% and the relationship between the mass of CPB is illustrated in Figure 7. The mass of CPB is decreased with increasing the amount of WBA which is classified in a linear relationship. The equation shows the relationship between the mass of the CPB and the amount of WBA in concrete with the coefficients of calculation R^2 derived from the result.

Table 4
The result of the compressive strength of CPB specimens

Specimen	Maximum Load (kN)	Compressive Strength (MPa)
NCPB	2322.67	59.56
WBA50CPB	1978.22	50.72
WBA100CPB	1198.35	30.73

(a)

(b)



(c)

Fig. 6. The mass of (a) NCPB, (b) WBA50CPB, and (c) WBA100CPB specimen

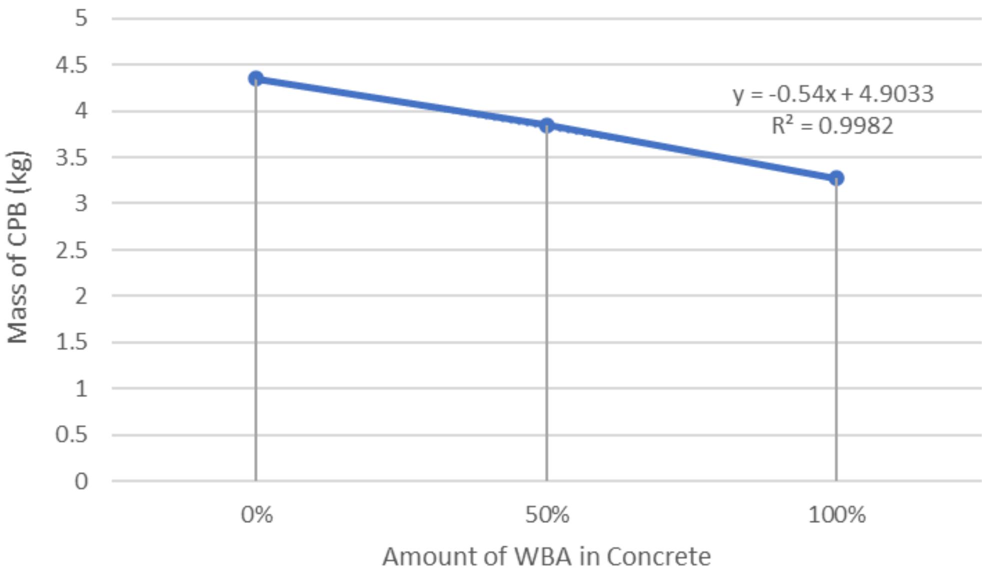


Fig. 7. The relationship of the mass of CPB with all types of specimens with a difference in WBA amount.

The percentage difference of the maximum load and compressive strength between NCPB and WBA50CPB is 14.84% and NCPB and WBA100CPB is 48.40%. 39.41% are reported when the WBA50CPB is distinguished from WBA100CPB. The maximum load and compressive strength of CPB are reduced with increasing WBA amount in CPB. Besides, according to a study by Gencel *et al.*, [38], compressive strength rises as CPB density rises. This is because the WBA in high water absorption influenced the compressive strength of CPB to reduce. Olofinnade *et al.*, [13] stated that the minimum compressive strength of CPB is 30 MPa recommended by a code of practice of BS 6717, ESS 4382, and IS 15658 and 40-55 MPa from a code of practice of ASTM C936. The result of the compressive strength for all specimens obtained is acceptable by referring to BS 6717, ESS 4382, and IS 15658, and only two specimens; NCPB and WBA50CPB are acceptable for ASTM C936. Djamaluddin *et al.*, [24] have mentioned the code of practice of SNI 03-069 which explained the minimum compressive strength of CPB with 12.5 MPa for pedestrian application and 8.5 MPa for garden application. From the result, the value of compressive strength of CPB made by WBA met the SNI 03-069 requirements either for pedestrian or garden applications. Additionally, Isa *et al.*, [39] stated that the compressive strength of concrete will be impacted by a lack of water during the curing process. The relationship between the maximum load of CPB with the amount of WBA is shown in Figure 8. When the concrete is made with the WBA in full sand replacement, the CPB is becoming more brittle when compared with NCPB. Furthermore, the lack of bonding between WBA with other concrete ingredients is clearly observed from the failure mode of WBA100CPB. Euniza *et al.*, [40] reported that the absence of adequate bonding between the waste material particle and the cement paste is what causes the drop in compressive strength. The failure mode of the CPB is illustrated in Figure 9. All specimens are noted to have a failure on the corner of the CPB and along the side surface of the CPB which fallout from the original surface. The failure of the side surface of WBA100CPB is higher when compared with NCPB and WBA50CPB. The middle surface of the CPB for all specimens is reported as not having any serious failure and no change in shape condition.

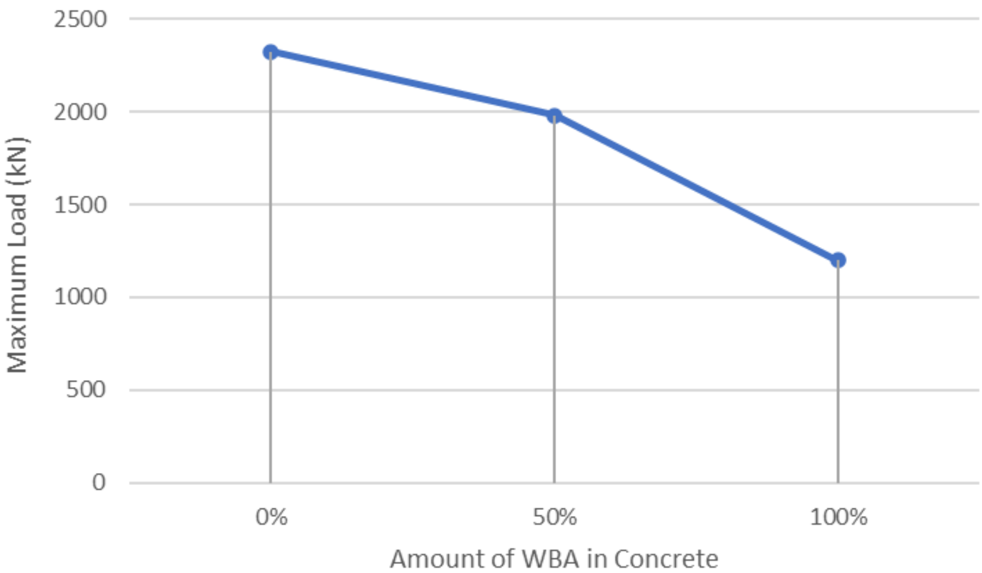


Fig. 8. The relationship of the maximum load with a difference in WBA amount

(a)

(b)

(c)

Fig. 9. The failure mode of the (a) NCPB, (b) WBA50CPB, and (c) WBA100CPB specimen

4. Conclusions

The washed bottom ash (WBA) concrete paving block (CPB) specimen is carried out in an experiment to determine the mechanical behaviour, especially maximum load and compressive strength. Additionally, CPB also conducted the test of skid resistance and water absorption. Although, the WBA that is used as sand replacement in concrete is tested for its chemical and physical behaviour. From all results and observations of WBA and CPB, a few conclusions can be drawn:

i. The physical behaviour of the WBA by using the sieve analysis test is shown appropriately for partial and full replacement of sand in CPB.
ii. The bottom ash with the washed process can reduce the carbon content for producing the WBA that is used in concrete, especially CPB. The total percentage of the chemical composition of Silicon Dioxide, Aluminium Oxide, and Iron Oxide is 91.8% which is classified as important in concrete.
iii. As the amount of WBA increases, the skid resistance decreases. For dry conditions, the difference between the WBA50CPB and WBA100CPB is 3.33%, while for wet conditions, it is 2.70%.
iv. The compressive strength and water absorption of WBA100CPB are illustrated as suitable for use as CPB. The percentage difference between the maximum load and compressive strength of NCPB with WBA100CPB is 48.40% and the values are reduced when the amount of WBA is increased.

From the observation and experimental activity, the CPB is recommended to produce with a variety of thicknesses and shapes. Finally, further strength behaviour testing should be done such as flexural strength and tensile strength to determine the relationship with the value of compressive strength.

Acknowledgement
The authors gratefully acknowledge the financial support from Universiti Teknologi MARA (UiTM) Cawangan Pahang. Thanks also extend to the School of Civil Engineering of UiTM Cawangan Pahang for providing laboratory equipment. Special thanks are extended to the lecturer and technician of UiTM Cawangan Pahang for their assistance and support during the experimental program.

References

[1] Patel, Vikas Kumar, and V. V. Singh. "A Review on Precast Cement Concrete Paver Blocks Using Fly Ash." *International Journal of Advance Research, Ideas and Innovations in Technology* 3, no. 6 (2017): 961-965.
[2] Venkatarama Reddy, B. V. "Sustainable materials for low carbon buildings." *International Journal of Low-Carbon Technologies* 4, no. 3 (2009): 175-181. https://doi.org/10.1093/ijlct/ctp025
[3] D'Alessandro, Antonella, Claudia Fabiani, Anna Laura Pisello, Filippo Ubertini, A. Luigi Materazzi, and Franco Cotana. "Innovative concretes for low-carbon constructions: A review." *International Journal of Low-Carbon Technologies* 12, no. 3 (2017): 289-309. https://doi.org/10.1093/ijlct/ctw013
[4] Fayaz, D., Malik, A., Zakir, M. and Malik, T.A. “Effects on the properties of concrete by replacement of cement with carbon black and natural fine aggregate with robo sand.” *International Journal of Technical Innovation in Modern Engineering and Science* 4, no. 6 (2018): 1-8.
[5] Sankh, Akshay C., Praveen M. Biradar, S. J. Naghathan, and Manjunath B. Ishwargol. "Recent trends in replacement of natural sand with different alternatives." In *Proceedings of the International Conference on Advances in Engineering and Technology*, pp. 59-66. 2014.
[6] Srividya, T., and PR Kannan Rajkumar. "Mechanical and durability properties of alkali-activated binders-based paver blocks derived from secondary sources." *Case Studies in Construction Materials* 17 (2022): e01561. https://doi.org/10.1016/j.cscm.2022.e01561
[7] Jiménez, Luis F., Jose A. Dominguez, and Ricardo Enrique Vega-Azamar. "Carbon footprint of recycled aggregate concrete." *Advances in civil engineering* 2018 (2018). https://doi.org/10.1155/2018/7949741

[8] Evangelista, Beatriz Leão, Laís Peixoto Rosado, and Carmenlucia Santos Giordano Penteado. "Life cycle assessment of concrete paving blocks using electric arc furnace slag as natural coarse aggregate substitute." *Journal of Cleaner Production* 178 (2018): 176-185. https://doi.org/10.1016/j.jclepro.2018.01.007

[9] Kumar, BAV Ram, and J. Venkateswara Rao. "Effect of Inclusion of Glass Fibers and GGBS in Concrete Paver Blocks."

[10] Jankovic, Ksenija, Dragan Nikolic, and Dragan Bojovic. "Concrete paving blocks and flags made with crushed brick as aggregate." *Construction and Building Materials* 28, no. 1 (2012): 659-663. https://doi.org/10.1016/j.conbuildmat.2011.10.036

[11] Ling, Tung-Chai, and Chi-Sun Poon. "Use of recycled CRT funnel glass as fine aggregate in dry-mixed concrete paving blocks." *Journal of cleaner production* 68 (2014): 209-215. https://doi.org/10.1016/j.jclepro.2013.12.084

[12] Penteado, Carmenlucia Santos Giordano, Eduardo Viviani de Carvalho, and Rosa Cristina Cecche Lintz. "Reusing ceramic tile polishing waste in paving block manufacturing." *Journal of Cleaner Production* 112 (2016): 514-520. https://doi.org/10.1016/j.jclepro.2015.06.142

[13] Olofinnade, Oluwarotimi, Ayoyinka Morawo, Oluwatomisin Okedairo, and Boksun Kim. "Solid waste management in developing countries: Reusing of steel slag aggregate in eco-friendly interlocking concrete paving blocks production." *Case Studies in Construction Materials* 14 (2021): e00532. https://doi.org/10.1016/j.cscm.2021.e00532

[14] Liu, Yue, Yan Zhuge, Christopher WK Chow, Alexandra Keegan, Danda Li, Phuong Ngoc Pham, Jianyin Huang, and Rafat Siddique. "Utilization of drinking water treatment sludge in concrete paving blocks: Microstructural analysis, durability and leaching properties." *Journal of environmental management* 262 (2020): 110352. https://doi.org/10.1016/j.jenvman.2020.110352

[15] Al-Kheetan, Mazen J. "Properties of lightweight pedestrian paving blocks incorporating wheat straw: Micro-to macro-scale investigation." *Results in Engineering* 16 (2022): 100758. https://doi.org/10.1016/j.rineng.2022.100758

[16] Kumar, D. Chandan, and P. Vasanthi. "Characterization of paver blocks using Eggshell powder." *Materials Today: Proceedings* 68 (2022): 1658-1662. https://doi.org/10.1016/j.matpr.2022.08.120

[17] da Silva, Fabiana Maria, Luisa Andréia Gachet Barbosa, Rosa Cristina Cecche Lintz, and Ana Elisabete PGA Jacintho. "Investigation on the properties of concrete tactile paving blocks made with recycled tire rubber." *Construction and Building Materials* 91 (2015): 71-79. https://doi.org/10.1016/j.conbuildmat.2015.05.027

[18] Indhiradevi, P., A. K. Selvamuhil, V. Vengainayaki, and G. Gokul. "Experimental study of paver blocks using palm shell and coconut shell." *Materials Today: Proceedings* 68 (2022): 2581-2585. https://doi.org/10.1016/j.matpr.2022.09.420

[19] Sweta, A.C., Malagi, V., Prashant, K. and Satish, G. “Utilisation of waste plastic in concrete paver block as a partial replacement of coarse aggregate.” *International Research Journal of Engineering and Technology* 7, no. 3 (2020): 567-569.

[20] Binu, Athira M., Amrutha S. Vinod, P. Sethuraj, and S. Akil. "Experimental study on the replacement of coarse aggregates with recycled hospital plastic waste in paver blocks." *International Journal for Advance Research and Development* 4, no. 6 (2019): 1-3.

[21] Atici, U., and A. Ersoy. "Evaluation of destruction specific energy of fly ash and slag admixed concrete interlocking paving blocks (CIPB)." *Construction and Building Materials* 22, no. 7 (2008): 1507-1514. https://doi.org/10.1016/j.conbuildmat.2007.03.028

[22] Limbachiya, Vireen, Eshmaiel Ganjian, and Peter Claisse. "Strength, durability and leaching properties of concrete paving blocks incorporating GGBS and SF." *Construction and Building Materials* 113 (2016): 273-279. https://doi.org/10.1016/j.conbuildmat.2016.02.152

[23] Anusha, G., and R. Dineshkumar. "Study on paver blocks using waste plastics and sugarcane bagasse ash." *Materials Today: Proceedings* 68 (2022): 2088-2092. https://doi.org/10.1016/j.matpr.2022.08.367

[24] Djamaluddin, Abdul Rachman, Muhammad Akbar Caronge, M. W. Tjaronge, Asiyanthi T. Lando, and Rita Irmawaty. "Evaluation of sustainable concrete paving blocks incorporating processed waste tea ash." *Case Studies in Construction Materials* 12 (2020): e00325. https://doi.org/10.1016/j.cscm.2019.e00325

[25] National Energy Technology Laboratory (NETL) “Clean coal technology: coal utilization by-products.” *Topical Report* 24, (2006). Department of Energy Office of Fossil Energy. Washington D.C., United State of America.

[26] Singh, Malkit, and Rafat Siddique. "Effect of coal bottom ash as partial replacement of sand on properties of concrete." *Resources, conservation and recycling* 72 (2013): 20-32. https://doi.org/10.1016/j.resconrec.2012.12.006

[27] Agyeman, Stephen, N. K. Obeng-Ahenkora, S. Assiamah, and G. Twumasi. "Exploiting recycled plastic waste as an alternative binder for paving blocks production." *Case Studies in Construction Materials* 11 (2019): e00246. https://doi.org/10.1016/j.cscm.2019.e00246

[28] Rathee, Manali, and Navdeep Singh. "Durability properties of copper slag and coal bottom ash based I-shaped geopolymer paver blocks." *Construction and Building Materials* 347 (2022): 128461. https://doi.org/10.1016/j.conbuildmat.2022.128461

[29] Singh, Malkit, and Rafat Siddique. "Strength properties and micro-structural properties of concrete containing coal bottom ash as partial replacement of fine aggregate." *Construction and Building Materials* 50 (2014): 246-256. https://doi.org/10.1016/j.conbuildmat.2013.09.026

[30] Aggarwal, Yogesh, and Rafat Siddique. "Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates." *Construction and Building Materials* 54 (2014): 210-223. https://doi.org/10.1016/j.conbuildmat.2013.12.051

[31] Caprai, V., A. Lazaro, and H. J. H. Brouwers. "Waterglass impregnation of municipal solid waste incineration bottom ash applied as sand replacement in mortars." *Waste Management* 86 (2019): 87-96. https://doi.org/10.1016/j.wasman.2019.01.025

[32] Nathe, Deepak N., and Yogesh D. Patil. "Performance of coal bottom ash concrete at elevated temperatures." *Materials Today: Proceedings* (2022). https://doi.org/10.1016/j.matpr.2022.03.519

[33] Fwa, T. F. "Determination and prediction of pavement skid resistance–connecting research and practice." *Journal of Road Engineering* 1 (2021): 43-62. https://doi.org/10.1016/j.jreng.2021.12.001

[34] Sadek, Dina M., Mohamed M. El-Attar, and Ahmed M. Ali. "Physico-mechanical and durability characteristics of concrete paving blocks incorporating cement kiln dust." *Construction and Building Materials* 157 (2017): 300-312. https://doi.org/10.1016/j.conbuildmat.2017.09.107

[35] Ganjian, Eshmaiel, Ghassan Jalull, and Homayoon Sadeghi-Pouya. "Using waste materials and by-products to produce concrete paving blocks." *Construction and Building Materials* 77 (2015): 270-275. https://doi.org/10.1016/j.conbuildmat.2014.12.048

[36] Muthusamy, Khairunisa, Nur Farah Aziera Jamaludin, Mohamad Nurfahmi Kamaruzzaman, Muhammad Zulhusni Ahmad, Nur Azzimah Zamri, and Ahmed Mokhtar Albshir Budiea. "Compressive strength of palm oil clinker lightweight aggregate concrete containing coal bottom ash as sand replacement." *Materials Today: Proceedings* 46 (2021): 1724-1728. https://doi.org/10.1016/j.matpr.2020.07.527

[37] Shah, Syed Haroon Ali, Babar Ali, Ghafur H. Ahmed, Syed Muhammad Talal Tirmazi, Mohamed Hechmi El Ouni, and Iqrar Hussain. "Effect of recycled steel fibers on the mechanical strength and impact toughness of precast paving blocks." *Case Studies in Construction Materials* 16 (2022): e01025. https://doi.org/10.1016/j.cscm.2022.e01025

[38] Gencel, Osman, Cengiz Ozel, Fuat Koksal, Ertugrul Erdogmus, Gonzalo Martínez-Barrera, and Witold Brostow. "Properties of concrete paving blocks made with waste marble." *Journal of cleaner production* 21, no. 1 (2012): 62-70. https://doi.org/10.1016/j.jclepro.2011.08.023

[39] Isa, N. F., M. F. Mohammad Zaki, L. Ahmad Sofri, M. Abdul Rahim, Z. Md Ghazaly, and N. Bidin. "The use of rubber manufacturing waste as concrete additive." *Advanced Research in Applied Mechanics* 4, no. 1 (2014): 12-18.

[40] Euniza, Jusli, Md Nor Hasanan, Putra Jaya Ramadhansyah, and Haron Zaiton. "Use of waste tyre rubber as aggregate in double layer concrete paving blocks." *Journal of Advanced Research in Applied Mechanics* 1: 25-30.