DOI: 10.5604/01.3001.0015.7042
Volume 110 • Issue 2 • February 2022
Journal of Achievements in Materials and Manufacturing Engineering
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Plastic waste reinforced with inorganic pigment from red stone in manufacturing paving block for pedestrian application

D.K. Sastrawidana [a],*, I.N. Sukarta [a], L.P.A. Saraswati [a], S. Maryam [a], G.A. Putra [b]
[a] Department of Chemistry, Mathemathic and Natural Sciences Faculty, Universitas Pendidikan Ganesha, Singaraja 81116 Bali, Indonesia
[b] Student of Department of Chemistry, Mathemathic and Natural Sciences Faculty, Universitas Pendidikan Ganesha, Singaraja 81116 Bali, Indonesia
* Corresponding e-mail address: ketut.sastrawidana@undiksha.ac.id
ORCID identifier: https://orcid.org/0000-0002-4639-7002 (D.K.S)

ABSTRACT

Purpose: This study was aimed to investigate the effectiveness of plastic waste as fine aggregates to partial replacement of sand reinforced with inorganic pigment from red stone to manufacture paving block for pedestrian application. This is an effort not only to reduce plastic waste in the environment but also as an innovative way to find out an alternative eco-friendly paving block material for public walkways with an attractive appearance while ensuring pedestrian comfort.

Design/methodology/approach: Approaches were converted the plastic waste to plastic powder which is then used as fine particles to sand partial replacement. The red stone powder is used to give red color to the paving block surface. The paving block materials were completely mixed in a pan mixer and added water as much as 12% of the total mass of the materials used. The paving block was cast in a mold dimension size of 20 cm × 10 cm × 6 cm and pressed with a load of 6 tons using a pressing machine. The effect of natural river sand to plastic powder ratio and curing time on the compressive strength and water absorption were investigated.

Findings: The study results confirmed that the replacement of sand with plastic powder decreased the compressive strength of paving block. By partial replacement of sand with plastic powder in the range of 10% to 50% by weight, the compressive strength and water absorption value of pavement after 30 days agitation were at range of 18.06-12.78 MPa and 4.28-3.25%, respectively. This value was still met the minimum requirement for pedestrian applications according to Indonesian National Standard.

Research limitations/implications: Replacing sand up to 50% by weight with plastic waste produces paving blocks with compressive strength and water absorption suitable for sidewalks and pedestrians. It is needed to continue research in terms of durability tests in order to be comfortable with the practical use of the material.

Practical implications: The use of plastic waste reinforced with red stone powder as fine aggregate makes it one of the alternative ways to reduce plastic waste in the environment and obtain eco-friendly paving blocks with an attractive appearance.

Originality/value: It has been experimentally proven that replacing sand up to 50% by weight with plastic powder produces paving blocks that are suitable for pedestrians application. The addition of red stone powder pigment makes the color of paving block surface become more attractive appearance.

Keywords: Crushed stone, Paving blocks, Pedestrian, Plastic waste, Red stone powder, River sand

Reference to this paper should be given in the following way:

D.K. Sastrawidana, I.N. Sukarta, L.P.A. Saraswati, S. Maryam, G.A. Putra, Plastic waste reinforced with inorganic pigment from red stone in manufacturing paving block for pedestrian application, Journal of Achievements in Materials and Manufacturing Engineering 110/2 (2022) 49-58. DOI: https://doi.org/10.5604/01.3001.0015.7042

PROPERTIES

1. Introduction

Plastic are made of synthetic organic polymers which widely used in different application such as for product storage and packaging. According to Organization for Economic Co-operation and Development 2018, it was reported that the global plastics production were reached 407 million tons per year in 2015 and annual plastic production was estimated up to 1600 million in year 2050 [1]. An estimated about 50% of plastic is used for single use application and immediately discharge into the environment as a waste. There are several toxic chemicals within plastic such as bisphenol and phthalates which harmful for human and animals. Disposal of plastic waste into the environment has caused the various problems. In soil, plastic waste has a toxic effect on soil microorganisms thereby reducing its diversity which results in disruption of the soil material cycle. Approximately 8 million tons of plastic waste was discharge into the ocean, causing to mortification of marine habitat [2]. Therefore, it is necessary immediately to find alternative ways to solve the problem of plastic waste.

Most plastic waste handling was carried out by conventional methods such as landfilling, recycling, and incineration. However, all of these techniques have a great potential to release polycyclic aromatic hydrocarbon (PAH) gases such as dioxin, furan and other derivatives into the atmosphere [3]. Li et al. [4] reported that emission factor of PAHs from incineration of polyvinyl chloride (PVC) and high-density polyethylene (HDPE) plastic wastes were found 195.4 and 462.3 mg/kg waste, respectively. For this reason, the plastic waste conversion into economic value materials is one of the important and innovative ways to protect the environment from plastic wastes. Numerous studies have been conducted to utilize plastic waste in various beneficial processes such as liquid fuels [5-9], hydrogen gas production, carbon nanotubes [10], and as a binder on paving blocks production [11].

According to Indonesian National Standard (SNI) 03-0691-1996 [12], The paving block is a composite building material that comprises a mixture of portland cement or other adhesives, water, and aggregates with or without other additives that do not significantly reduce the quality of the paving blocks. Nowadays, paving block has been widely used to enhance the park esthetic and residential areas due to its inexpensive price, weather resistant, and ability to reassemble easily. Paving block quality was affected significantly by the material types and compositions which are used as aggregates and binder. Basically, the mixture of paving blocks materials consists of fine aggregate (sand), coarse aggregate (crushed stone), binder (cement), water, and chemical pigment. Based on the Indonesian National Standard for paving block, the maximum average of water absorption and minimum of compressive strength allowed for pedestrians was 8% and 12.5 MPa. Additionally, paving block with high water absorption is slippery, thus high risk for pedestrians and others users while compressive strength is important factor related to durability of paving block.

Sand is a main material which used as fine aggregate for paving blocks production. It is give significant affect to paving block properties including compressive strength and water absorption. The increasing demand for sand due to global growth in manufacturing has led to depletion sources of sand for paving block. Thus, it is important to conduct intensively research to develop the alternative materials which used to replace sand while reducing the cost of paving blocks manufacture. Several recycled materials such as crushed glass, crumb rubber, and ground granulated blast furnace [13-15] have a great potential effective used to partial substitution of sand in paving blocks production. Meanwhile, calcium carbide residue, fly ash [16], quarry dust [17], mussel shell ash [18], and plastic waste [19,20] were used as binders for partial replacement of cement.

In general, the use of plastic waste in the paving blocks preparation was started by the conversion of plastic into plastic slurry through heating it in a drum containing a little oil. The hot plastic slurry and other materials were mixed in paving blocks mold and then pressed using mechanical pressing machine. Nevertheless, the weakness of plastic waste as a binder can cause the paving block surface less compact and less attractive due to the fact that the hot plastic slurry immediately solid when mixed with other aggregates. The present study was conducted to assess the potential of plastic from drinking water bottles waste reinforced with red stone powder as fine aggregates to partial replacement of sand as well as used as natural inorganic pigment in paving blocks production for pedestrian application. The presence of plastic within paving blocks was not only to reduce the sand usage but also combined with red stone powder will significantly contribute in the coloring of the paving blocks so make it seem more attractive. Several parameters tested include compressive strength, water absorption, and micostructure through SEM observations. The compressive strength and water absorption value of pavement blocks were compared to the control and Indonesian National Standard for paving block to assess their application.

2. Materials and methods

2.1. Materials

In this study, materials used for the manufacture of paving block are consist of crushed stone (filtered using a sieve with 10 mm, followed by 6 mm holes), plastic waste powder, red stone powder (filtered using a sieve with 1 mm holes), river sand (filtered using a sieve with 5 mm holes), and Portland cement name as Tiga Roda. Plastic waste utilized is a drinking water bottles which can be grouped as polyethylene terephthalate (PET) plastic. Materials used for paving blocks preparation are presented in Figure 1.

Paving block materials was characterized the specific gravity, water absorption and metal oxides content. The specific gravity was measured by pycnometer method whereas the water absorption capacity was determined by recommended method in SNI 03-0691-1996.

The metal oxides content was analyzed using X-Ray Fluorescence. The physical properties of paving block materials are shown in Table 1, while the metal oxides content presented in Table 2.

Fig. 1. Materials for paving blocks preparation

Table 1.
Physical properties of aggregates

Properties	Fine Aggregate		Coarse aggregate	Pigment
	River sand	Plastic powder	Crushed stone	Red stone
Specific gravity, kg/m^3	2.56	1.02	2.34	2.45
Water absorption, wt. %	1.26	0.18	1.08	1.29

Table 2.
Metal oxides content of aggregates (weight %)

Materials	Al_2O_3	Fe_2O_3	SiO_2	CaO	TiO_2	MnO	K_2O
River Sand	13	24.8	41.1	15.4	1.92	0.41	1.58
Crushed stone	15	19.8	44.7	15.9	1.65	0.36	1.92
Red stone	12	29.8	40.4	9.35	2.74	0.52	3.4
Portland cement	2.1	5.07	10.2	76.01	0.39	0.05	0.27

Table 3.
Mixture mass proportion of paving block for one specimen

Paving block	Mixture proportion of paving block, by weight				
	Fine aggregate		Coarse aggregate	Binder	Pigment
	River sand, kg	Plastic powder, % w/w	Crushed stone, kg	Portland cement, kg	Red stone powder, kg
1	1.50	0	0.75	0.5	0.1
2	1.35	10	0.75	0.5	0.1
3	1.20	20	0.75	0.5	0.1
4	1.05	30	0.75	0.5	0.1
5	0.90	40	0.75	0.5	0.1
6	0.75	50	0.75	0.5	0.1
7	0.60	60	0.75	0.5	0.1
8	0.45	70	0.75	0.5	0.1
9	0.30	80	0.75	0.5	0.1
10	0.15	90	0.75	0.5	0.1

2.2. Preparation of plastic powder

Drinking water bottles were collected from the plastic scavenger. Plastic powder is made by cutting drinking water bottles into small sizes and then converted into plastic pulp by heating it in a drum that already contains a little oil while stirring it evenly. The slurry was cooled and grinded into powder using grinder machine completed with filter in size of 1 mm.

2.3. Manufacture of paving blocks

The materials used for paving block production consist of fine aggregates (river sand and plastic powder), coarse aggregate (crushed stone), and binder (Portland cement) at ratio of 3:1.5:1 with addition of 3.51% w/w red stone powder as a colorant. A total of ten paving block formulations were made by partial sand replacement with plastic powder. The summary formulation of paving block was listed in Table 3. In each paving block production, two mixtures were prepared, the first mixture was consist of red stone powder and cement with a little water added, whereas the second mixture comprises the aggregates and binder with water addition as much as 12 % of total material weight used. The first mixture is evenly placed on the paving block mold in size of 20 × 10 × 6 cm, then followed by the second mixture until the mold was full filled. The mixture was pressed by 6 tons load using a mechanical pressing machine. Paving block was cured at ages of 7; 14; 21 and 30 days in atmospheric air condition.

2.4. Compressive strength test

The compressive strength of paving blocks were tested after ages of 7, 14, 21 and 30 days based on the procedure described in SNI 03-0691-1996 using hydraulic compressive testing machine as given in Figure 2.

Fig. 2. Set-up for the hydraulic compressive strength machine

Each tested sample cut into cubes with dimension of 6 cm × 6 cm × 6 cm then put on compressive strength machine and applied load slowly until the specimen cracks. Compressive strength value was calculated as formula:

$$Compressive\ strength\ (MPa)\ \sigma = \frac{P}{A} \quad (1)$$

where σ = compressive strength (MPa), P = force press (Newton) and A = sectional area (cm^2).

2.5. Water absorption test

The paving block that have been cured at 30 days were tested its water absorption using the accordance method in SNI-03-0691-1996. The tested specimen was immersed in water for 24 h, and then removed from the water and left for 2 min. The remaining water on the surface of the paving blocks was removed using a cloth, and then the weight of the paving blocks was measured. The specimen was then dried in a ventilated oven at 105°C for 24 h and weighed immediately.

Table 4.
The compressive strength and water absorption standard value of paving block accordance to SNI 03-0691-1996

Class	Compressive strength, MPa		Water absorption, %	Application
	Max.	Min.	Max. average	
A	40	35	3	Road
B	20	17	6	Parking area
C	15	12.5	8	Pedestrian
D	10	8.5	10	Parks and other users

Heating and weighing were repeatedly done until the mass loss found no higher than 0.2% from the previous determined specimen weight. The percentage of water absorption was calculated by formula:

$$Water\ absorption\ (\%) = \frac{W_w - W_d}{W_d} x100\% \qquad (2)$$

where W_w and W_d are wet and dry weight of paving block.

The value compressive strength and water absorption of paving blocks made by replacement of sand with plastic powder at different ration was compared to the compressive strength and water absorption standard was issued by the Indonesian National Standard (SNI) 03-0691-1996 for paving block to assess met application. The standard value of compressive strength and water absorption of pavement classes related to its application are presented in Table 4.

2.6. Microstructure analysis

Microstructure of hardened paving block was observed using SEM type Inspect-S50. SEM investigation was conducted on the paving block after agitation at 30 days.

3. Results and discussion

3.1. Compressive strength

Compressive strength is one of the parameters used to assess the ability of paving blocks in holding a given load. The higher strength value of paving blocks indicates the better of its quality. The compressive strength of paving blocks with different content (10-90%) of plastic waste powder as the partial sand substitution at the ages of 30 days are shown in Figure 3.

It can be clearly observed from Figure 3, that the compressive strength was influenced significantly by the plastic content, in which the higher the plastic content used as the substitute fine aggregate for sand in the paving blocks, the lower the compressive strength produced. The compressive strength value in 30 days for paving blocks without plastic waste powder addition was 25.0 MPa indicates suitable for parking area application. A slight decrease on compressive strength was obtained from paving blocks with 10-50% w/w content of plastic powder. Nevertheless, the substitution of sand by plastic powder in portion of 10-50% by weight having compressive strength value at range of 180.06-12.78 Mpa, which are suitable for pedestrian application. This finding is consistent with previous research conducted by Karthikeyan et al. [21], in which they use plastic waste as a coarse aggregate on concrete preparation. They found out that the compressive strength of concrete reduces with increasing the percentage of plastic used. A similar trend was also observed in the number of researchers, where the compressive strength decreases as the plastic content in the paving block increases [22-25]. The reduction in compressive strength of paving block which is prepared by the addition of plastic is caused by the hydrophobic property of plastic was the main factor contributing to the weak interfacial bond between cement and plastic [26-27]. Hama and Hilal [28] suspected that the decrease in compressive strength with an increase in the amount of plastic in paving blocks was due to the plastic material being softer than natural aggregate.

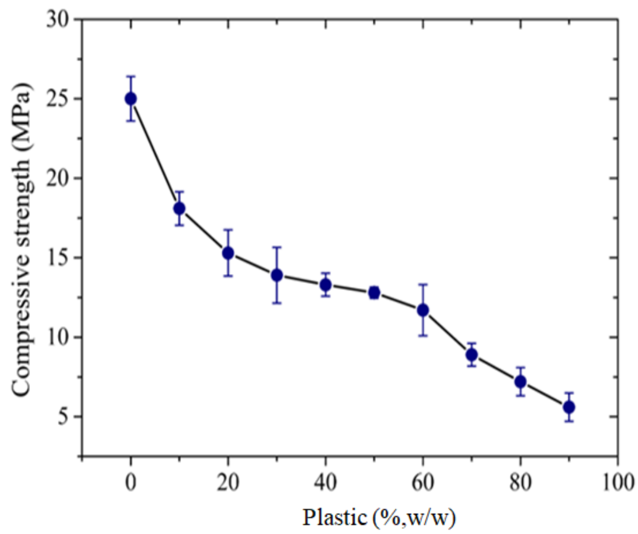

Fig. 3. Effect of plastic waste content on compressive strength at ages of 30 days

According to Indonesian National Standard (SNI) 03-0691-1996, the minimum value of compressive strength required for road, parking areas, pedestrians, parks or other users were 35; 17; 12.5 and 8.5 MPa, respectively. Based on the graph in Figure 3, it can be seen that the compressive strength of paving blocks with the addition of 10% w/w plastic was 18.2 MPa. This value is acceptable for parking area application. Furthermore, increasing the plastic content at range of 20-50% w/w resulted in the decrease of the compressive strength to 15.5-12.78 MPa. These paving blocks are suitable for pedestrians, parks and sidewalks applications.

3.2. Water absorption

Water absorption is an important property for construction materials and is generally used as an indicator of the material durability. Figure 4 demonstrates the water absorption of paving block at different plastic content within pavement after ages of 30 days. It is clearly observed that the water absorption decrease with the increase of plastic powder as the substitute river sand. Water absorption of paving blocks without the addition of plastic was 5.04%. This value decreased to 2.80% after the addition of plastic powder up to 90% w/w for replacement of sand.

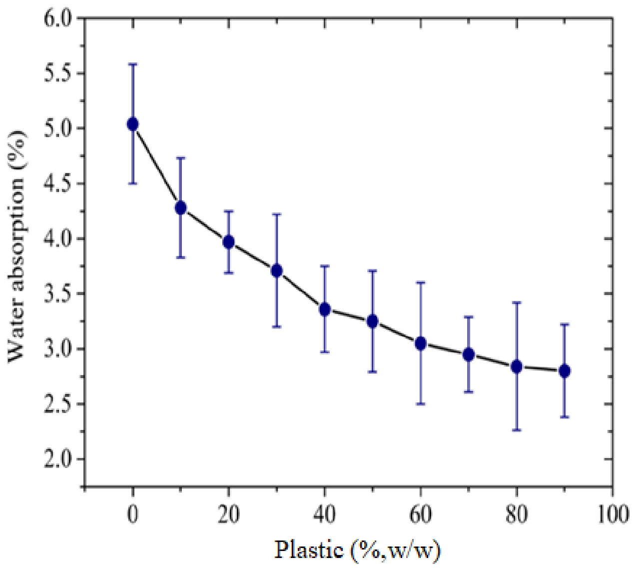

Fig. 4. Effect of plastic content on water absorption at ages of 30 days

Basically, water absorption capacity of paving block significantly influenced by the hydrophobicity of materials within the pavement [29-30]. It can be seen in Table 1, that plastic powder has the lowest water absorption compare to river sand, crushed stone, and red stone. With constant amount of other aggregates, the water absorption decreased with the increase ratio of plastic powder/sand content in the paving blocks. The addition of hydrophobic particles such as plastic to concrete materials provides strong water repelency [31-33]. Our research showed that the water absorption was not proportional to the compressive strength of the paving block since plastic repels the water penetration to the microstructure surface of the paving block. This finding is in line with number of researchers who reported that the water absorption of paving blocks were decrease with increase of plastic waste content [34-36]. The study revealed by Agyeman et al. [11] also reported that the water absorption of paving blocks prepared without plastic addition is higher than paving blocks containing plastic due to their hydrophobic properties. They found, the water absorption of paving blocks without plastic, less in plastic, and high in plastic was 4.9%, 2,7%, and 0.5% at ages of 21 days, respectively. As presented in Table 4, that maximum average of water absorption capacity for standard paving blocks class A (for roads), B (parking areas), C (pedestrians), and D (parks and other uses) in successively are 3; 6; 8; and 10%. Based on the water absorption values obtained, paving blocks resulted in all our experiments are met for non-traffic application such as parking area, pedestrian, parks and others uses. The average water absorption of paving blocks are also met to the specification threshold values British standard BS EN 1338:2003[37]. According to BS EN-1338: 2003, the minimum requirement for water absorption for paving blocks shall be equal to or smaller than 6.5%. However, we recommended that paving block containing the plastic powder up to 50% w/w as fine aggregate to replace sand was suitable for pedestrians. This is because the replacement of sand with plastic up to 50% as fine aggregate resulted in the paving blocks with compressive strength (12.78 MPa) and water absorption (3.25%) meet the requirements used as a road hardener for pedestrians.

3.3. Relation of curing time to compressive strength

Curing is the process of controlling the rate and degree of moisture loss of pavement during cement hydration. The properties of concrete are significantly affected by curing time because they greatly affect the hydration of cement. It can be seen in Figure 5, the compressive strength of all mixtures increases gradually with the continued curing age of the concrete due to the continuity of the hydration process in the paving block. The compressive strength for control (paving block without plastic addition) after of 7, 14, 21 and 30 days of curing time was 12.75; 15.28; 20.06 and 25.00 MPa, respectively. Meanwhile, the compressive strength of paving blocks made with the addition of 10-90% w/w plastic waste as a substitute for sand has increased gradually, that was 8.25-2.15; 12.76-3.48; 16.85-4.15 and 18.06-5.56 as the curing age increases.

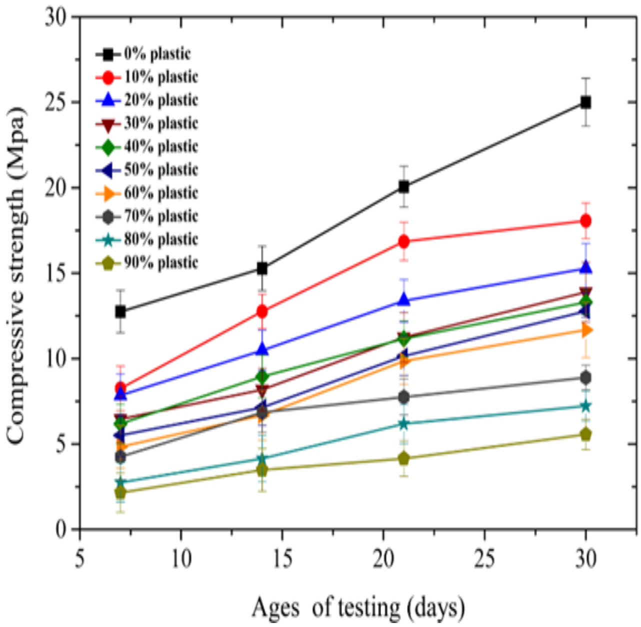

Fig. 5. Compressive strength of paving blocks at 7, 14, 21 and 30 days

The previous research from Vanitha et al. [38] reported an investigation on compressive strength of concrete using plastic as a partial replacement of coarse aggregate at the ages of 7-28 days. As a results, compressive strength increase with the increase of curing time, in which the best paving blocks obtained was made with the addition of 4% plastic as a substitute coarse aggregate with compressive strength value of 26.1 MPa.

3.4. Microstructural properties

The surface microstructure analysis of paving blocks without plastic (control), the addition of 30% w/w, and 50% w/w plastic replacement of sand at 30 days cure samples were observed using SEM type Inspect-S50.

The samples selected to observe microstructural changes were limited to control mixtures (without plastic addition) and mixtures with 30% w/w and 50% w/w plastic contents. As shown in Figure 6, it appears that the increase of voids in the paving blocks is proportional to the plastic content. Comparing the three images, it can be observed that the sample with 50% w/w plastic aggregate (C) has more voids than the paving block containing 30% w/w (B) plastic and the control (A).The result indicates that the microstructure of the paving blocks prepared by plastic addition is non uniform surface and less compact than the paving block without plastic addition. This also represents that the leak interfacial bond between plastic and cement due to the hydrophobic property of plastic is the main cause of the decline in the compressive strength of paving blocks. This finding agrees with Imtiaz et al [39] in which, the decrease of compressive strength is in line with the increase in the number of voids. Our research was also found that the water absorption capacity decreased slightly with the increase in the amount of plastic used to replace the sand despite the increase in the number of voids in the paving block. This may be caused by the hydrophobicity property of plastic aggregates that repel water. This agrees with Hassani et al. [40], who said that the presence of hydrophobic compounds in concrete functions as hydrophobic pore blockers which minimize water penetration.

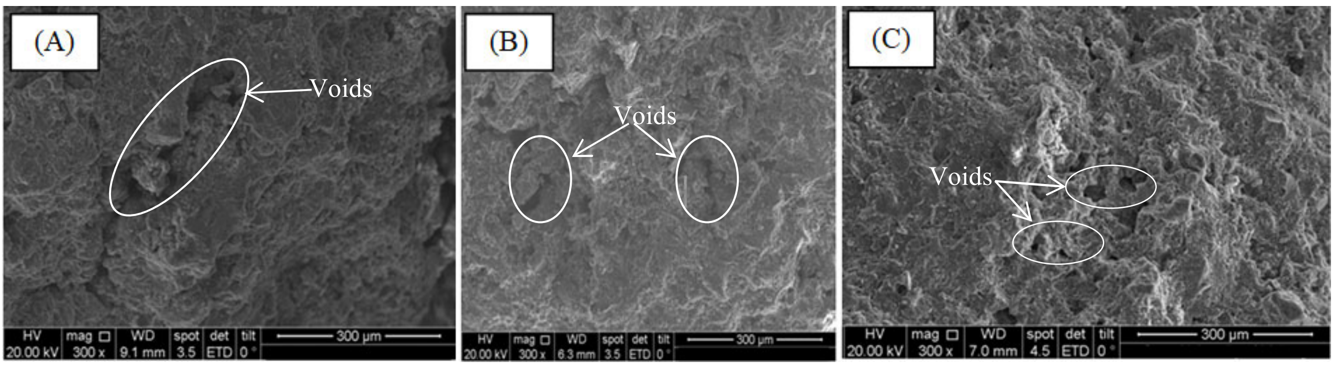

Fig. 6. SEM image of paving block surface morphology with different plastic content (A) 0% w/w plastic, (B) 30% w/w plastic, and (C) 50% w/w plastic at 30 days of curing

4. Conclusions

A study has been conducted to investigate the compressive strength and water absorption value of pavement which were prepared using plastic waste powder as fine aggregate to partial replacement of sand and reinforced with inorganic colorant from red stone powder. The use of sand was replaced gradually by plastic powder up to 90% w/w. The compressive strength and water absorption of pavement were greatly influenced by the percentage of plastic waste used. The compressive strength and water absorption of pavement with plastics powder content at the range of 10%-50% w/w after 30 days curing time reached up to 18.06-12.78 MPa and 4.28-3.25%, respectively. Paving blocks with 10-50% w/w plastic content instead of sand are acceptable used for non-traffic areas such as pedestrians, landscapes, and public walkways.

Acknowledgements

We gratefully acknowledge the financial support from Directorate of Research and Community Service, the Ministry of Research, Technology and Higher Education of Indonesia (contract no. 131/UN48.16/LT/2019.) We also thank the research and community service institution of Universitas Pendidikan Ganesha for the administration services.

References

[1] Organization for economic co-operation and development, Improving plastics management: trends, policy responses and the role of international co-operation and trade, 2018. Available from: https://www.oecd.org/environment/waste/policy-highlights-improving-plastics-management.pdf

[2] O.A. Alabi, K.I. Ologbonjaye, O. Awosolu, O.E. Alalade, Public and environmental health effects of plastic wastes disposal: A review, Journal of Toxicology and Risk Assessment 5/2 (2019) 1-13. DOI: https://doi.org/10.23937/2572-4061.1510021

[3] R. Verma, K.S. Vinoda, M. Papireddy, A.N.S. Gowda, Toxic pollutants from plastic waste: A review. Procedia Environmental Sciences 35(2016) 701-708. DOI: https://doi.org/10.1016/j.proenv.2016.07.069

[4] C.T. Li, H.K. Zhuang, L.T. Hsieh, W.J. Lee, M.C. Tsao, PAH Emission from the incineration of three plastic wastes. Environment International 27/1(2001) 61-67. DOI: https://doi.org/10.1016/S0160-4120(01)00056-3

[5] M. Sarker, A. Kabir, M.M. Rashid, M. Molla, A.S.M. Din Mohammad, Waste polyethylene terephthalate (PETE-1) conversion into liquid fuel, Journal of Fundamentals of Renewable Energy and Applications 1 (2011) 1-5. DOI: https://doi.org/10.4303/jfrea/R101202

[6] S. Bezergianni, A. Dimitriadis, G.C. Faussone, D. Karonis, Alternative diesel from plastics waste, Energies 10/11(2017) 1-12. DOI: https://doi.org/10.3390/en10111750

[7] R. Thahir, A. Altway, S.R. Juliastuti, Susianto, Production of liquid fuel from plastic waste using integrated pyrolysis method with refinery distillation bubble cap plate column, Energy Reports 5 (2019) 70-77. DOI: https://doi.org/10.1016/j.egyr.2018.11.004

[8] G. Yu, C.Y. Hung, I. Hung, An optimized pyrolysis technology with highly energy efficient conversion of waste plastics into clean fuel while substantially reducing carbon emission, International Journal of Environmental Science dan Development 9/4(2018) 95-99. DOI: https://doi.org/10.18178/ijesd.2018.9.4.1080

[9] N. Kholidah, M. Faizal, M. Said, Polystyrene plastic waste conversion into liquid fuel with catalytic cracking process using Al_2O_3 as catalyst, Science and Technology Indonesia 3/1 (2018) 1-6. DOI: https://doi.org/10.26554/sti.2018.3.1.1-6

[10] S.S. Sharma, V.S. Batra, Production of hydrogen and carbon nanotubes via catalytic thermo-chemical conversion of plastic waste: A review, Chemical Technology and Biotechnology 95/1 (2020) 11-19. DOI: https://doi.org/10.1002/jctb.6193

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

[12] SNI 03-0691-1996: Indonesian National Standard Method for Paving Block Test.

[13] X. Wang, C.C. Chin, J. Xia, Materials characterization for sustainable concrete Paving Blocks. Applied Sciences 9/6(2019) 1197. DOI: https://doi.org/10.3390/app9061197

[14] S.P. Gautam, V. Srivastav, V.C. Agarwal, Use of glass wastes as fine aggregate in concrete, Journal of Academia and Industrial Research 1/6 (2012) 320-322.

[15] T.C. Ling, H. Nor, M.R. Hainin, Properties of crumb rubber concrete paving blocks with SBR latex, Road Materials and Pavement Design 10/1 (2009) 213-222. DOI: https://doi.org/10.1080/14680629.2009.9690188

[16] C. Namarak, C. Bumrungsri, W. Tangchirapat, C. Jaturapitakkul, Development of concrete paving blocks

prepared from waste materials without portland cement, Material Science 24/1 (2018) 92-99. DOI: https://doi.org/10.5755/j01.ms.24.1.17566

[17] P. Sharma, M. Sharma, Utilization of quarry dust in cement concrete paver blocks for rural roads, International Research Journal of Advanced Engineering and Science 2/1 (2017) 118-124.

[18] M.S. Sainudin, N.H. Othman, W.A. Soffian, W. Mohammad, M.H.W. Ibrahim, K. Muthusamy, Properties of concrete containing mussel (*Perna viridis*) shell ash as partial cement replacement, International Journal of Integrated Engineering 11/9 (2019) 154-163. DOI: https://doi.org/10.30880/ijie.2019.11.09.017

[19] B. Shanmugavalli, K. Gowtham, P.J. Nalwin, B.E. Murthy, Reuse of plastic waste in paver blocks, International Journal of Engineering Research and Technology 6/2 (2017) 313-315. DOI: http://dx.doi.org/10.17577/IJERTV6IS020162

[20] C. Nivetha, M. Rubiya, S. Shobana, E.G. Vaijayanthi, M.E. Viswanathan, M.E. Vasanthi, Production of plastic paver block from the solid waste (quarry dust, flyash & PET), ARPN Journal of Engineering and Applied Science 11/2 (2016) 1078-1079.

[21] M. Karthikeyan, K. Balamurali, V. B. Kumar, S.M. Prabakar, R. Janarthanan, Utilization of waste plastic in concrete, International Research Journal of Engineering Technology 6/4 (2019) 1400-1405.

[22] B. Rai, S.T. Rushad, Kr. Bravesh, S.K Duggal, Study of waste plastic mix concrete with plasticizer, International Scholarly Research Network 2012 (2012) 469272. DOI: https://doi.org/10.5402/2012/469272

[23] E.A. Ohemeng, P.P. Kopi-Yalle, J. Dadzie, S.D Djokoto, Utilization of waste low density polyethylene in high strengths concrete pavement blocks production, Civil and Environmental Research 6/5 (2014) 126-135.

[24] A.M. Hameed, B.A.F. Ahmed, Employment the plastic waste to produce the light weight concrete, Energy Procedia 157(2019) 30-38. DOI: https://doi.org/10.1016/j.egypro.2018.11.160

[25] E. Bachtiar, Mustaan, F. Jumawan, M. Artayani, Tahang, M.J. Rahman, A. Setiawan, M. Ihsan, Examining polyethylene terephthalate (PET) as artificial coarse aggregates in concrete, Civil Engineering Journal 6/12 (2020) 2416-2424. DOI: https://doi.org/10.28991/cej-2020-03091626

[26] P. Panyakapo, M. Panyakapo, Reuse of thermosetting plastic waste for lightweight concrete, Waste Management 28/9 (2008) 1581-1588. DOI: https://doi.org/10.1016/j.wasman.2007.08.006

[27] X. Shu, B. Huang, Recycling of waste tire rubber in asphalt and portland cement concrete: An overview, Construction and Building Materials 67/B (2013) 217-224. DOI: https://doi.org/10.1016/j.conbuildmat.2013.11.027

[28] S.M. Hama, N.N. Hilal, Fresh properties of selt-compacting concrete with plastic waste as partial replacement of sand, International Journal of Sustainable Built Environment 6/2 (2017) 299-308. DOI: https://doi.org/10.1016/j.ijsbe.2017.01.001

[29] A.R. Djamaludin, M.A. Caronge, M.W. Tjaronge, A.T. Lando, R. Irmawaty, Evaluation of sustainable concrete paving blocks incorporating processed waste tea ash, Case Study in Construction Materials 12 (2020) e00325. DOI: https://doi.org/10.1016/j.cscm.2019.e00325

[30] E. Mora, G. Gonzales, P. Romero, E. Castellon, Control of water absorption in concrete materials by modification with hybrid hydrophobic silica particle, Construction and Building Materials 221 (2019) 210-218. DOI: https://doi.org/10.1016/j.conbuildmat.2019.06.086

[31] C.M. Tibbetts, K.A. Riding, C.C. Ferraro, A critical review of the testing and benefits of permeability-reducing admixtures for use in concrete, Cement 6 (2021) 100016. DOI: https://doi.org/10.1016/j.cement.2021.100016

[32] P.O. Awoyera, O.B. Olalusi, S. Ibia, K. Prakash A., Water absorption, strength and microscale properties of interlocking concrete block made with plastic fibre and ceramic aggregates, Case Studies in Construction Materials 15 (2021) e00677. DOI: https://doi.org/10.1016/j.cscm.2021.e00677

[33] E. Jusli, H. Md Nora, R.P. Jaya, Z. Haron, Strength and microstructure properties of double layered concrete paving blocks containing waste tyre rubber granules, Jurnal Teknology 73/4/P2 (2015) 85-90. DOI: https://doi.org/10.11113/jt.v73.4294

[34] G.B. Avinash, A.P. Roja, M.R. Santhosh, H.P. Kumari, Utilisation of waste plastic in manufacturing of paver blocks, International Journal of Innovative Research in Science, Engineering and Technology 8/6 (2019) 6674-6680. DOI: https://doi.org/10.15680/IJIRSET.2019.0806025

[35] A.M. Binu, A.S. Vinod, P. Sethuraj, S. Akil, Experimental study on the replacement of coarse aggregates with recycled hospital plastic waste in paver blocks. International Journal of Advance Research and Development 4/6 (2019) 1-3.

[36] B.K. Khasiyani, J. Pitroda, B.K. Shah, Effect on compressive strength and water absorption of

interlocking paver block by addition of polypropylene fiber. Journal of International Academic Research for Multidisciplinary 1/3 (2013) 66-77.

[37] BSI. BS EN 1338:2003 Concrete paving blocks requirements and test methods; British Standards Institution: London, UK.

[38] S. Vanitha, V. Natrajan, M. Praba, Utilization of plastics waste as a partial replacement of coarse aggregate in concrete blocks, Indian Journal of Science and Technology 8/12 (2015) 1-6.
DOI: https://doi.org/10.17485/ijst/2015/v8i12/54462

[39] T. Imtiaz, A. Ahmed, M.D.S. Hossain, M. Faysal, Microstructure analysis and strength characterization of recycled base and sub-base materials using scanning electron microscope, Infrastructures 5/9 (2020) 70.
DOI: https://doi.org/10.3390/infrastructures5090070

[40] M. Hassani, K. Vessalas, V. Sirivivatnanon, D. Baweja, Influence of permeability-reducing admixtures on water penetration in concrete, ACI Materials Journal 114/6 (2017) 911-922. DOI: http://dx.doi.org/10.14359/51701002