IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 8 Issue 12, December 2021
ISSN (Online) 2348 – 7968 | Impact Factor (2020) – 6.72
www.ijiset.com

The Utilization Of Black Stone Waste As An Alternative Material To Replace Partial Cement And Aggregate In Concrete

I. W. Gde Erick Triswandana[1], Putu Aryastana[2], Christian Winata[3]

[1]Department of Civil Engineering, Warmadewa University, Denpasar City, Bali Province, Indonesia

[2]Department of Civil Engineering, Warmadewa University, Denpasar City, Bali Province, Indonesia

[3]Department of Civil Engineering, National Central University, Taoyuan City, Taiwan (R.O.C.)

Abstract

Every ton of cement produced leads to about 0.9 tons of CO_2 emissions with a typical cubic yard of concrete contains around 10% by weight of cement. Besides, the availability of black stone waste has increased significantly in Bali Province. This is due to the waste product from building ornament craftsmen in the form of powder, granules, chunks up to 30% of total production along with the absence of a waste management regulation. To address those issues, this study aims to utilize black stone waste as cement and aggregate replacement. The results showed that 7.5% of black stone powder (BSP) and 25% of the black stone aggregate (BSA) achieved the highest strength compared to the control mixture. Thus, it can be concluded that the components could be replaced by BSP and BSA not more than 7.5% and 25%, respectively. It is expected that black stone waste might reduce environmental pollution.

Keywords: black stone waste, cement replacement, aggregate replacement, water-cement ratio, compressive strength.

1. INTRODUCTION

Concrete is the most common construction material used to improve the infrastructure in high-demand countries, especially in Indonesia, Vietnam, the Philippines, etc. The use of concrete in modern industrial society currently has been reaching more than ten billion tons annually [1]. However, it has been reported that every ton of cement produced leads to about 0.9 tons of CO_2 emissions and a typical cubic yard of concrete contains around 10% by weight of cement [2]. Hence the general desire for sustainable development associated with the awareness of climate change had declared to begin impacting the practice of waste material in the construction industry. Several studies have begun on finding alternatives that can be used as a substitute for cement [3-6] for example, the availability of industrial and agricultural waste materials has great potential to be used as a substitute for cement, such as fly ash, slag, silica fume, glass powder, ceramic powder, brick powder, rice husk ash, palm oil waste ash, bagasse ash, wood waste ash, bamboo leaf ash, and maize pod ash. In addition, other waste materials are difficult to recycle and needs long term recycling that potential environmental damage such as PET (Polyethylene Terephthalate), rubber tire [7-10].

Recently, the availability of black stone waste has increased significantly in Bali Province, especially in Karangasem Regency. It is due to many craftsmen use black stone as ornament materials for statues, temples, aesthetic walls. The process of ornament materials from the black stones produce waste in the form of powder, granules, and chunks up to 30% of the total production which has the potential to cause damage to the surrounding environment. However, there is no uncertainty in waste management or even regulation to solve those issues.

Figure 1. The huge number of black stone waste piles in Karangasem Regency

In general, the black stone is a type of volcanic rock originally from frozen volcanic lava. It is known that the scientific name of black stone is basaltic scoriae, which contains 40 – 75% of silica compound (SiO_2) formed by plagioclase minerals, pyroxene of lumps in the lava flow [11, 12]. In addition, the black stone has a sharp, porous, rough surface which is the potential to interlock on any aggregate in concrete. A study conducted by Intara et. al. utilizing black stone waste as cement substitution of 0%, 5%, 10%, 15%, 20%, 25% respectively. The weight ratio of cement: sand: the crushed stone was 1: 1.93: 2.67 and the water-cement (w/c) ratio was maintained at 0.52 [13]. The results indicated that the optimum use of black stone powder as a substitute for cement is in the range of 5-10%. Other studies also investigated the use of black stone waste as fine aggregate replacement of 0%, 25%, 50%, 75%, 100% in concrete mixture with w/c ratio at 0.5, which has been designed using a weight ratio of 1 cement: 2 fine aggregate: 3 coarse aggregate. It was found that the replacement of natural sand using black stone waste from 50% to 75% showed a significant increment of compressive strength. However, the compressive strength relatively decreased with the replacement of natural sand by 25% [14]. Although several studies have identified the black stone utilization, there are still limited studies to know exactly the effectiveness of utilizing black stone waste as alternative materials to the constituent components of concrete. Thus, this study utilized black stone waste as cement and aggregate substitution which have the prestigious potential to support the eco-friendly sustainable materials in the future.

2. MATERIAL PROPERTIES

Portland Composite Cement (PCC) Type I was used throughout this study. Fine and coarse aggregates with a specific gravity of 2.59 and 2.60 respectively were originated from Karangasem Regency, Bali. The grain distribution of fine aggregate was satisfied on zone 2, while coarse aggregate with max. size of 20 mm has also fulfilled the requirement based on ASTM C33 [15]. Meanwhile, black stone waste substituted as Portland cement and aggregates with a specific gravity of 2.65 and 1.60 respectively were picked up from Dewata Temple enterprise. To meet the criteria of mix proportion, Table 1 and Figure 2 show various material properties referring to Indonesian National Standard (SNI) and American Society for Testing and Material (ASTM). Water was funneled by Denpasar Governmental Water Company, which was taken directly from the Department of Civil Engineering at Warmadewa University, Indonesia.

Table 1. Material properties for mix proportion

No	Material properties	Fine aggregate	Coarse aggregate	Black stone aggregate	Black stone powder	Reference standard
1	Water content (%)	6.29	2.27	16.55	0.15	[16]
2	Sludge content (%)	3.90	2.67	7.81	0.02	[17]
3	Specific gravity in SSD	2.59	2.60	1.60	2.65	[18, 19]
4	Absorption (%)	3.43	2.88	17.28	0.16	[18, 19]

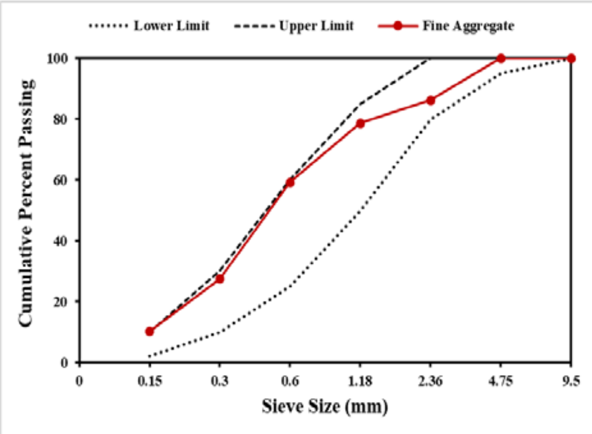

Fig 2. The grain size distribution of fine aggregate was fulfilled on zone 2

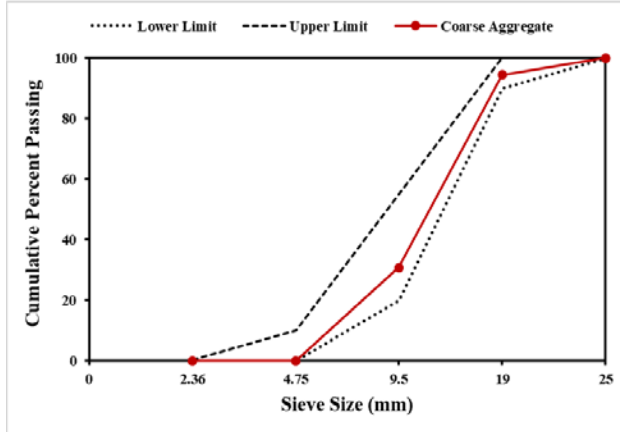

Fig 3. The grain size distribution of coarse aggregate per ASTM C-33 [15]

3. EXPERIMENTAL METHODS

3.1 Mix Proportion

This study was designed following SNI 03-2834 [20] using a weight ratio of cement: the fine aggregate: the coarse aggregate of 1: 2: 3 with water-cement (w/c) ratio kept at 0.4, 0.45, and 0.5 as control mixtures. Meanwhile, black stone powder (BSP) was substituted as Portland cement (PC) by 5%, 7.5%, 10%, respectively. Black stone aggregate (BSA) was also substituted as fine aggregate (FA) by 25% and coarse aggregate (CA) of 25%, 50%, respectively. The slump test was determined in the range of 30 – 60 mm. Table 2 represents the composition of using black stone waste as cement and aggregate substitution, where each composition has three samples with different w/c ratio, hence the total samples in this study were 63 specimens.

Table 2. Percentage of black stone waste utilization

Code	Portland Cement (PC)	Fine Aggregate (FA)	Coarse Aggregate (CA)	w/c	Number of Samples
B1a	100% PC	100% FA	100% CA	0.4	3
B1b	100% PC	100% FA	100% CA	0.45	3
B1c	100% PC	100% FA	100% CA	0.5	3
B2a	95% PC + 5% BSP	75% FA + 25% BSA	75% CA + 25% BSA	0.4	3
B2b	95% PC + 5% BSP	75% FA + 25% BSA	75% CA + 25% BSA	0.45	3
B2c	95% PC + 5% BSP	75% FA + 25% BSA	75% CA + 25% BSA	0.5	3
B3a	92.5% PC + 7.5% BSP	75% FA + 25% BSA	75% CA + 25% BSA	0.4	3
B3b	92.5% PC + 7.5% BSP	75% FA + 25% BSA	75% CA + 25% BSA	0.45	3
B3c	92.5% PC + 7.5% BSP	75% FA + 25% BSA	75% CA + 25% BSA	0.5	3
B4a	90% PC + 10% BSP	75% FA + 25% BSA	75% CA + 25% BSA	0.4	3
B4b	90% PC + 10% BSP	75% FA + 25% BSA	75% CA + 25% BSA	0.45	3
B4c	90% PC + 10% BSP	75% FA + 25% BSA	75% CA + 25% BSA	0.5	3
B5a	95% PC + 5% BSP	75% FA + 25% BSA	50% CA + 50% BSA	0.4	3
B5b	95% PC + 5% BSP	75% FA + 25% BSA	50% CA + 50% BSA	0.45	3
B5c	95% PC + 5% BSP	75% FA + 25% BSA	50% CA + 50% BSA	0.5	3
B6a	92.5% PC + 7.5% BSP	75% FA + 25% BSA	50% CA + 50% BSA	0.4	3

B6b	92.5% PC + 7.5% BSP	75% FA + 25% BSA	50% CA + 50% BSA	0.45	3
B6c	92.5% PC + 7.5% BSP	75% FA + 25% BSA	50% CA + 50% BSA	0.5	3
B7a	90% PC + 10% BSP	75% FA + 25% BSA	50% CA + 50% BSA	0.4	3
B7b	90% PC + 10% BSP	75% FA + 25% BSA	50% CA + 50% BSA	0.45	3
B7c	90% PC + 10% BSP	75% FA + 25% BSA	50% CA + 50% BSA	0.5	3
Total samples					63

To know exactly the amount of black stone waste used as Portland cement and aggregates substitution, Table 3 represents each mix proportion per meter cubic. There are seven variations with different water-cement (w/c) ratios, including the control mixture.

Table 3. Mix proportion of black stone utilization per m^3

Code	Portland cement (kg)		Fine Aggregate (kg)		Coarse Aggregate (kg)		Water (kg)
	PC	BSP	Natural sand	BSA (FA subs.)	Natural gravel	BSA (CA subs.)	
B1a	400	0	800	0	1200	0	160
B1b	400	0	800	0	1200	0	180
B1c	400	0	800	0	1200	0	200
B2a	380	20	600	200	900	300	160
B2b	380	20	600	200	900	300	180
B2c	380	20	600	200	900	300	200
B3a	370	30	600	200	900	300	160
B3b	370	30	600	200	900	300	180
B3c	370	30	600	200	900	300	200
B4a	360	40	600	200	900	300	160
B4b	360	40	600	200	900	300	180
B4c	360	40	600	200	900	300	200
B5a	380	20	600	200	600	600	160
B5b	380	20	600	200	600	600	180
B5c	380	20	600	200	600	600	200
B6a	370	30	600	200	600	600	160
B6b	370	30	600	200	600	600	180
B6c	370	30	600	200	600	600	200
B7a	360	40	600	200	600	600	160
B7b	360	40	600	200	600	600	180
B7c	360	40	600	200	600	600	200

3.2 Slump Test, Casting, and Curing of Concrete

Casting concrete was done by pouring all materials into the concrete mixer then mixed regularly based on ASTM C192 [21]. After the mixture was well mixed, the next step was carried out by measuring a slump test using Abrams's cone and a plate was placed on the base. Once if the slump test meets the criteria of mix design, the fresh concrete was then poured into cylindrical molds and compacted slowly. The cylindrical molds were removed after conducting for 24 hours and cured by immersing those samples to water with normal temperature until the time of testing at 28 days.

3.3 Compressive Strength Test and Unit Weight of Concrete

The compressive strength test was followed by SNI 03-1974 [22]. The cylindrical samples with a diameter of 150 mm and a height of 300 mm were loaded under the compression testing machine at 28 days of water curing. Before loading, the determination of unit weight was carried out following ASTM C138 [23]. The samples were weighed using digital scales and ensure the surface of each sample was capped using heated sulfur to make a distributed load during compression. To attain reliable data, those results were calculated by averaging three samples of each variation with different w/c ratio.

4. RESULTS AND DISCUSSION

Table 4 summarizes the results of utilizing black stone waste as cement and aggregate substitution from code B2 to B7, and B1 is a comparison of a control mixture. These data provide slump values, compressive strength, and unit weight with different water-cement (w/c) ratios.

Table 4. The results of utilizing black stone waste

Code	w/c	f'c (MPa)	Unit weight (kg/m^3)	Slump (mm)
B1a	0.4	21.27	2158	90
B1b	0.45	22.25	2141	85
B1c	0.5	23.50	2141	90
B2a	0.4	20.09	2087	85
B2b	0.45	22.73	2082	85
B2c	0.5	18.46	2068	85
B3a	0.4	22.39	2074	72
B3b	0.45	23.35	2092	75
B3c	0.5	17.44	2057	75
B4a	0.4	18.50	2096	70
B4b	0.45	17.56	2081	68
B4c	0.5	14.20	2036	68
B5a	0.4	18.34	2004	65
B5b	0.45	16.77	2003	60
B5c	0.5	19.32	2005	60
B6a	0.4	18.35	2013	40
B6b	0.45	15.31	1993	40
B6c	0.5	16.27	2006	40
B7a	0.4	16.33	2005	40
B7b	0.45	12.61	1987	40
B7c	0.5	10.96	1979	40

4.1 Slump Test

As shown in Figure 4, the effect of black stone waste as Portland cement and aggregates substitution to concrete indicate the reduction of slump value. It implies substituting black stone waste may reduce the consistency of concrete compared to a control mixture. However, the mixed design criteria were designed in the range of 30 - 60 mm. Hence only B5 to B7 satisfy the criteria of mixed design. On the other hand, Figure 5 exhibits B6 and B7 with the w/c ratio of 0.4, 0.45, and 0.5 respectively meet the criteria design which is below 60 mm. B5 with the w/c ratio of 0.45 and 0.5 also satisfy the requirements.

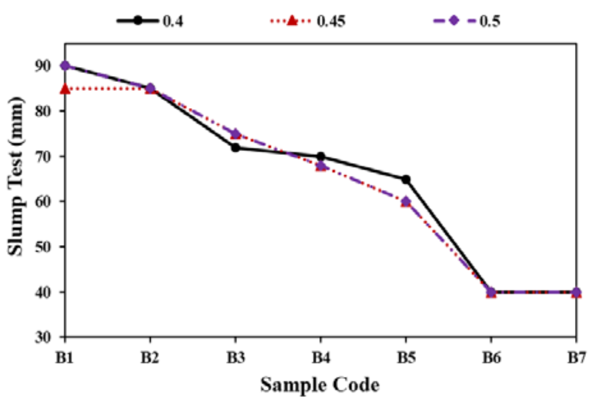

Fig 4. Slump test vs. various mixtures

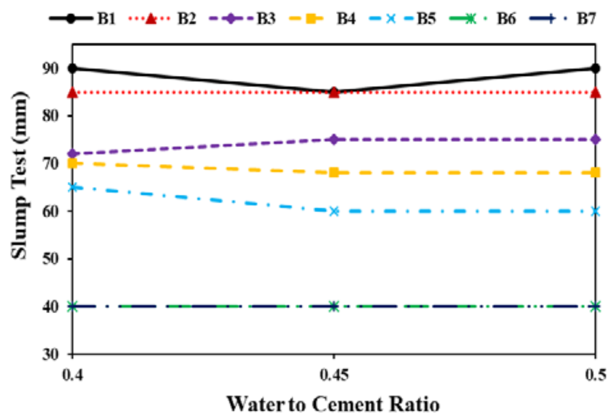

Fig 5. Slump test vs. water-cement ratio

4.2 Unit Weight of Concrete

Figure 6 indicates that the substitution of black stone waste as Portland cement and aggregates show a significant reduction in unit weight compared to a control mixture with different w/c ratios. Pane et. al [24] mentioned that the unit weight of concrete can be divided into three types, such as lightweight concrete (< 2100 kg/m^3), normal concrete (2100 - 2400 kg/m^3), and heavy-weight concrete (> 2400 kg/m^3). As can be seen in Figure 7, the control mixtures as B1 with various w/c ratios are categorized as normal concrete, whereas B2 to B7 can be categorized as lightweight concrete in the range 1900 to 2100 kg/m^3.

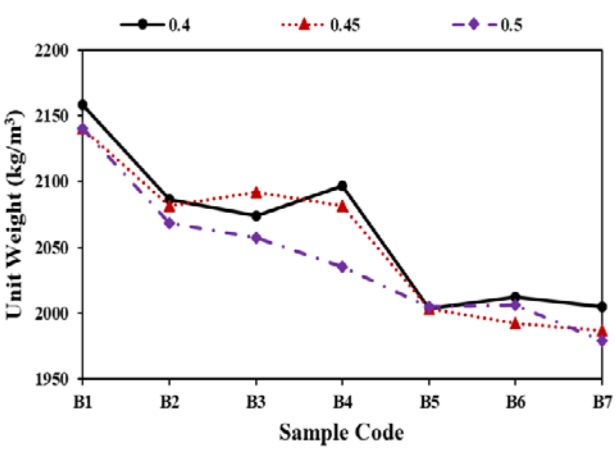

Fig 6. Unit weight vs. various mixtures

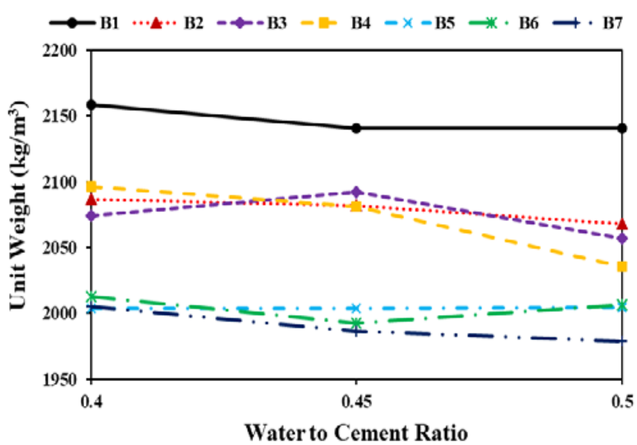

Fig 7. Unit weight vs. water-cement ratio

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 8 Issue 12, December 2021
ISSN (Online) 2348 – 7968 | Impact Factor (2020) – 6.72
www.ijiset.com

4.3 Compressive Strength Test

Compressive strength was obtained at 28 days of testing. Figure 8 demonstrates various mixtures of substituting cement and aggregates by black stone waste. It was identified that B3 (7.5% of BSP + 25% of BSA) attained the highest strength compared to the control mixture at w/c ratio 0.4 and 0.45 with a slight increase of 9.1%, 4.7%, respectively. It should be noted that substituting cement into BSP with a percentage of 5% to 7.5% increased the compressive strength. Nevertheless, the compressive strength decreased with the increase of black stone powder (BSP) by more than 7.5%. This could be due to the silica content of BSP which helped cement particles to hydrate rapidly. However, it could be presumed that too much silica content might interfere to cement hydration. The same observation was found when black stone aggregate (BSA) was substituted as coarse aggregate by more than 25%, a significantly decreased strength also occurred as the percentage of BSA increased.

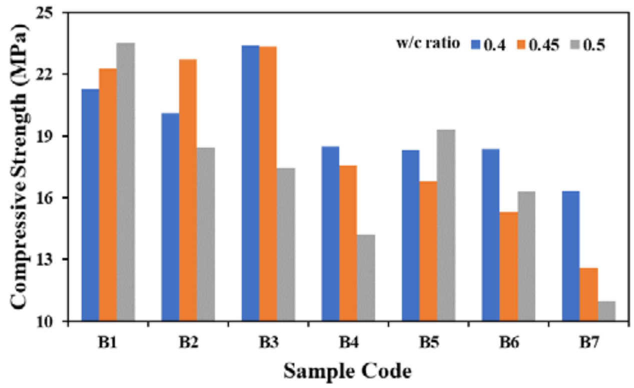

Fig 8. Compressive strength vs. various mixtures with different w/c ratios

When the w/c ratio was increased by more than 0.45, the compressive strength was significantly reduced compared to the control mixture as shown in Figure 8. Yet, the sample code of B5 (5% of BSP + 50% of BSA as coarse aggregate replacement) was satisfied the slump test at w/c ratio 0.5 which refers to mix design criteria and results in greater strength than other various mixtures as displayed in Figure 5 and Figure 9.

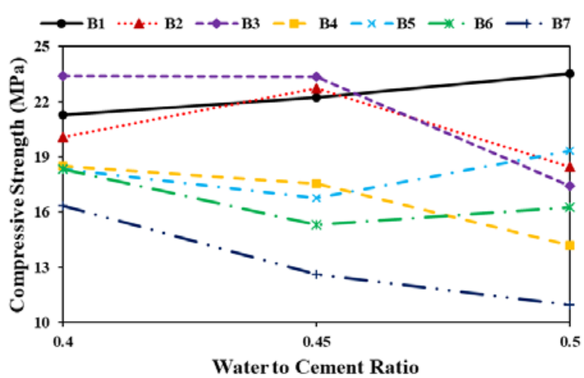

Fig 9. The effect of w/c ratio on compressive strength

5. CONCLUSIONS

This study experimentally investigated the potential of black stone waste utilization as an alternative material to replace partial cement and aggregates in concrete. Based on the results above, the major conclusions of this study are drawn as follows:

1. It can be categorized as lightweight concrete when the black stone waste was replaced by partially cement and aggregate in the range 1900 to 2100 kg/m^3.
2. For water-cement ratios 0.4 and 0.45, the sample code of B3 with 7.5% of BSP + 25% of BSA achieved the highest compressive strength compared to the control mixture with a slight increase of 9.1%, 4.7%,

respectively. However, the compressive strength decreased with the increase of black stone powder (BSP) as cement replacement by more than 7.5% and black stone aggregate (BSA) as coarse aggregate replacement by more than 25%.

3. When the w/c ratio was more than 0.45, the compressive strength was significantly reduced. But the sample code of B5 with 5% of BSP + 50% of BSA as coarse aggregate replacement satisfied the slump test in the range 30 – 60 mm, which refers to mix design criteria and exhibits greater strength than other various mixtures.

ACKNOWLEDGEMENTS

The authors would like to graciously thank the Research Institute of Warmadewa University, Bali, Indonesia for financial support. We also appreciate the Laboratory of Civil Engineering Study Program, Warmadewa University has provided the facilities to complete this research. Those opinions, findings, and conclusions expressed in this paper are those of the authors and do not necessarily reflect those of the sponsor.

REFERENCES

[1] Meyer, C., *The greening of the concrete industry.* Cement and Concrete Composites, 2009. 31(8): p. 601-605.

[2] Obla, K., *What is Green Concrete?* Engineering Ecology, 2009. 83.

[3] Owaid, H.M., R.B. Hamid, and M.R. Taha, *A review of sustainable supplementary cementitious materials as an alternative to all-portland cement mortar and concrete.* Australian Journal of Basic and Applied Sciences, 2012. 6(9): p. 287-303.

[4] Aprianti, S.E., *A huge number of artificial waste material can be supplementary cementitious material (SCM) for concrete production – a review part II.* Journal of Cleaner Production, 2016. 142: p. 4178-4194.

[5] Tavakoli, D., M. Hashempour, and A. Heidari, *Use of waste materials in concrete: A review.* Pertanika Journal of Science and Technology, 2018. 26(2): p. 499-522.

[6] Gautam, S.P., V. Srivastava, and V.C. Agarwal, *Use of glass wastes as fine aggregate in Concrete.* J. Acad. Indus., 2012. 1(6): p. 320-322.

[7] Suhendro, B., *Toward Green Concrete for Better Sustainable Environment.* Procedia Engineering, 2014. 95.

[8] Widyawati, R., *Studi Kuat Tekan Beton Beragregat Ramah Lingkungan.* Jurnal Rekayasa, 2012. 15(3): p. 217-224.

[9] Chowdhury, M.T.U., et al., *A Review On The Use Of Polyethylene Terephthalate (Pet) As Aggregates In Concrete.* Malaysian Journal of Science, 2018. Vol 37 No 2 (2018): p. 118-136.

[10] Ganjian, E., M. Khorami, and A.A. Maghsoudi, *Scrap-tyre-rubber replacement for aggregate and filler in concrete.* Construction and Building Materials, 2009. 23: p. 1828–1836.

[11] Verhoef, P.N.W. and E.E. Stapel, *The Use of The Methylene Blue Adsorption Test in Assessing The Quality of Basaltic Tuff Rock Aggregate.* Journal of Engineering Ecology, 1989. 26(3).

[12] Sunartha, I.K., *Pengaruh Penggunaan Serbuk Batu Tabas (Scoriae Basaltik) sebagai Filler dalam Campuran LATASTOS*, in *Department of Civil Engineering*. 2004, Universitas Atma Jaya Yogyakarta: Yogyakarta, Indonesia.

[13] Intara, I.W., Salain, I. M. A. K., & Wiryasa, N. M. A., *Penggunaan Serbuk Batu Tabas Sebagai Pengganti Sebagian Semen Dalam Pembuatan Beton.* Jurnal Spektran, 2013. 1(1): p. 1-7.

[14] Salain, I.M.A.K., Ciawi, Y., Nadiasa, M., Sutapa, A. A. G., & Dewi, N. P. T. K. *Penggunaan Limbah Batu Tabas Sebagai Agregat Halus dalam Campuran Beton*. in *Seminar Nasional Sains Dan Teknologi (Senastek) IV*. 2017. Badung.

[15] International, A., *Standard Specification for Concrete Aggregates*, in *C33/C33M-18*. 2018, ASTM International: West Conshohocken, PA.

[16] Nasional, B.S., *Metode Pengujian Kadar Agregat*, in *SNI 03-1971-1990*. 1990, Badan Standardisasi Nasional: Indonesia.

[17] Nasional, B.S., *pemeriksaan kadar lumpur pada agregat halus*, in *SNI S-04-1989-F*. 1989, Badan Standardisasi Nasional: Indonesia.

[18] International, A., *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*, in *C128-15*. 2015, ASTM International: West Conshohocken, PA.

[19] International, A., *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate*, in *C127-15*. 2015, ASTM International: West Conshohocken, PA.

[20] Nasional, B.S., *Tata cara pembuatan rencana campuran beton normal.*, in *SNI 03-2834-2000*. 2000, Badan Standardisasi Nasional: Indonesia.

[21] International, A., *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*, in *C192/C192M-19*. 2019, ASTM International: West Conshohocken, PA.

[22] Nasional, B.S., *Cara uji kuat tekan beton dengan benda uji silinder*, in *SNI 03-1974*. 2011, Badan Standardisasi Nasional: Indonesia.

[23] International, A., *Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*, in *C138/C138M-17a*. 2017, ASTM International: West Conshohocken, PA.

[24] Pane, F.P., H. Tanudjaja, and R.S. Windah, *Pengujian Kuat Tarik Lentur Beton Dengan Variasi Kuat Tekan Beton.* Jurnal Sipil Statik, 2015. 3(5): p. 313-321.

I Wayan Gde Erick Triswandana is the first author who completed undergraduate education in civil engineering in 2014 and achieved master degree in civil engineering specifically on construction management in 2018 both on Udayana University, Indonesia. The author also worked at the construction sector since 2013 and served as a construction manager at a local construction company before becoming a lecturer in late 2018 at warmadewa university and appointed as a Secretary of Civil Engineering Undergraduate Program of Warmadewa University from 2020 until 2024. The author is also a member of some professional association and serves as a board among others: Vice Representative of Indonesian Safety Experts Association Bali Chapter (A2K4 Indonesia Cabang Bali) around year of 2016-2020, Head of Organisation and Membership Department on Indonesian National Construction Executor Association Denpasar Branch (BPC. GAPENSI Denpasar) from 2019 until 2024, Head of Organisation and Training Department of Indonesian Construction Management Expert Association Chapter Bali (HAMKI Bali) from 2020 until 2025. The current research interest from author is green construction which cover green construction management, construction waste management, and alternative construction materials. There are several scientific conferences that the author has participated in regularly such as National Conference of Civil Engineering in Indonesia that called KoNTekS which is held annualy, actively participated on AASEC (Annual Applied Science and Engineering Conference) since 2019. So far, author have released 6 papers on the topics of construction safety, collaborative risk management, value engineering and green construction.

Putu Aryastana is the second author who completed undergraduate education in civil engineering in 2004 on Udayana University, Indonesia and achieved master degree in civil engineering specifically on remote sensing in 2012 on Yamaguchi University, Japan, and currently undergoing a doctoral program on National Taiwan University. Author also qualify for a Indonesian Ministry of High Education Research on year 2019. The author also has published a book chapter entitled Geospatial Technology for Water Resources Application, Section III, Chapter 9: Validation of Hourly GSMAP dan Ground Base Estimate of Precipitation for Flood Monitoring in Kumamoto, Japan in year 2016.