Civil Engineering and Architecture 12(2): 1180-1189, 2024 http://www.hrpub.org
DOI: 10.13189/cea.2024.120236

Lava Stone Waste Extract as a Substitute for Cement in the Mixture Concrete to Maintain Environmental Sustainability

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Received August 16, 2023; Revised November 27, 2023; Accepted January 8, 2024

Cite This Paper in the Following Citation Styles

(a): *[1] I Made Sastra Wibawa, Shinta Enggar Maharani , "Lava Stone Waste Extract as a Substitute for Cement in the Mixture Concrete to Maintain Environmental Sustainability," Civil Engineering and Architecture, Vol. 12, No. 2, pp. 1180 - 1189, 2024. DOI: 10.13189/cea.2024.120236.*

(b): *I Made Sastra Wibawa, Shinta Enggar Maharani (2024). Lava Stone Waste Extract as a Substitute for Cement in the Mixture Concrete to Maintain Environmental Sustainability. Civil Engineering and Architecture, 12(2), 1180 - 1189. DOI: 10.13189/cea.2024.120236.*

Abstract Concrete is used as a construction material causing the excavation of concrete mixture materials available in nature so that its existence becomes depleted. It takes effort to find substitute materials but still maintain the quality of concrete. Lava stone waste that disturbs environmental sustainability, can be used to replace cement in concrete. The purpose of this study is to determine the percentage of lava stone waste as a substitute for cement so that compressive strength is obtained in accordance with the plan and to determine its effect on environmental sustainability after lava stone waste is used as a concrete mixture. The study was conducted at the Laboratory of the Faculty of Engineering Universitas Mahasaraswati Denpasar, by making cylindrical test objects measuring 15 cm in diameter and 30 cm high. The replacement of lava waste is made in 6 categories P0, P1, P2, P3, P4, P5 with each category of 8 test objects, where compressive strength tests are carried out at the age of 28 Days and 90 Days with category P0 as a control without being replaced with lava waste. The results showed an increase in the compressive strength of concrete in the P1 and P2 categories, a decrease that still ranged from the compressive strength of the plan in the P3 category, and a decrease below the compressive strength of the plan in the P4 and P5 categories. The conclusion of this study is that lava stone waste extract can be used as a substitute for some cement.

Keywords Lava Stone Waste, Cement, Concrete Compressive Strength, Environmental Sustainability

1. Introduction

Developments in various sectors require reliable infrastructure development that can meet all needs and can answer all existing demands. The provision of land, modern equipment, qualified materials, sophisticated technology, and qualified human resources are needed as a support in an effort to realize reliable infrastructure in supporting developments in these various fields. Physical infrastructure development such as bridge construction, high-rise buildings, roads, dams, airports and other constructions are some examples of infrastructure that requires serious attention related to obstacles that are often faced. In some countries such as Indonesia, a serious problem that often becomes an obstacle in infrastructure development is the provision of materials derived from nature because their availability is running low. Construction that is often used in infrastructure development is concrete construction, the main material for making it is a mixture of coarse aggregate (coral / split), fine aggregate (sand), cement, and water, and if needed added additives (additional materials). Cement as a binder in concrete mixtures is mainly obtained from the processing of several minerals obtained from nature. The availability of the main material forming cement is increasingly depleted in nature so efforts are needed to find other materials as substitutes both in whole and partially.

In general, the price of cement is regulated by the local benchmark price by the government, but due to increasing demand and increasing cement production costs, the price has increased as well. This incident directly affects the cost of infrastructure development in general, therefore efforts to find alternatives as an innovative thinking effort are needed. In an effort to find alternative materials as a substitute for cement, the basic properties of cement must be known first, or the material used as a substitute should have the same properties as a binder. Cement as a hydraulic binder, that is, cement functions if it has been mixed with water, is a material that contains a lot of silicates, therefore substitutes should be sought that have the same or close properties. Mountain lava stone which is widely used as a substitute for rock, red brick, *Palimanan* stone as Balinese style ornament, when processed causes a lot of residues in the form of small fragments so that it becomes construction waste that is often disturbing. Lava stones from volcanic eruptions are widely used as material for making Balinese style ornaments and also as material for making temples [1]. Lava stones in the form of chunks are taken in the quarry and then taken to the processing site then cut into small pieces whose size (dimensions) are adjusted to needs, processed stones that are mostly flat in shape are usually used as ornaments which are exposed and have a fairly high artistic value. When chunks of stone are cut into flat stones according to the desired size, this is what causes processed residues in the form of small chips or sand which then become waste if left scattered very disturbing and can cause environmental pollution. Soil contaminated by lava processed waste is disturbed fertility and can no longer be planted because it is mixed with stone chips, there are difficulties when tillage. This mountain lava processed waste after testing also contains silicates in accordance with those contained in the cement content. In order to participate in maintaining a sustainable environment, and efforts to find alternative materials for concrete mixtures, lava processed waste is then crushed (extracted) into rock ash and then used as a substitute for some cement in the concrete mixture.

Based on the description of the background of the problem above, it is very necessary to conduct a study on the scale of laboratory research on the use of mountain lava processed waste as a substitute for some cement in the concrete mixture. In this case, it is closely related to obtaining qualified compressive strength, efforts to preserve the environment, and efforts to find alternative materials or renewable materials for concrete mixtures.

1.1. Problem Statement

Based on the background of the problem described above, the formulation of the problem is as follows:

1) What is the percentage of replacing cement with lava stone waste powder in order to obtain the most optimal concrete compressive strength in accordance with the planned compressive strength?
2) How much influence does it have on environmental sustainability after lava processed waste is used as a substitute for cement in concrete mixture?

1.2. Research Purposes

The objectives of this study are as follows:

1) Knowing the right percentage of cement replacement with lava stone waste so that it is in accordance with the compressive strength of the concrete plan.
2) Knowing the magnitude of the influence of environmental sustainability on the use of lava stone waste as an alternative material in concrete mixtures.

2. Materials and Methods

2.1. Lava Rock Waste

Volcanic eruptions are often referred to as lava rock, then used as a result of mining some Karangasem people, especially those in Kubu District and Bebandem District [1]. The lava of the volcanic eruption after gradually cooling and even freezing through natural processes finally becomes hard black rock that has a unique and strong texture, even the fibers have ornaments that have high aesthetic value so it is very well used as a material for making Bali style ornaments. The community conducts mining and processing of lava through a very simple process, so the results are also not so encouraging, and many stone fragments are wasted. After the discovery of processing technology, namely cutting lava using a cutting machine, the craft of lava processing is increasingly in demand by the community and only a few stone chips are wasted. Processed products are getting better both in the form of tides and types of preparations that have the potential for community handicrafts such as material for making sculptures. Processed lava stones formed according to certain sizes are usually used for making temples, walls, *kori agung* (fences and gates from the entrance to the yard of a traditional building in Bali), and others. The shape and size of lava cutting depends on public orders or commonly used orders. Lava stones around Strait District, Karangasem, Bali, because of the large number of lava rocks so there is an opportunity to choose raw materials used as lava stones to be processed or formed. Starting with choosing basic materials, cut according to size or according to existing orders, the rest is in the form of flakes and stone ash which is then used as lava processed waste. If this waste is left scattered and mixed with plantation or agricultural land, it can damage the performance of the soil as fertile land for farmers. This lava processing activity is large enough to absorb labor and can provide work so as to lift the standard of living of the local village community [1].

Lava logs have been sent to all districts in Bali to be carried out cutting according to needs. While lava stones processed around the mining site have also been sent to remote areas of Bali and outside the region, even abroad such as: Australia, America, the Netherlands, and Belgium.

The processing of lava rock, both at the mining site and at the cutting and processing plant, certainly causes small fragments and rock ash, this is what we hereinafter refer to as waste. Rejected lava rock and waste are often only disposed of which are eventually used as landfill material, but some are left scattered so that they can disturb the condition of the original land, especially those used as plantation land. The most detrimental condition is if this waste is allowed to mount then in the rainy season it is washed into ditches or sewers which can eventually clog the flow of water and reduce the performance of the channel. The use of lava stone waste as a partial substitute for cement because lava rock forming compounds are very similar to those contained in Portland Cement such as: fly ash (The finest grains from the process of breaking rocks using a stone crusher), silica fume, and slag. The content of chemical compounds in lava rocks is: Al_2O_3, SiO_2, TiO_2, K_2O, MnO_2, MgO, and CaO [2]. The similarity of chemical compounds is what underlies that lava stone waste can replace the function of cement in the concrete mixture, but as initial testing is carried out partially.

2.2. Cement

As a binder in concrete, cement is the main material and in terms of the highest price when viewed in terms of the same volume. In terms of the manufacturing process, it does require high technology in terms of equipment, material preparation, and resource capabilities as users of the technology. In Indonesia there are two standards governing cement, namely the Indonesian National Standard (SNI) 15-2049-2004, which regulates Portland Cement, and SNI 15-0302-2004, concerning Portland Pozzolan Cement. The process of making cement that produces clinker is known that two-thirds of its constituent compounds consist of: calcium silicate, aluminum and magnesium oxide with a small part in the form of gypsum compounds, potassium oxide and sodium oxide. The chemical components of cement can be seen in Table 1.

Table 1. Cement Components

Mineral	Formula	Notation
Tricalcium Silicate	$3CaO.SiO_2$	C3S
Dicalcium silicate	$2CaO.SiO_2$	C2S
Tricalcium Aluminate	$3CaO.Al_2O_3$	C3A
Tetra Calcium Alumino-Ferrite	$4CaO.Al_2O_3.\ Fe_2O_3$	C4AF

Source: T. S., Umesha [3]

2.3. Aggregate

The use of aggregate in concrete mixture, both coarse aggregate and fine aggregate in this study is adjusted to the applicable standards in Indonesia. In concrete mixtures usually aggregate occupies the most composition. So that the quality of the aggregate greatly affects the quality of the concrete itself. Generally, concrete forming aggregates range from 65% to 85%, and greatly contribute to the mechanical, thermal, and physical performance of concrete [4]. Quality testing and aggregate test methods are guided by the Indonesian National Standard SNI 03-1750-1990[5]. The physical properties of aggregate are the shape of its surface texture, affecting the workability of concrete and the adhesion between aggregate and cement paste. Aggregate with a rough surface is better used in concrete mixtures when compared to aggregates with slippery surfaces, this is because aggregates with rough textures can increase adhesion between aggregate and cement paste. Inspection carried out on coarse aggregate and fine aggregate include:

1) Gradation (Sieve Analysis)
2) Specific gravity and water absorption.
3) Unit Weight
4) Mud Content
5) Kadar air (Surface Moisture Content)

2.4. Water

Water in concrete mixture is a mixing agent that facilitates other mixed ingredients. Water is also a very important basic material in the formation of concrete, in concrete mixtures water serves to allow chemical reactions that cause binding and hardening, besides that water also functions as a diluent in concrete mixtures. Water and cement will react into a cement paste that will bind fine aggregate and coarse aggregate into one whole. The amount of aggregate in the concrete mixture will affect the ease of concrete work, concrete strength, and shrinkage. If the water used in the mortar volume is small, the concrete will be difficult to work, while if the water used is too much, the shrinkage that occurs will be greater after the hardening process. To get good concrete quality, the use of water in the concrete mixture must be right. In general, water requirements must be in accordance with SNI 7974-2013, which does not contain oil, acids, alkaline salts, and organic matter that interfere with concrete performance [6].

2.5. Properties of Concrete

Concrete has strong properties to accept compressive forces, therefore constructors really trust concrete if the planned structure carries compressive loads. On the other hand, concrete is less able to accept tensile forces, so to overcome this, steel is used as reinforcement to bear the tensile forces that occur. In addition to the compressive and tensile properties, concrete also has durable and waterproof properties that can be reliable, and concrete construction requires very minimal maintenance costs.). The strength of concrete is influenced by several factors such as the water-cement ratio and its compaction rate [7]. Usually in the implementation of concrete this is a serious concern for supervisors. Obtaining good concrete quality has paid attention to the selection of materials, mixing, casting, compaction, finishing, and treatment of young concrete. The strength of concrete is reflected in the quality written with the appendage "K", meaning the characteristic compressive strength. This strength is obtained from the results of the examination of test objects in the form of cylinders or cubes that are tested with varying ages when tested, the possibility of compressive strength less than the set is limited to 5%. The compressive strength of concrete is the amount of load per unit area of the compressive field that can be received by the specimen until the specimen is destroyed [8].

2.6. Standard Deviation

Standard Deviation is obtained from the results of examination of several test objects carried out in the laboratory by testing the compressive strength of concrete. From several variations in shape, age when tested obtained a result whose value is spread but still around the average value. The size of this spread value is called Standard Deviation (S). Wangsadinata [8] states that the occurrence of the spread of the average value when testing the compressive strength of concrete depends on the level of perfection of the stage of concrete work implementation and vice versa the smaller the spread value against the average value, the greater the level of perfection of the level of concrete work implementation and vice versa the smaller the spread value against the average value, the greater the level of perfection of the level of concrete work.

2.7. Compressive Strength Characteristics of Concrete

What is meant by Characteristic Compressive Strength of Concrete is the compressive strength value of concrete from the results of examining test objects in the form of cubes or cylinders. The possibility of compressive strength less than the stipulated is limited to 5% [8]. The compressive strength of concrete is the amount of the wide unity load that can be received by the specimen until the specimen is destroyed. Wangsadinata [8] state that in calculating the compressive strength of concrete the formulas used follows the Indonesian Concrete Regulations [8] (PBI 1971 – NI-2), as follows:

$$\sigma b = \frac{P}{A \times fu \times fb} \quad (1)$$

$$\sigma bm = \frac{\sum_{i}^{n} \sigma b}{n} \quad (2)$$

$$S = \frac{\sqrt{\sum(\sigma b - \sigma bm)^2}}{n-1} \quad (3)$$

$$\sigma bk = \sigma bm - 1{,}64.S \quad (4)$$

Description:

1) σb = Concrete tension (kg/cm^2)
2) P = Maximum pressure load (kg)
3) A = Compressive field area of the specimen (cm^2)
4) fu = Age factor (PBI 1971; 34)
5) fb = Form factor (PBI 1971, cube 15x15x15cm)
6) σbm = Average concrete stress (lg/cm^2)
7) n = Number of specimens
8) S = Standard Deviasi
9) σbk = Characteristic Concrete Tension (kg/cm^2)

(Source; Wangsadinata [8]).

The magnitude of the concrete age factor when testing can be seen in Table 2.

Table 2. Comparison of Compressive Strength of Concrete at various ages

Age of concrete (days)	3	7	14	21	28	90	365
Ordinary Portland cement	0,40	0,65	0,88	0,95	1,00	1,20	1,35
High-strength Portland cement	0,55	0,75	0,90	0,90	1,00	1,15	1,20

Source: Indonesian National Standard [6]

Meanwhile, the shape coefficient of the test object used can be seen in Table 3. Table 4 describes the coefficient of the number of specimens used in concrete testing in one period of calculation of compressive strength characteristics of concrete.

Table 3. Comparison of Compressive Strength of Concrete on various shapes of test specimens

No	Test Specimen Shape	Compressive Strength Comparison
1	Cube 15x15x15 cm	1,0
2	Cube 20x20x20 cm	0,95
3	Cylinder Ø 15-30 cm	0,83

Source: Wangsadinata [8]

Table 4. The correlation price of the standard deviation value corresponds to the number of test objects

N = Number of specimens	Sr achieved (K1)	Sr not reached (K2)
8	1,92	2,38
9	1,87	2,24
10	1,83	2,12
11	1,80	2,04
12	1,78	1,96
13	1,75	1,90
14	1,73	1,83
15	1,71	1,80
16	1,69	1,77
17	1,68	1,73
18	1,65	1,69
19	1,65	1,60
20	1,64	1,64

Source: Subakti [9]

2.8. Sustainable Environment

Infrastructure development should continue to pay attention and participate in preserving the environment, starting from upstream material extraction and processing, to building construction, as well as downstream development, namely its environmentally friendly use. Because all infrastructure development is under the organization of Civil Engineering, the infrastructure created can certainly also regulate the guarantee of environmental sustainability. Intara [10] states, that if waste is allowed to enter the channel stream will be able to close or reduce the effective wet cross-sectional area of the channel, and this can interfere with channel performance and if left continuously will be able to cause wider environmental damage. The limited availability of materials for infrastructure development while the demands for infrastructure provision are very high and the development is rapid, it is necessary to find alternative materials so as not to always damage nature, the strength of the structure remains reliable, but does not damage the environment. Local wisdom is an outlook on life and knowledge as well as various life strategies in the form of activities carried out by local communities in responding to various problems in meeting their needs. The existence of several local wisdom in Bali such as: *Tri Hita Karana, Tri Angga, Hulu-Teben,* and others can be a reference to participate in promoting the environment. Government policy to limit the height of buildings is also an effort to preserve the environment as stated in Regional Regulation No. 16 of 2009 [11].

Making cement is predicted to contribute to global warming because there are factory activities that cause exhaust emissions and, in the process, cause a lot of flying dust. Associated with human activities, one of the activities responsible for CO_2 exhaust emissions is the cement industry [12]. Because global warming is an environmental problem, it is considered to be the most dangerous problem that has threatened the preservation of nature on this earth [13]. Exhaust emissions in the form of Carbon Dioxide (CO_2) are the main cause of global warming which greatly affects the greenhouse effect [14]. With the increase in infrastructure development, it is certain that the need for cement also increases. Therefore, cement production must also be increased to be able to answer the need for the use of cement. As a result of the increase in cement production, the increase in CO_2 emissions is also expected to increase [15].

2.9. Material Inspection and Concrete Testing

Wangsadinata [8] states that materials used as concrete mixtures must meet the requirements stipulated in regulations on concrete. To find out whether the concrete mixture material has met the requirements or not, a material examination is carried out to find out the basic properties of the material used. Materials used for concrete mixtures such as coarse aggregate, fine aggregate (sand), cement, and sand are tested in the laboratory for their basic properties. Coarse aggregate and fine aggregate are tested on specific gravity, unit weight, moisture content, gradation, and sludge content. Cement in general is rarely subjected to special testing because according to experience there has never been a forgery of cement, but a visual examination must be carried out on the cement grains whether they clump or not. The use of cement in concrete mixture is in accordance with the specifications contained in the Indonesian National Standard (SNI) 15-0302-2004, which regulates cement [16]. However, testing of cement is usually carried out on the unit weight only, this is done to ensure that there is no leaking cement packaging so that it is not contaminated by water or outside air.

In this study, the inspection of cement using lava stone as a substitute was carried out on the fineness of the grains, because the processed lava stone waste was first crushed until the grains were very fine and close to the cement grains on the market. The collection of processed lava stones was carried out at several companies that process lava stones from the eruption of Mount Agung in Bali, Indonesia. Previously, it was confirmed to the company owner that the lava stone they bought was from the vomit of Mount Agung whose quarry was located in Selat village, Kubu District, Karangasem Regency, Bali Province, Indonesia. Crushing uses a special tool in the form of a stone crusher that has been tuned to obtain very fine grains. However, for use as a substitute for cement in this study, a save analysis test was still carried out so that grains close to cement grains were obtained. The use of cement using lava processed powder is carried out with several categories, namely: replacement of 0%, 5%, 10%, 15%, 20%, and 25% of the weight of cement.

Furthermore, calculations are carried out on the mix design to find out the mixture formula needed to achieve compressive strength of the plan. As the last step, procedures are carried out in the laboratory starting with mixing concrete, slump test, making test specimens, and testing the compressive strength of concrete specimens. The concrete mixing steps follow the applicable standards in Indonesia, namely the Procedure for Making a Normal Concrete Mix Plan [17].

2.10. Environmental Sustainability

Analysis of environmental sustainability affected by pollution by lava waste, and after using lava stone waste as a concrete mixture, was carried out qualitatively based on direct observations in the field and interviews with related stake holders. A structured interview is conducted with several questions that have been prepared in advance. The stake holders interviewed were those whose domiciles were around the location of the lava processing company, so those who really felt affected by the lava waste discharge. The questions asked were about: the stake holder's understanding of lava stone, lava waste, and his opinion on the use of waste as a concrete mixture and its impact on environmental sustainability.

2.11. Concrete Testing

In accordance with the results of the inspection of concrete mixture materials, it can be presented that all the requirements needed to meet the requirements are in accordance with those contained in the Indonesian Concrete Regulations as follows:

2.11.1. Fine Aggregate (Sand)

From the results of sand examination in the laboratory, sand data are obtained as follows:

1) Specific gravity of sand in SSD state = 2.315 Kg/Lt and water absorption = 5.90%.
2) Gradation of fine aggregate (sand) with fineness modulus (Fm) = 2.74. This value qualifies according to ASTM (American Standard for Testing Materials) that the fineness modulus for sand ranges from 1.5 - 3.8.
3) Mud Content = 1.25%. This means that the sand is qualified for concrete mix as required in PBI. 71 that fine aggregate for concrete mixture should not contain sludge more than 5% to dry weight.
4) Unit weight (Wight Unit) of sand = 1.40 Kg/Lt.
5) Sand surface moisture = 9.41%.

2.11.2. Coarse Aggregate

Based on preliminary tests and experiments in the laboratory, the following aggregate data was obtained:

1) From the results of the coral gradation test (sieve analysis), obtained the fineness modulus (Fm) = 7.06. This value meets the requirements in ASTM that is the fineness modulus for coarse aggregates ranges from 6.0-7.1.
2) Specific gravity of coral in SSD = 2.45 Gram / Cc and water absorption = 1.92%.
3) Unit weight (wight) of coral from examination obtained = 1.516 Gr/Lt.
4) Coral mud content from the inspection results obtained = 0.87% this value shows that the coral has met the requirements for concrete mixture, because coarse aggregate for concrete mixture has been required in PBI 71 is not to contain more than 1% mud against dry weight. The moisture content (surface moisture) of this coral from the results of examination in the laboratory was 9.38%.

Gradation testing is carried out to ensure that the grain arrangement requirements of the aggregate used in the concrete mixture are in accordance with the regulations governing material requirements.

2.11.3. Cement Testing

Cement is a material that functions as a binder in concrete, often called a hydraulic binder because cement will function after mixing water. The cement hardens and binds the grains of coarse aggregate and fine aggregate so that it becomes an artificial stone. Testing of the unit weight of Portland Cement Type I obtained its unit weight = 1,224 Kg / M3, while visual observation confirmed that there were no lumps, in this case it was categorized that cement did not clump, thus the cement test results could be used as a concrete mixture.

Table 5. Sieve Analysis Results of Portland Cement Type I

No	Sieve Size (mm)	Restrained on a Sieve (Gr)	Restrained Cumulative (Gr)	% Cumulative Restrained
1	0,60	0,00	0,00	0,00
2	0,30 (No. 100)	0,00	0,00	0,00
3	0,15 (No. 200)	4,29	4,29	8,58
Pan		45,71	50,00	100,00
Sum		50,00		

Table 6. Results of Sieve Analysis of replacement cement (lava waste)

No	Sieve Size (mm)	Restrained on a Sieve (Gr)	Restrained Cumulative (Gr)	% Cumulative Restrained
1	0,60	0,00	0,00	0,00
2	0,30 (No. 100)	0,00	0,00	0,00
3	0,15 (No. 200)	4,40	4,40	8,80
Pan		45,6	50,00	100,00
Sum		50,00		

The replacement cement derived from lava processed waste is tested on the arrangement of the grains so that there is a similarity of the replaced cement grains with the arrangement of cement grains as a replacement. The grain arrangement of each cement is presented in Table 5. The grain arrangement of the extracted lava waste is shown in Table 6.

3. Results and Discussion

3.1. Concrete Compressive Strength Test Results

A test was carried out on the compressive strength of concrete to determine the compressive strength of each test object according to the criteria made. Each category is made of cylindrical test specimens, each of which is 8 pcs [14]. The results that can be displayed are as follows:

To determine the compressive strength of concrete from each test object for each experiment, a concrete compressive strength test was carried out using a concrete compressive strength testing machine with a capacity of 500 tons. This test was carried out on five experiments / categories consisting of 8 test objects [9], namely:

1) Category I; As a control, the test was carried out on a concrete mixture that was not carried out adding lava stone processed waste (0%).
2) Category II: is a concrete mixture that has been replaced by cement with 5% lava processed waste.
3) Category III; is a concrete mixture that has been replaced with 10% lava processed waste.
4) Category IV; is a concrete mixture that has been replaced with 15% lava processed waste.
5) Category VI; is a concrete mixture that has been replaced by cement with 20% lava processed waste.
6) Category VII; is a concrete mixture that has been replaced by cement with 25% lava processed waste.

The test results of concrete cylinder test objects for each experiment / category are tabled in Table 7.

The complete results of the Concrete Stress test that occurred can be seen in Table 8.

Table 7. Test Results of Concrete Cylinder Test Objects Ø15 x 30 centimeters, age 28 days (0%)

No	Age of the specimen	Max Load (Kg)	Concrete Stress ($\sigma^1 b$) (Kg/cm^2)	$\sigma^1 b$ - $\sigma^1 bm$	($\sigma^1 b$ - $\sigma^1 bm$)^2
1	28 days	42.000	286,50	-1,92	3,68
2	28 days	42.250	288,20	-0,21	0,05
3	28 days	41.500	283,09	-5,33	28,40
4	28 days	42.500	286,50	-1,92	3,68
5	28 days	41.500	283,09	-5,33	28,40
6	28 days	43.000	293,32	4,90	24,04
7	28 days	44.000	300,14	11,72	137,46
8	28 days	42.000	286,50	1,92	3,68
			2.307,31		299,38

Fu: 28 days = 1.0

fb: Cylinder Ø 15 x 30 cm = 0.83

$$\sigma^1 b = \frac{P}{A\ x\ fu\ x\ fb}$$

$$\sigma^1 bm = \frac{\sum_1^n \sigma^1 b}{n} = \frac{2{,}307{,}31}{8} = 288.41 \text{ kg/cm}^2$$

$$S = \sqrt{\frac{\sum_1^n (\sigma^1 b - \sigma^1 bm)^2}{N-1}} = \sqrt{\frac{229{,}38}{7}} = 5{,}72 \text{ kg/cm}^2$$

$\sigma^1 bk = \sigma^1 bm$ - k x S

= 288,41 - 1,92 x 5,72

= 227.42 Kg/Cm. (Equivalent to 22.74 MPa)

Table 8. Concrete Stress test result

No	Cement Replacement Treatment (%)	Concrete Stress 28 Days (MPa)	Concrete Stress 90 Days (MPa)
1	Category I; (0 %)	22,74	23,50
2	Category II; (5%)	22,95	23,25
3	Category III; (10 %)	22,80	22,85
4	Category IV; (1.5%)	22,55	22,65
5	Category V; (20%)	22,00	22,10
6	Category VI; (25%)	21,80	21,95

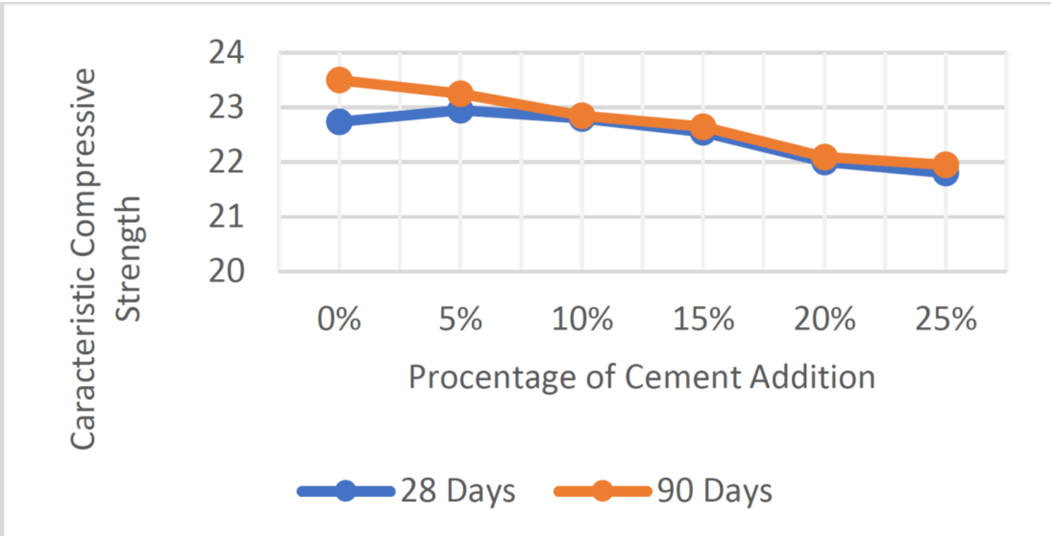

Figure 1. Compression Strength Chart Characteristics of Concrete

Furthermore, the results of the Compressive Strength Characteristics of Concrete test are graphed as shown in Figure 1.

Based on the results of laboratory tests and analysis of the results carried out, the compressive strength of concrete varies, by replacing cement using lava processed waste in several categories, it was found that the replacement of 5% to 10% of the compressive strength increased. After the replacement of 15% the strength decreases much even out of the compressive strength of the plan. Similar studies conducted by adding or replacing some aggregates and cement also showed similar results, *Tabas* stone (a black stone that comes from frozen volcanic lava) is mashed later as a substitute for cement, where the result is that *Tabas* Stone powder can be considered as a component of composite Portland cement [10]. Another study was conducted on quality and environmentally friendly concrete, resulting in the addition of palm kernel shell ash as a partial substitute for cement as much as 6% increasing the compressive strength of concrete, and decreasing it after the addition of 9% to the dry weight of cement [18]. The soil cement is a good alternative as a construction material in rural houses in the district of Pilcomayo, demonstrating in this study that it meets the requirements for each type of application, a floor concrete base requires according to the Peruvian Technical Standard, a minimum f'c of 100 kg /cm^2, in this study a f'c of 129.42 kg/cm^2 was obtained with a percentage of cement of 21% at 28 days of curing [19].

3.2. Environmental Sustainability Analysis

For the effect of using lava stone processed waste after being used as a mixture in concrete, in this case, a qualitative analysis was carried out by conducting interviews with a number of related stakeholders who were confirmed to be exposed to the waste. Based on observations in the field, lava stone waste that is discarded and left scattered eventually merges with the soil in yards, gardens, and even farmers' fields. This incident certainly has a major effect on soil conditions, especially the fertility value, especially on land intended for plantations and agriculture. Based on the results of interviews with several stakeholders on the existence of lava stone waste are as follows:

1) The question of: their understanding of lava stone, they answered that most of them know about lava stone with its various uses and qualities highlighted especially for Balinese style building materials.
2) His understanding of lava waste is also quite understanding, especially related to the processing process to the presence of waste and pollution by dust

at the time of processing. It is fully understood to greatly affect the health of the environment, therefore this must be addressed.

3) The use of lava stone waste into concrete mixture material is considered very appropriate, because it can process waste into more useful materials, and more importantly is the reduction of lava stone waste that can pollute the environment and disrupt the fertility of agricultural land.

Realizing environmentally friendly concrete is very desirable in this case, namely by finding renewable materials from concrete mixtures, stating that the development of environmentally friendly concrete is for sustainable development without damaging natural resources [20]. Using cement in concrete mixes should be reduced so that cement production can be reduced. The cement production process causes CO_2 emissions. CO_2 is one of the dangerous greenhouse gases which causeglobal warming in the environment [21].

Lava rock waste consisting of small, medium, rather large diameter hard rock grains, even in the form of dust, is very disturbing to environmental and soil conditions. The sharp granules, if stepped on by bare feet, cause pain in the soles of the feet. Based on the results of research that has been carried out, lava rock waste extract can be used as a partial replacement for cement in concrete mixes, it can also increase the quality of concrete and remain in certain categories. This is very profitable from an economic perspective and can save material costs by up to 15%, because the materials used are free waste, which is leftover processed lava rock from the factory where it is processed. The addition of 15% lava rock waste extract as a cement substitute produces concrete compressive strength whose range is still within the design compressive strength limit.

4. Conclusions and Suggestions

4.1. Conclusions

Based on the results of research on the compressive strength of concrete using cement replacement using lava processed waste, several conclusions can be drawn as follows:

1) After carrying out the compressive strength test of concrete cylinders and analysis of the compressive strength of concrete from 8 test objects, where in each experiment a cylindrical test object was made by replacing part of the cement using processed lava rock waste, with various mixed categories the compressive strength of concrete was obtained at the age of the 28 test and 90 days: increasing at 5% to 10% replacement. The decrease in the compressive strength of the concrete occurred when the 15% coarse aggregate was replaced, but it was still around the quality of the design concrete. While at the replacement of 20 and 25% the decrease in compressive strength is below the design compressive strength.
2) With the efforts to use lava processed waste as a concrete mixture, renewable materials are obtained as concrete materials, and environmental sustainability efforts can be achieved because there is no more lava stone waste that pollutes the environment.

4.2. Suggestions

Suggestions that can be put forward in connection with this study are as follows:

1) In this study, it is still limited to adding six categories, so it is necessary to add treatments to be more varied so that the results are more accurate.
2) It is necessary to conduct direct research on the project to obtain more accurate results.
3) The use of waste as a substitute for concrete is not limited to waste processed by lava stone, it can be developed on other waste, so that efforts to find renewable materials and preserve the environment can be achieved

REFERENCES

[1] G. Arsa, "Tabas Stone," 2012. http://dokumen.tips/documents/batu-tabas.html# (accessed Jan. 21, 2016).

[2] E. J. P. M. Service, "Building Potential," 2008. www.pertambangan-jatim (accessed Jan. 17, 2013).

[3] and P. V. S. T. S. Umesha, S. V. Dinesh, "Control of dispersivity of soil using lime and cement," *Int. J. Geol.*, vol. 3, pp. 8–16, 2009, [Online]. Available: https://www.researchgate.net/publication/288958349.

[4] J. J., Sale, S., Emmanuel, and I., "Use of Waste Plastics in Cement Based Composite for Ligthweight Concrete Production," *Int. J. Res. Eng. Technol.*, vol. 2, 2017.

[5] N. S. Agency, "Indonesian National Standard; Quality and Test Method of Concrete Aggregate. SNI 03-1750-1990," Jakarta, 1990.

[6] N. S. Agency, "Indonesian National Standard; Specification of Mixing Water Used in the Production of Hydraulic Cement Concrete", SNI 7974-2013," Jakarta, 2013.

[7] L. J. Murdock, *Concrete Materials and Practices*. Surabaya: Erlangga, 1986.

[8] W. Wangsadinata, *Directorate of Building Problem Investigation, Directorate General of Cipta Karya, Indonesian Concrete Regulation 1971 N.I.-2*. Malang: Departemen Pekerjaan Umum dan Tenaga Listrik, 1971.

[9] A. Subakti, *Concrete Technology in Practice*. Sirabaya: Jurusan Teknik Sipil. FTSP, ITS, Surabaya., 1994.

[10] W. N. M. A. Intara. I. W., Alit K., "The Use of Tabas Stone Powder as a Partial Substitute for Cement in Concrete

Making," *J. Spektran*, vol. 1, 2013, doi: DOI: https://doi.org/10.24843/SPEKTRAN.2013.v01.i01.p01.

[11] Bali Province Goverment, *Bali Provincial Regional Regulation No. 16 of 2009 on: Bali Provincial Spatial Plan 2009 – 2029*. Denpasar, 2009.

[12] H. Mikulčić, M. Vujanović, and N. Duić, "Reducing the CO_2 emissions in Croatian cement industry," *Appl. Energy*, vol. Vol. 101, pp. 41–48, 2013, doi: 10.1016/j.apenergy.2012.02.083.

[13] Z. Aksan and D. Celikler, "The Turkish Adaptation Study of Global Warning Quisttionnaire," *Procedia – Soc. Behav. Sci.*, vol. 31, pp. 681–684, 2012, doi: 10.1016/j.sbspro.2011.12.124.

[14] R. N. S. X. F. Zhang, S. Y. Zhang, Z. Y. Hu, G. Yu, C. H. Pei, "Identification of Connections Units With High GHG Emission for Low-Carbon Product Structure Design," *J. Clean Prod.*, vol. 27, pp. 118–125, 2012, doi: 10.1016/j.jclepro.2012.01.011.

[15] K. H. M. Mahasenan, *To Word A Sustainable Cement Industry-Substudy 8: Climate Change*. Geneva, 2002.

[16] National Standarization Agency, "National Standardization Agency, "Indonesian National Standard Semen Portland Pozzolan," Jakarta, 2004.

[17] N. S. Agency, "Indonesian National Standard; Procedures for Making Normal Concrete Mixture Plans. SNI 03-1750-1993," Jakarta, 1993.

[18] S. P. Simanjuntak, Johan Oberlyn; Saragih, Tiurma Elita; Lumbangaol, Partahi; Panjaitan, "Quality and Environmentally Friendly Concrete by Utilizing Palm Shell Ash Waste," *J. Darma Agung*, vol. 28, pp. 387–401, 2020, doi: http://dx.doi.org/10.46930/ojsuda.v28i3.803.

[19] N. I. V. Tolentino, E. O. G., Llihua, N. S. C., Rodriguez, I. L., Inga, A. J. V., Ninahuanca, L. E. E., Montoya, "Technical Analysis of Soil Cement as A Construction Material Applied in Rural Houses," Civil Engineering and Architecture. Vol. 10, No.7, pp. 3003–3014, 2022, doi: 10.13189/cea.2022.100716.

[20] J. O. Simanjuntak, T. E. Saragi, and B. T. Lumban Gaol, "BETON BERMUTU DAN RAMAH LINGKUNGAN DENGAN MEMANFAATKAN LIMBAH TONGKOL JAGUNG (Penelitian Laboratorium)," *J. Visi Eksakta*, vol. 1, no. 1, 2020, doi: 10.51622/eksakta.v1i1.53.

[21] M. R. Jawad, I. T., Taha, "Portland Cement Treated Soil: Evaluation and Conflict Results," Civil Engineering and Architecture, vol. 11, No.2, pp. 560–568, 2022, doi: 10.13189/cea.2023.110203.