

ENHANCEMENT OF MECHANICAL PROPERTIES AND CHARACTERIZATION OF CONCRETE WITH THE ADDITION OF SCORIA BASALT AS A FINE AGGREGATE SUBSTITUTE ACTING AS A FILLER

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Abstract

This research was conducted to determine the effect of adding basalt stone as a filler in sand in the manufacture of mortar. The basalt powder used is grain size of 100 mesh and 270 mesh, the concentration variations are 0% (standard) as a comparison without basalt, 5%, 10%, 15%, 20%, 25%, 30%, and 35% with the age of the test. 7, 14, and 21 days. The results of the analysis show that basalt can be used as a filler material in sand which has a SiO₂ compound of 48.463% which can increase the compressive strength of the mortar significantly. The highest compressive strength is found in 270 mesh of 7 Mpa, 10.2 Mpa, 13.4 Mpa. The highest density was found at 270 mesh at 1.841 g/cm³, 2 g/cm³, 2.013 g/cm³. The highest porosity is found in 270 mesh of 16.841%, 14.606%, 13.265%. The highest absorption was found in 270 mesh of 7.92%, 6.878%, 7.204%. The content of SiO₂ compounds in B100 5% mortar was 19.348%, followed by B100 30% by 26.701%, B270 5% by 20.895%, and B270 30% by 27.255%. The dominant crystalline phases were formed in mortar with a size of 100 mesh and 270 mesh, namely CASH, quartz and calcite phases.

Keywords: basalt, mortar, physical testing, mechanical testing, and characterization

INTRODUCTION

Concrete, as the most widely used construction material globally, serves as the primary structural element in a wide range of projects, from skyscrapers to large-scale infrastructure. Its compressive strength is considered a fundamental indicator of structural load-bearing capacity and safety aspects, as well as being an important reference for quality control throughout the project life cycle and disaster prevention efforts.[1][2][3][4]. Curing Duration and Improvement of Standard Mechanical Properties: Concrete typically reaches 50–70% of its compressive strength within 3 to 7 days, 85% by the 14th day, and 100% of its full design strength (reference value) by the 28th day under ideal moisture conditions.[5][6][7][8].

Aggregates occupy the largest proportion in concrete, namely around 60–75% of the total volume of concrete. Fine aggregates function as microscopic bridges filling critical geometric voids between larger coarse aggregates while interacting directly with the cement paste to form a dense matrix capable of supporting loads. When cement and water mix to form a cement paste, the larger surface area of sand allows it to bond tightly with the paste, thus playing a vital role in the concrete mix. On the one hand, sand functions as a filler that fills the gaps between coarse aggregates, making the aggregate composition denser. [9][10][11][12] Uncontrolled sand exploitation has triggered a severe environmental crisis, such as river ecosystem degradation, groundwater level decline, riverbank erosion, and the collapse of surrounding infrastructure. Therefore, the search for alternative, environmentally friendly local materials to partially replace sand in sustainable concrete is urgent.[13][14][15]

Basal scoria is a mafic igneous rock formed from the cooling of lava rich in gas fractions, resulting in physical characteristics in the form of a porous microstructure, rough surface, and angular particle geometry. Basal scoria has excellent chemical stability, a solid level of mechanical hardness, and intrinsic pozzolanic properties when ground to a microstructural size.[16][17][18]. The mechanism for improving the quality of the concrete matrix through the use of basal scoria *filler* relies on two main effects, namely physical effects and mechanical effects. Physically, the finer size of basal scoria particles than conventional sand works through a *particle packing effect*, namely infiltrating and

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filling micro gaps between aggregates and in the unfilled cement matrix. Scoria basalt is a porous volcanic rock that is rich in silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) compounds, fulfilling the main requirements as a pozzolanic material according to the ASTM C618 standard which can maximize the mechanical properties of concrete such as compressive strength, splitting *tensile strength*, and flexural *strength*. [19][20][21][22][23][24]

RESEARCH METHODS

Research Location

The research was conducted at the Materials Laboratory of the Civil Engineering Department of Sang Bumi Ruwa Jurai University, Bandar Lampung and the Mineral Technology Research Center Laboratory - BRIN for both aggregate physical properties testing and concrete compressive strength testing and material and concrete characterization.

Material

The material used to make concrete, namely fine aggregate, is taken from the area.

Gunung Sugi Village, Gunung Sugih District, Central Lampung. Scoria basalt stone was taken from Jabung Village, Jabung District, East Lampung Regency, which was reduced in size and sieved with a grain size of 100 and 325 meshes. Coarse aggregate was taken from Tanjungan Village, Katibung District, South Lampung, with a size of 10-20 mm. The cement used was from the market, *Portland Composite Cement* (PCC) type I, a product of PT. Semen Baturaja. The water used came from Langkapura District, Bandar Lampung, which is clean, colorless, and odorless

K-300 Quality Concrete Mix Design and Experimental Design According to SNI 03-2834-2000 and SNI 7656: 2012 The composition of raw materials for making K.300 quality concrete requires 413 kg of cement, 681 kg of fine aggregate, 1021 kg of coarse aggregate and 125 liters of water. Meanwhile, in this study, 3 samples of each composition will be made with an average weight per sample. 12.5 kg, resulting in a total weight of 37.5 kg. The design of the raw material composition for the research on making concrete with scoria basalt as a substitute for fine aggregate is shown in Table 1.

Test Object Manufacturing Process

The method for making test objects is as follows:

1. Prepare a 15 x 30 cm cylindrical mold, grease it with oil.
2. Put the concrete mixture into the mold in 3 layers. Each layer was pounded with an iron pounder 25 times.
3. Then tap it with a rubber hammer.
- on the outside of the mold with the aim of removing air bubbles in the mold.
4. Smooth the sides with a straightener, so that they are even and solid.
5. Once full, flatten and compact the top of the mold with a trowel, by pressing it down slightly.
6. The sample is left for 24 hours, then removed and soaked in water for 7, 14, 21 days.

Table 1. Design of Raw Material Composition for Making Concrete with a Total Weight of 37.5 kg

No	Raw Material Composition Design						Basalt stone substitution (%)
	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Basalt Rock (kg)	Water (lt)	Total Weight (kg)	
1	6.92	11.40	17.09	-	2.09	37.5	0
2	6.92	10.83	17.09	0.57	2.09	37.5	5
3	6.92	10.26	17.09	1.14	2.09	37.5	10
4	6.92	9.69	17.09	1.71	2.09	37.5	15
5	6.92	9.12	17.09	2.28	2.09	37.5	20
6	6.92	8.55	17.09	2.85	2.09	37.5	25
7	6.92	7.98	17.09	3.42	2.09	37.5	30
8	6.92	7.41	17.09	3.99	2.09	37.5	35

Testing of Physical Properties of Aggregate Materials

The physical properties of fine and coarse aggregates used must meet the specified requirements so that they can be used as concrete components. Aggregate physical testing is in accordance with the type of physical test and ASTM

number: Sieve Analysis (Gradation): ASTM C136.[25] to determine the distribution of fine grain size. Silt Content (Material Passing Sieve No. 200): ASTM C117.[26] to test the content of fines or clay. Specific Gravity and Water Absorption: ASTM C128.[27] to measure the bulk specific gravity, surface dry saturated specific gravity (SSD), and water absorption of fine aggregate. Water Content: ASTM C566.[28] to test the percentage of water content in the aggregate. Organic Matter Content: ASTM C40.[29] to check the content of organic matter in the sand. Wear/Weather Resistance: ASTM C88.[30] using sodium sulfate or magnesium sulfate solution. The results of aggregate physical properties testing are shown in Table 1.

Testing of Physical Properties of Concrete

The physical properties of concrete, namely physical tests of absorption (water absorption), porosity, and density of concrete are used to determine the quality, strength, and durability of concrete structures before or during use in construction. Testing is based on ASTM C642-21.[31]. The absorption, porosity, and density tests of concrete are tested and calculated based on the following equation:

$$Absorption = \frac{W_2 - W_1}{W_1} \times 100\% \quad (1)$$

$$Porositas = \frac{W_3 - W_2}{W_3 - W_1} \times 100\% \quad (2)$$

$$Densitas = \frac{W_1}{W_3 - W_2} \times \rho_{air} \quad (3)$$

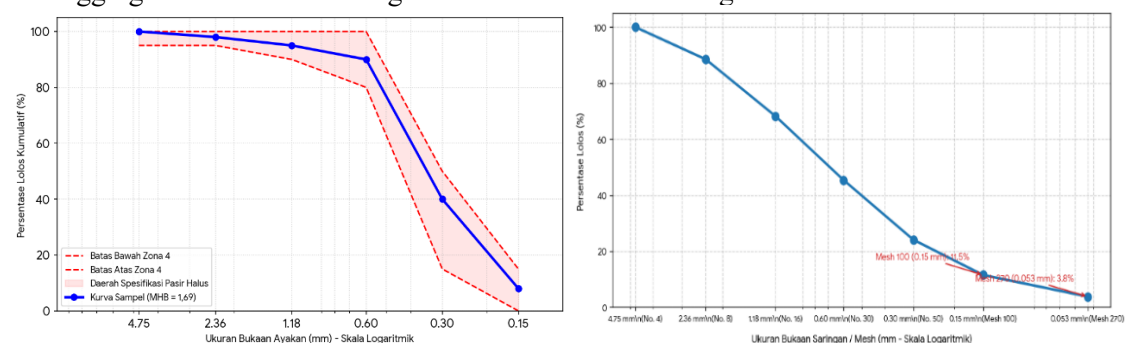
Concrete Characterization

X-Ray Fluorescence (XRF) characterization [32], *X-Ray Diffraction* (XRD)[33], and *Scanning Electron Microscope* (SEM)[34] in concrete are used to analyze the chemical content, mineralogical phase, and microstructure of the material in depth in the raw materials and concrete. XRF characterization is necessary to determine whether the chemical compounds derived from the mixture of fine aggregate, scoria basalt, and cement are formed and react perfectly in the concrete. XRD characterization is carried out to determine the type of mineral resulting from cement hydration (such as the formation of calcium silicate hydrate (CSH) or calcium hydroxide/portlandite (CaOH)), to monitor the level of pozzolanic reaction of the added material. Characterization is based on ASTM

RESULTS AND DISCUSSION

Fine Aggregate Grain Size Distribution Test Results

The results of the fine aggregate and scoria basalt gradation test were conducted to determine the distribution or distribution of sand grain sizes. This test also determines the particle size and grain size variation in the sample. The fine aggregate and scoria basalt gradation test is shown in Figure 1.



(b)

Figure 1. Results of Fine Aggregate Gradation Test (a) and Fine Scoria Basalt Stone Size 100 and 270 Mesh

Based on Figure 1(a), it is shown that the fine aggregate to be used meets the aggregate specification standards, because all parts of the dotted line (sample) are within the boundary area between the upper and lower solid lines. The fine sand curve immediately climbs high to 90% - 100% passability even when it reaches the middle diameter sieve limit such as (0.60mm) to (1.18mm). Referring to the SNI standard, the gradation test results show that the fine aggregate used is included in zone 4, namely fine-sized aggregates with MHB between [35]. Figure 1(b), shows that

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the percentage of material that passes is 15%. As much as 15% of the total weight of the scoria basalt sample had a grain size smaller than or equal to 0.15 mm. In contrast, 85% of the material was retained on the 100-mesh sieve. Meanwhile, for the 270-mesh basalt size, the percentage of material that passed was 3.8%. Only 3.8% of the total sample weight had a very fine grain size (passing the 0.053 mm sieve).[20][36][37]

Concrete Slump Test Results

The *slump* test is intended to measure the consistency, viscosity, and workability of fresh concrete before casting. The results of the concrete slump test are shown in Figure 2 .

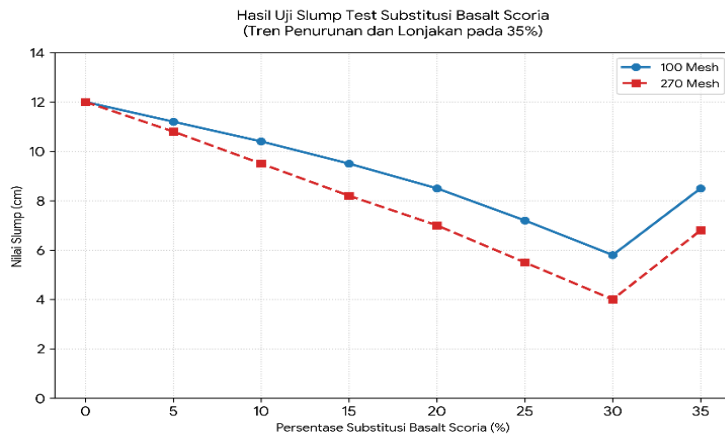


Figure 2. Results of Concrete Slump Test with the Addition of Basalt Scoria Stone

Figure 2 shows that the greater the substitution of basalt scoria in fine aggregate, the greater the slump value, this indicates that the greater the planned limit, meaning the fresh concrete mix becomes too runny. This can have a positive impact in terms of workmanship, but also carries a major risk to the strength of the building structure. The slump value of the 270 mesh variation is lower than 100 mesh because the larger particle surface area absorbs more free water. This is due to the inability of the cement to bind excess fine aggregate, so that free water escapes and makes the mix become thinner artificially. However, overall the resulting concrete mix has good workability. [20][38][39]

Table 1. Physical Properties of Fine Aggregates and Coarse Aggregates

Types of Testing	Fine aggregate	Coarse Aggregate	Unit	Standard ASTM
Sieve Analysis	Regional gradation III, Fine Sand	Graded Good, maximum 20 mm	-	
Water content	6.83	1.22	%	<10%
Sludge Content	2.37	0.11	%	<5%
Specific Gravity (SSD)	2.50	2.61	grams/ cm ³	2.40-2.90 grams/cm ³
Specific Gravity (Apparent)	2.69	2.53	-	-
Content Weight	1.39	1.31	grams/ cm ³	-
Water Absorption	4.86	1.73	%	<13.37%
Wear (%)	-	27.57	%	<30.0%

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Based on Table 1, Overall, both fine and coarse aggregates meet the ASTM/SNI quality standards required as concrete or road construction materials. Both in terms of mud content quality which is $<5\%$, water content is $<10\%$ and specific gravity is between 2.40-2.90 grams/cm³. This is very important because it will affect the quality of the concrete to be as expected. [40][41]

Concrete Absorption and Porosity Test Results

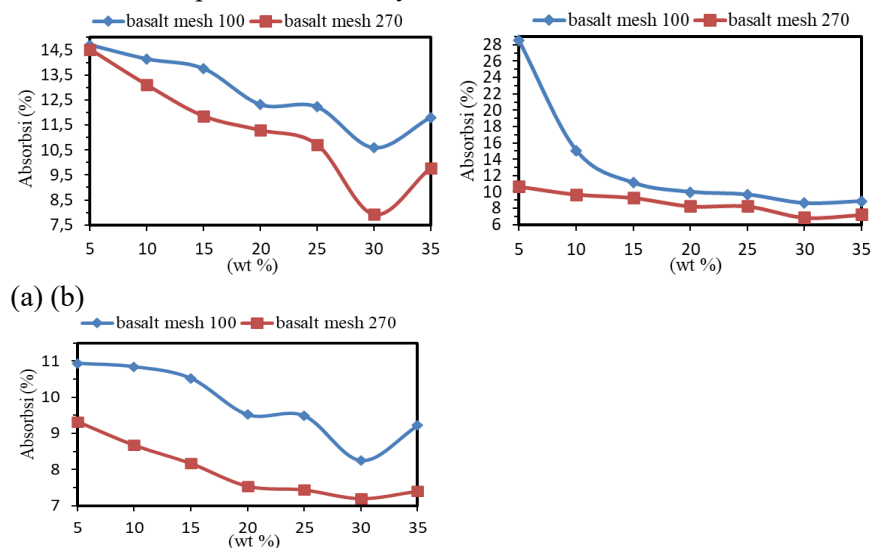


Figure 3. Graph of Concrete Absorption Test Results for Basalt Weight Substitution Variations with Test Ages of 7 Days (a), 14 Days (b) and 21 Days (c).

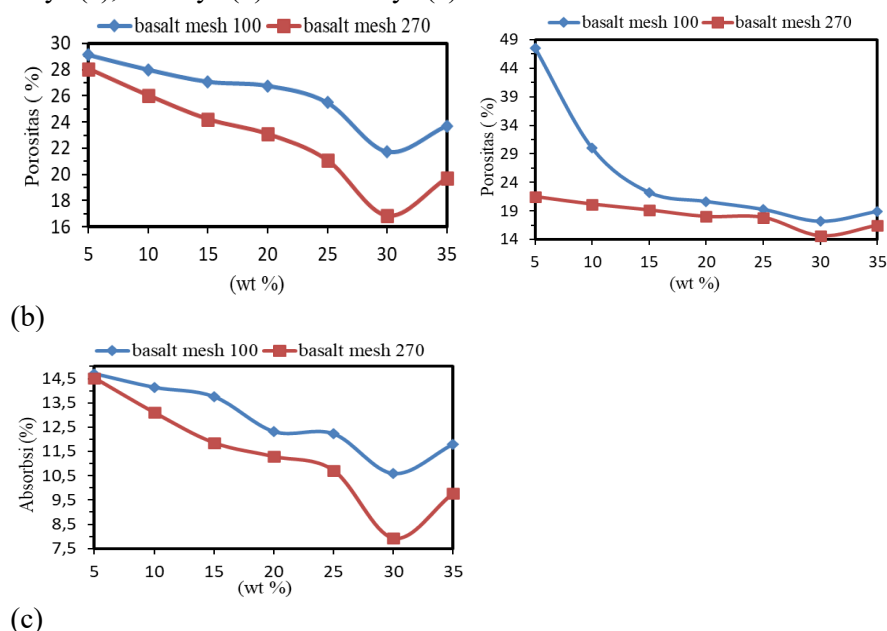


Figure 4. Graph of Concrete Porosity Test Results for Basalt Weight Substitution Variations with Test Ages of 7 Days (a), 14 Days (b) and 21 Days (c).

From the results of the concrete absorption test, a comparison graph was obtained between concrete absorption and the percentage of basalt scoria substitution against fine aggregate for both immersion ages of 7, 14, and 21 days, which is shown in Figures 3, 4, and 5 below. The absorption value and porosity value of concrete tend to be the same. Without substitution, basalt scoria (0%) has a high absorption and porosity value and when substituted with basalt scoria of 100 and 270 mesh size up to 30%, the absorption and porosity values are smaller. However, when the substitution is 35%, the porosity increases. This is because the fine basalt scoria which functions as a filler can fill the cavities in the concrete so that it becomes denser and also increases the adhesion of the concrete which results in reduced pores in the concrete [42].

Concrete Compressive Strength Test Results

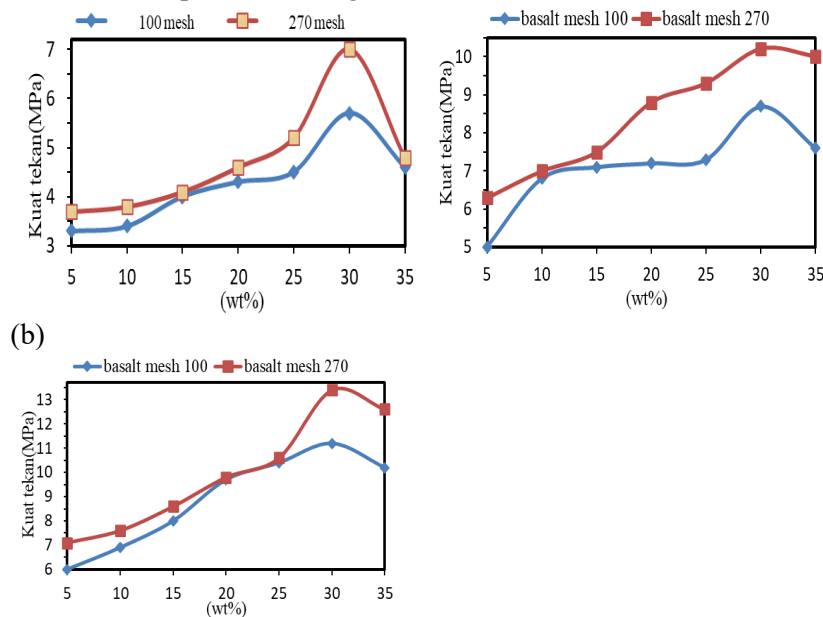


Figure 5. Graph of Concrete Compressive Strength Test Results for Basalt Weight Substitution Variations with Test Ages of 7 Days (a), 14 Days (b) and 21 Days (c).

The compressive strength of concrete with 0% to 30% substitution of basalt scoria stone, the compressive strength continues to increase. However, when the substitution is 35%, the compressive strength decreases. The increase in the average compressive strength of concrete up to 30% substitution of basalt scoria stone occurs because the Ca(OH)_2 compound from the mixture of water with calcium silicate in cement reacts with the *pozzolanic compound* in basalt scoria stone, namely SiO_2 and CaO , producing a Calcium Silicate Hydrate (CSH) gel which functions as an adhesive in concrete. In addition, with the addition of basalt scoria stone, the concrete becomes denser and has less porosity so that the compressive strength increases.[43][36]

XRF Characterization Results of Concrete

Based on the results of the concrete compressive strength test which produced the lowest compressive strength at a substitution of 5% and the highest at a substitution of 30% for each scoria basalt stone size of 100 and 270 mesh, it was selected as a sample for XRF, XRD and SEM characterization.

XRF Characterization of Concrete

Table 2. XRF Characterization Results of Concrete Sizes 100 and 270 Mesh Variation of Basalt Weight Concentration with a test age of 21 days.

No.	Compound	concentration (%)			
		B100 5% (L1)	B100 30% (L2)	B270 5% (L3)	B270 30% (L4)
1.	CaO	67,004	48,411	61,911	44,732
2.	SiO ₂	19,348	26,701	20,895	27,255
3.	Al ₂ O ₃	3,163	6,465	4,157	7,600
4.	Fe ₂ O ₃	7,301	14,289	9,588	16,258
5.	SO ₃	0.627	0.277	0.494	0.178
6.	TiO ₂	1,182	1,655	1,369	1,668
7.	MgO	0.524	1,009	0.647	1,142
8.	K ₂ O	0.355	0.488	0.339	0.456
9.	MnO	0.115	0.190	0.146	0.226

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Table 2 shows the results of XRF characterization of 100 mesh and 270 mesh basalt scoria concrete with variations in basalt powder weight concentration of 5% and 30% with a test age of 21 days. The XRF characterization results show that the concrete samples have the highest CaO compound content in each concrete sample with a range of 44.732 - 67.004%, SiO₂ amounting to between 19.348 – 27.255%, Fe₂O₃ amounting to between 7.301 – 16.258% and Al₂O₃ amounting to between 3.163 – 7.600% and followed by a small portion of other compounds. In addition, the content of CaO and SiO₂ has the potential to provide an early indication. The presence of CaO and SiO₂ compounds dominates because concrete is formed from (Calcium Silicate Hydrate) which comes from cement while the content of Al₂O₃ functions as a binder that comes from pozzolanic compounds derived from scoria basalt. However, commonly used silica aggregates also contain high levels of SiO₂. The less scoria basalt added, the higher the CaO content, and conversely, the more scoria added, the lower the CaO content. This is because concrete consists mostly of aggregate and cement, and as is known, cement is mostly CaO.[44][45]

XRD Characterization of Concrete

³ XRD equipment. Powder with Cu target $\lambda = 1.5406 \text{ \AA}$. The diffractogram pattern of the obtained sample was then analyzed using the *High Score Plus version application*. 3.0e (3.0.5) with parameters namely 2θ (°), d_{spacing} (Å) and intensity (%). The results of XRD characterization are shown in Figure 6.

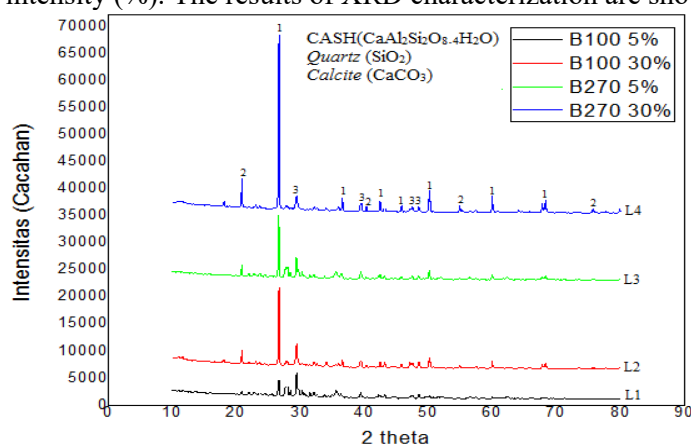
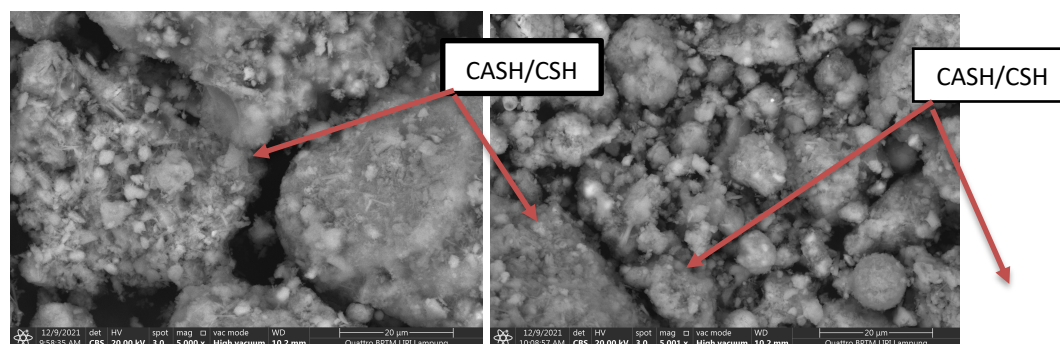


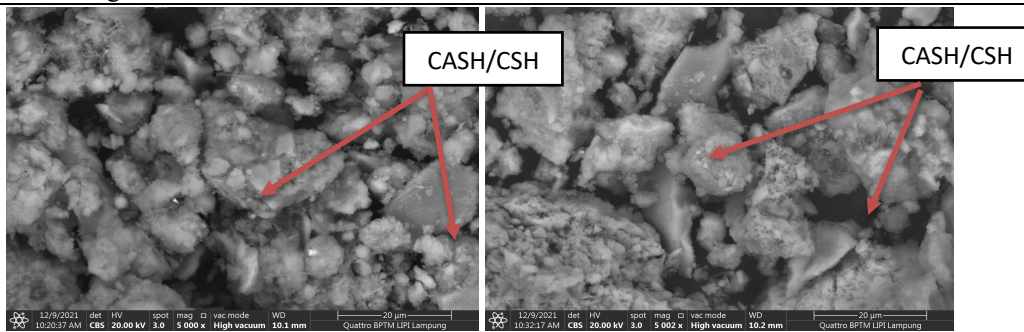
Figure 6. XRF Characterization Results of Concrete Sizes 100 and 270 Mesh Variation of Basalt Weight Concentration with a test age of 21 days.

Figure 6 shows the overall results of the XRD characterization of all sample variations. It was found that the highest peak was in each concrete sample. is the CASH/CSH phase or *calcium aluminum silicate hydrate*. In addition, the phases that appear frequently in PCC cement mortar with varying concentrations of basalt scoria powder are *quartz* (SiO₂), *calcite* (CaCO₃), and *portlandite* (Ca(OH)₂), which are phases of compounds that have a significant influence on the strength and other properties of the mortar material. The CASH phase appears due to the presence of composite or inorganic materials in the PCC cement itself in the form of basalt stone. and other pozzolanic materials. The hydration of the composite cement compound produces a CASH phase with the mineral name *Gismondine*. The CASH phase also plays a role in the compressive strength of the mortar paste.[46][47]

SEM Characterization of Concrete



(b)



(d)
Figure 7. Results of SEM Characterization of Concrete Sizes 100 and 270 Mesh Variations in Basalt Weight Concentration with a test age of 21 days.

Figure 7 (b) and (d) with the addition of 30% basalt scoria stone with a fineness of 100 and 270 mesh which experienced agglomeration to become larger. This aggregation destabilizes the system by inhibiting the formation of a uniform and denser hydrate microstructure which ultimately leads to an increase in strength, when compared to Figure 7 (a) and (c). The formation of CSH and CSAH hydrates can be achieved by ensuring adequate spacing between particles, so that the formation of portlandite derived from the addition of new basalt scoria can increase the hydration reaction. With the occurrence of new hydrate reactions, the growth of which is induced by the reactivity of basalt scoria, which binds well and reacts with the cement matrix. [48][49]

CONCLUSION AND SUGGESTIONS

Conclusion

Microsilica and microalumina derived from scoria basalt have high pozzolanic activity and the largest specific surface area, accelerating the hydration reaction resulting in the formation of CASH/CSH gel. At 21 days of immersion, the compressive strength of the modified sample compared to the control sample increased by 55%, due to the homogeneous density and structure of the concrete. This sample had the lowest total porosity and the highest closed porosity due to the high pozzolanic activity of microsilica. Compositions with scoria basalt exhibit more intense calcite peaks (CASH). Specifically, the resulting CaCO_3 interactions are greater.

Suggestion

Research with immersion ages longer than 21 days, such as 28, 56, 120 days, needs to be carried out and mechanical testing is added with flexural strength and tensile strength tests.

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