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Andesite waste powder as mineral admixture in concrete: A Review

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Abstract. Massive production of andesite natural stone causes environmental problems due to the large amount of powder waste produced. Andesite stone contains a high percentage of SiO2 which indicates its possibility to be used as a mineral additive for concrete. Research that has been conducted by researchers from various countries shows that andesite stone has fine grains with a specific gravity of 2.66 - 2.68, Loss on Ignition 2.37 - 3.38, has a content of SiO2+Al2O3+Fe2O3>70% which can be classified as fly ash type F based on ASTM 618-92a. The use of andesite stone powder waste as a partial replacement of cement in concrete showed that concrete properties improved at an optimum of 10% at 28 days and 90 days of concrete age, respectively. The use of andesite waste powder in larger quantities showed a decrease in concrete properties. The use of andesite powder waste in concrete is recommended to reduce the impact of waste on the environment as well as to reduce the use of cement in concrete as an effort to support sustainable and more environmentally friendly construction.

1 Introduction

Concrete is listed as the most demanded construction material in the world [1]. Concrete is the most consumed material, with three tons per year used for every person in the world [2]. Concrete is made up of cement, water, coarse aggregate and fine aggregate. In terms of energy efficiency, cement production consumes relatively high energy. The thermal and electrical energy required in the cement production process is quite large [3]. In cement production activities about 35% of the weight of raw materials becomes carbon dioxide (CO_2) [4]. Cement production results in air pollution and greenhouse gas emissions that directly contribute to climate change [5]. In the last decade the concrete industry has made various innovations to realise the fulfilment of the demand for sustainable concrete that is more environmentally friendly [6]. Carbon dioxide emissions caused by the growing demand for concrete can be reduced by limiting the cement composition of concrete. Considering the amount of cement production is directly proportional to the carbon dioxide produced, the

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global carbon dioxide emission problem can be reduced by minimizing the quantity of cement consumption and substituting it with other materials, such as waste.

Andesite is typical igneous rock, a kind of volcanic stone generated from the lava of volcanic eruptions [7]. Indonesia's geographical condition, which is located on the Pacific Ring of Fire, has more than 130 active volcanoes with high volcanic activity making Indonesia one of the largest andesite natural stone producing countries worldwide. Andesite mining and processing in Indonesia is spread across various regions in Sumatra, West Java, Central Java, East Java, Bali, West Nusa Tenggara and Sulawesi [8,9]. The average production of stone and andesite in Indonesia between 2019 and 2021 reached 40.9 million tons/year [10]. Large-scale production of andesite produces a significant amount of industrial waste, amounting to 40% of the product [11]. Andesite processing waste is a by-product during the mining, cutting and polishing processes, this waste can be small unusable stone chips, sludge produced during the wet cutting process, or very small powder particles in the andesite polishing process. The increasing demand and production of andesite stone creates problems with the amount of waste generated. Strategic measures are needed to reduce the negative environmental and health impacts.

Along with the recent material technology, it is found that the substitution of certain materials as a substitute for concrete can reduce the adverse effects of concrete use for the environment. Efforts to reduce the use of cement in concrete continue to be developed to achieve improved concrete quality. This is driven by environmental challenges since approximately 5-7% of global CO2 emissions come from the concrete sector during the cement production process [12]. Some new materials with pozzolanic used as partial cement replacement materials in concrete. Pozzolan is utilized as a mineral additive to reduce the quantity of cement in the concrete [13].

Pozzolan is characterised by its ability to react with calcium hydroxide, producing more C-S-H binders [14]. The reactivity of pozzolan is extremely reliant on the material's particle size. Some materials are known to have pozzolanic properties only if their particles are less than 45 μm in diameter. Pozzolanic materials do not have the ability to hydrate like cement, but pozzolanic materials react with Calcium Hydroxide $Ca(OH)_2$ produced from the hydration process of cement with water so that they have the binding ability of cement [12]. The effect of these materials is projected to maximize the quality of concrete, and the ability of pozzolanic materials to improve its compressive strength depends on pozzolanic activity. The way pozzolanic materials work depends on their specific surface area, unique characteristics, chemical components and reactive silica content [15].

2 Literatur Review

The review examines the methods, changes in characteristics, compressive strength, and durability when andesite waste powder is applied as mineral admixture in concrete. This study also discusses its environmental impact. The assembled information in this study provides a solid foundation for the upcoming work in the green material field of andesite waste powder used as concrete's admixture. In 2017 Ceylan and Davraz researched the pozzolanic properties of andesite waste powder from Türkiye and its effectiveness for reducing the amount of cement needed in concrete production. The andesite waste powder's pozzolanic was determined according to the TS EN 450 and ASTM C 618-12 [13]. The result showed the andesite waste powder owned higher efficiency factor values compared to other mineral admixtures. Another research of Türkiye Andesite powder by Davraz et al. [16] investigated the effects of different replacement ratios of andesite waste powder as mineral additive on the compressive strength, efficiency factor, and modulus of elasticity in high strength concrete. Various ratios of andesite waste powder were used and found that the 10% rate was found to be the ideal replacement for andesite waste powder at the 28-day and 90-

day curing ages. for C40 strength class. Then the ideal replacement ratio for the C55 and C70 strength classes was 20%. For C70 concrete, a ratio of 15% andesite waste powder was ideal in terms of efficiency aspects.

A study to determine the effects of andesite waste powder in different ratios regarding the concrete's compressive strength using the Artificial Neural Network (ANN) model was carried out by Ceylan et al. [17]. It showed the use of andesite waste powder as the pozzolanic additive in concrete is suitable due to high content of SiO2. The developed ANN model provides reliable and practical results for predicting the compressive strength of andesite waste powder-added concrete. With the objective for finding sustainable solutions for andesite waste disposing and its economic potential, Özkan and Ceylan studied the application of andesite waste powder as a partial substitute for cement in cementitious composites. It varied the andesite waste substitute of 5%, 10%, 15%, 20%, 25%, and 30% over the total weight of cement. This research revealed that substituting the andesite waste powder with cement at small rates up to 15% generated beneficial outcomes on compressive, flexural, and tensile strengths [18].

Amin et al. [18] examined the impact of substituting andesite stone powder for cement in the production of paving blocks. The andesite stone used in this study was from Indonesia. The andesite powder’s substitution ratios were 10%, 20%, 30%, 40% and 50% of the total weight of cement. It concluded that there was decrease in compressive strength in line with increasing andesite substitution ratio caused by the excessive SiO2 which reacted with Ca(OH)2 to form calcium hydrate and leading to reduced density and the development of air cavities. Initiated by the huge interest in the growth of high strength self-compacting concrete, Elshikh et al. [19] conducted research on the use of andesite as a new type of coarse aggregate for producing green high-strength self-compacting concrete. This study compared four different kinds of aggregate which were gravel, dolomite, andesite, and rhyolite and tested the impacts of aggregate type on the properties of concrete. The different ratios 1:1, 2:1, 3:2, 5:2 were used to investigate the influence of aggregate ratio on concrete properties. This study proved that the aggregate type and ratio had a significant impact on the green high-strength self-compacting concrete properties. Using andesite as coarse aggregates was able to improve flowability and workability compared to pulverized rock and volcanic stone. The sharp angular shape and rough surface area of the aggregates provided better consistency between the aggregates and the cement paste then leading to increasing the strength. The possibility of using andesite waste powder in geopolymer mortars was investigated by Çelikten to observe the mechanical and microstructural properties of the mortars with variations of the NaOH molarity and the curing periods [20].

3 Result and Discussion

3.1 Chemical Component of Andesite Waste Powder

Table 1 below lists the chemical properties of andesite powder that have been investigated. The main component of andesite that affects the strength of concrete is SiO2. Therefore, the results of each study are described as follows. The results of the research that has been carried out show that andesite powder has a high SiO2 content so that it can be utilized as a pozzolanic material in concrete. Based on its chemical content, andesite powder can be classified as class F pozzolan with a SiO2+Al2O3+Fe2O3 content of more than 70% [13]. Since the researchers used regionally available andesite powders, the chemical components of each study were not exactly the same [21].

Table 1. Chemical component of andesite powder [11–13,15].

Chemical Component	M Amin et al. 2019	Ceylan, 2021	Çelikten, 2021	Ozkan, 2022
SiO2	62.30	56.34	57.82	58.41
Al2O3	14.70	18.21	19.24	21.05
Fe2O3	4.04,	5.61	5.87	5.61
MgO	2.78	1.62	1.87	1.78
CaO	4.26	4.45	6.32	4.52
Na2O	2.95	3.85	3.14	7.42
K2O	6.06	2.90	2.88	6.51
TiO2	0.98	-	-	-
P2O5	0.81	-	-	-
MnO	0.07	-	-	-
Cr2O3	0.014	-	-	-
SO3	-	0.19	0.22	0.16
Loss on Ignition	-	3.38	2.6	2.37
Specific Gravity /g/cm3	-	2.66	2.68	-
Fineness / cm2/g	-	5790	5480	-

Ceylan et al [17] defined Andesite as fine grained with colour between grey and black having specific gravity 2.66. Furthermore, andesite's porphyritic structure contains plagioclase and pyroxene microliths (clinopyroxene and orthopyroxene), feldspar, pyroxene, and biotite phenocrysts in a glass matrix, and trace quantities of magnetite minerals [17]. As stated before, the contents of SiO_2 in andesite powder have the main role in increasing concrete's strength. But the replacement ratio of andesite waste powder over the total weight of cement must be considered. The wrong ratio can actually reduce the compressive strength value. The reaction between SiO_2 with $Ca(OH)_2$ and forms calcium hydrate (CSH), which gets involved in the hardness of the concrete. Overrated SiO_2 content is able to connect with the free CaO in the cement and generate $Ca(OH)_2$. This reaction causes a decrease in the density of the concrete due to the air cavities formation [22]**.**

The experimental study by Amin et al. [23] used andesite stones from Indonesia which contains chemical composition of SiO_2 by 62.30%, Al_2O_3 by 14.70%, Fe_2O_3 by 4.04%, MgO by 2.78%, CaO by 4.26%, Na_2O by 2.95%, K_2O of 6.06%, TiO_2, 0.98 P_2O_5 of 0.81%, 0.07% MnO and Cr_2O_3 of 0.014% as listed in the table 1. With the chemical contents of SiO_2 + Al_2O_3 + Fe_2O_3 > 70%, it can be inferred that the andesite powder is able to be utilised as pozzolan in cement replacement according to ASTM C 618-92a [13].The listed chemical component of andesite powder from table 1 confirms the feasibility of using andesite powder as a partial replacement for cement in concrete.

3.2 Mix Design and Properties

Table 2 shows the mix design specifications used by four different studies [17,18,23,24]. The water-cement ratio and the composition of the constituent materials are very important for concrete mix design which determines the workability, strength, and durability of the concrete. The mix design for the mortar in this study was determined based on the desired slump value and planned use of the concrete as well as the water-cement ratio for different strength classes [15].

Table 2. Mix Design Specification

Author name	Author Notation	Concrete Grade	Proportion of Mix ratio	(W/C) ratio
M Amin et al, 2019	(a)	-	1: 4	0.8
Ceylan, 2021	(b)	C20	1: 2: 3.7	0.33
Ozkan, 2022	(c)	-	1:2	0.26
Davraz, 2018	(d)	C40	-	0.55

3.3 Compressive Strength

The compressive strength of a concrete defines its quality. If the compressive strength of concrete is less than the requirements, it is not able to be used in building. After comparing the studies in the table, a similar trend is detected, which decreases along with the addition of the ratio of andesite waste powder as a cement replacement material. The compressive strength of concrete determined by experimental studies and a paper through ANN model at curing time of 28 days and 90 days [15,17,18,23], Table 3, Figure 1, Table 4 and Figure 2. Below is the result of the compressive strength tests which were conducted by the researchers at curing time 28 days and 90 days respectively.

Table 3. Compressive strength 28 day (MPa).

Author name	Author not.	Replacement cement with andesit powder										
		0%	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**
M Amin et al 2019	(a)	-	-	16	-	9.80	-	5.50	-	5.00	-	5.20
Ceylan 2021	(b)	53	-	47.09	36.22	36.35	-	-	-	-	-	-
Ozkan, 2022	(c)	59.35	38.51	38.36	37.73	34.75	34.21	26.25	-	-	-	-
Davraz (2018)	(d)	52	-	50	41	38	-	-	-	-	-	-

Table 4. Compressive strength 90 day (MPa).

Author name	Author not.	Replacement cement with andesit powder										
		0%	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**
M Amin et al 2019	(a)	-	-	-	-	-	-	-	-	-	-	-
Ceylan 2021	(b)	60.96	-	52.42	44.85	43.07	-	-	-	-	-	-
Ozkan, 2022	(c)	63.90	43.64	42.29	40.32	36.65	35.49	30.45	-	-	-	-
Davraz (2018)	(d)	61	-	58	50	45	-	-	-	-	-	-

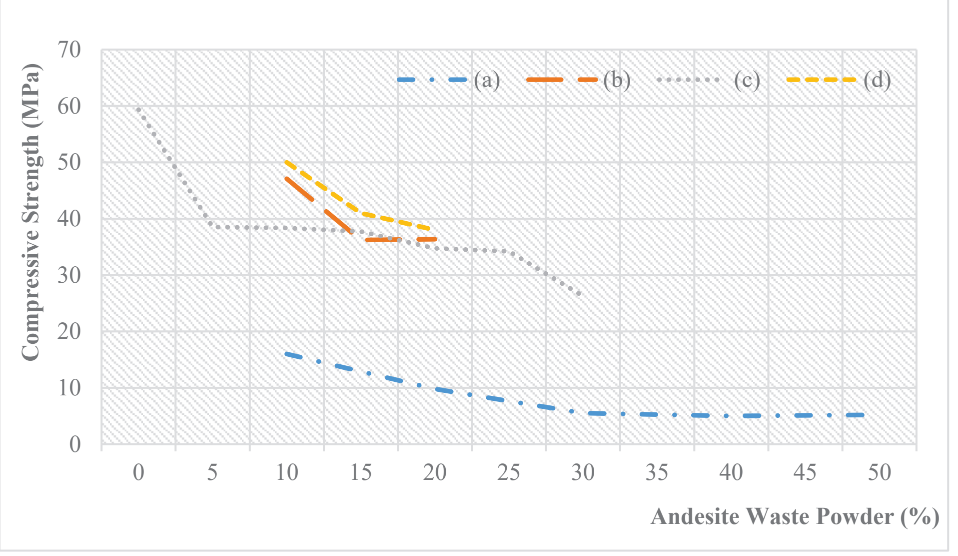

Fig. 1. Compressive strength 28 day (MPa).

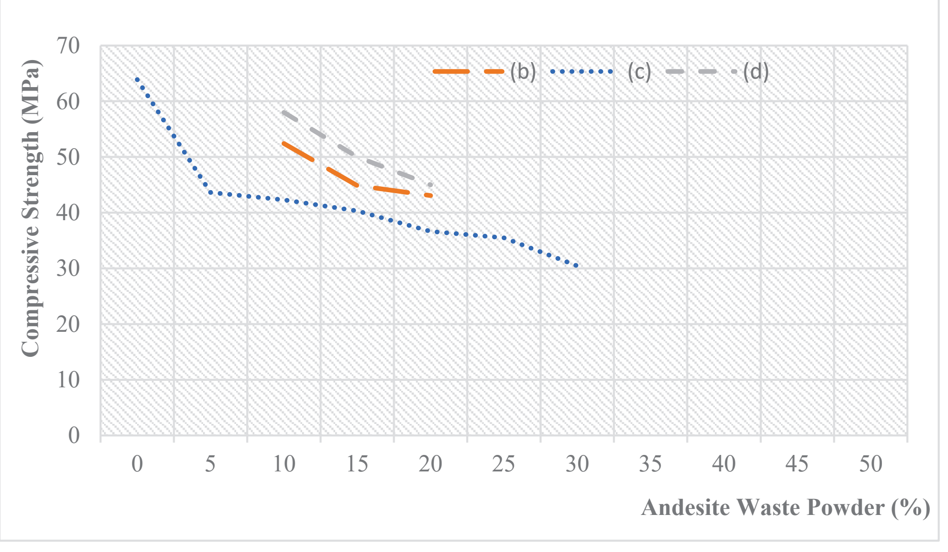

Fig. 2. Compressive strength 90 day (MPa).

Amin et al. discovered that the highest compressive strength is found in paving block with the substitution of andesite stone 10% of 28 days old, while the lowest compressive strength is found in andesite 50% of 7 days old [23]. This drop results from the high SiO2 component, which binds to the cement's free CaO to create $Ca(OH)_2$. Ceylan et al. [17] conducted both experimental data and an Artificial Neural Network to examine the compressive strength of the concrete specimens based on the andesite waste powder mixture and curing time parameters. The matching ratios for the generated model and the experimental findings were determined to be within 93% and 90% of each other, respectively. The outcomes achieved from the ANN model were in line with the experimental data. Based on this research's collected data, the use of andesite waste powder as the concrete's pozzolanic additive is suitable. The developed ANN model provides reliable and practical results for predicting the compressive strength of andesite waste powder added concretes without the need for extensive experimental studies. The experimental result by Ozkan and Ceylan [17] retrieved the andesite waste powder enhanced the mixtures'pore structure due to its porous nature. Substituting andesite waste powder with cement at the range of 5% up to 15% showed positive outcomes concerning of compressive, flexural, and tensile strengths. The specific case with a 5% substitution ratio exhibited approximately 2.31 and 1.88 times higher deflection and tensile strain capacities, respectively, compared to the reference sample. Based on the research by Davraz et al, the best substitution ratio of andesite waste powder is 10% for C40 strength class and 15% for C70 concrete [15]. The use of andesite waste powder as a mineral additive can lead to cement savings and achieve economical mix proportions [15]. Andesite waste powder is a suitable alternative to partially replace cement in concrete production in the right composition of about 10%. This is to support the preservation of the environment around the andesite natural stone mining area, as well as to develop sustainable construction that minimizes the use of resources.

4 Conclusion

Andesite waste powder is a waste material generated during the process of mining, cutting, and polishing of andesite stone as a pollutant that can have a detrimental impact on the environment. Mass production of andesite as construction material in Indonesia reached 40.9 million tons/year, producing 40% or 16.36 tons/year of industrial waste. The discharge of these wastes into the soil causes a decrease in permeability and also contaminates groundwater when deposited along water catchment areas [22]. From the above review, the use of andesite waste powder as mineral admixture that partially replaces cement in concrete can be concluded that:

1. The chemical composition of andesite stone powder waste in various places can vary slightly according to the type of rock it comes in [21]. Andesite stone has fine grains with a specific gravity of 2.66 - 2.68, Loss on Ignition 2.37 - 3.38, has a content of SiO2 + Al2O3 + Fe2O3 > 70% [17,18,20,23].
2. In terms of the efficiency factor, the results of this review indicate that the use of andesite waste powder as a mineral additive in concrete production is feasible due to its high SiO_2 content and its potential to exhibit pozzolanic properties. In addition, the use of andesite waste powder in concrete provides benefits in terms of reducing carbon emissions generated during cement production.
3. Recycling andesite waste powder in concrete is suggested to reduce the impact of environmental pollution due to andesite processing waste. It is also done to support sustainable construction and find new materials that are more environmentally friendly.

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