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THE PROMISING POTENTIAL OF SIDOARJO HOT MUD AS ADDITIONAL MATERIAL FOR CONCRETE LINING PRODUCTION

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ABSTRACT: The Lapindo hot mud in Sidoarjo, Indonesia (Lusi) has caused a detrimental effect on the environment and the community for more than 10 years. On the bright side, the waste mud contains a high amount of silica (SiO2) which makes it promising to be used as a concrete mix. This study tests the use of Lusi as an additive material in concrete lining production to reduce the use of sand. The standard of concrete lining considered is the national standard of Indonesia (SNI 03-4804-1998) for K250 concrete. Experiments were carried out using a mixture of Lusi 0%, 5%, 15%, and 25% of the weight. The results of the analysis of variance demonstrated an F-statistics of 173.883 with a significance value of 0.000 (< 0.05). This means that the compressive strength between concrete samples based on each percentage of the Lusi mixture is significantly different. Furthermore, the regression analysis demonstrates a staggering R-square value of 0.9999, which shows that the addition of Lusi material greatlaffectsct the compressive strength of the concrete. The addition of Lusi material greatly affects the decrease in the compressive strength of the lining concrete. The average compressive strength of concrete based on the addition of Lusi material of 0%, 5%, 15%, and 25% are 347.15 kg/cm^2, 297.85 kg/cm^2, 209.68 kg/cm^2, and 145.04 kg/cm^2, respectively. Therefore, it is concluded that a 5% addition of Lusi material is the most recommended level of Lusi material. This finding can be considered a solutive idea for managing the Lapindo mudflow disaster, which can also bring economic advantage in the production of the concrete lining by minimizing the use of sand.

Keywords: Sidoarjo hot mud, Concrete compressive strength, Canal lining.

1. INTRODUCTION

The Lapindo mudflow (Lusi) is a disaster in Sidoarjo, Indonesia, where geothermal mud erupts due to human error in the oil drilling process [1,2,3]. On the other hand, Lusi is also considered a natural phenomenon, a mud volcano located at a depth of 1000-2000 meters below the ground surface [4]. The hot mud spewed to the surface of the oil drilling area (Fig.1) and continued to expand until devouring at least 12 villages and forcing 40,000 people to be evacuated [5]. The initial mudflow occurred on May 29, 2006, in Renokenongo village, Porong district, Sidoarjo regency, East Java [6]. Experts estimate that the eruption will last for 31 years [7] until a new mountain is formed. Lusi has caused significant losses in the environmental aspect [8,9,10], especially in the Madura strait [11]. In addition, social and economic aspects are also greatly affected [12,13,14]. The drastic economic impact of the Lusi disaster cannot be compared to the annual disasters around the world [15].

Currently, mud eruptions are still occurring with a capacity of 30,000 m^3 to 80,000 m^3 per day, with temperatures at the center of the eruption reaching more than 100^{o}C. This condition demands better management and solution to prevent the mudflow from devouring more areas [16]. Experts suggest ideas to overcome the disaster, such as blocking the mud eruption through tilt drilling techniques, creating mud reservoirs, dredging the area to form a large crater, and so forth. These ideas are accompanied by various disadvantages, both in terms of costs and other side impacts. So far, the solution implemented by the local authorities is dumping the mud into the sea via the Porong River [17], which can disrupt the aquatic ecosystem.

Fig.1 Aerial view of the Lapindo mudflow in Sidoarjo, Indonesia

Hypothetically, the mud of the Lapindo has promising potential to be used as a concrete mix, especially to reduce the use of sand. Lusi has fine physical properties, is gray-black, malleable, and contains mineral elements. Previous studies reported that Lusi is rich in Silica/SiO2 content [18,19], alumina/Al2O3, and other substances found in cement [20]. Silica in Lusi makes up more than 47% of the total minerals contained in the material [21]. Si and Al elements in Lusi are promising potentials for construction materials. Aggregate can be produced through the combustion process to obtain a lightweight, strong, and stable material [16]. A previous study has attempted to utilize Lusi material for concrete mix [22]. Lusi can be used as the primary or additive material in concrete production [20]. Therefore, it is strongly assumed that Lusi material has a great potential to be used as lining concrete mix due to the simmsimilaritythe elements; silica and alumina.

Concrete is one of the most basic construction materials and is always needed in high numbers [23]; thus, the availability of concrete materials is getting limited [24] due to its high demand; pavement component, irrigation channel lining, dams, bridge, and so forth [25]. Common concrete constituents include sand [26], which is limited and not always available in every region in Indonesia; thus, the price is high. Therefore, alternative materials are needed to reduce common materials used in concrete production [27]. Previous studies have shown that Lusi can be used as raw material for various solid products with promising economic value [26].

The use of Lusi for additional construction material is an excellent solution to reduce the volume of mud in the eruption area and provide economic benefits to the community. However, Lusi has never been optimally utilized [29]. Lusi has a promising potential due to its minerals compounds that are similar to the construction materials [7]. This study aims to utilize Lusi material as a mixed material in the concrete production for canal lining. Theoretically, the mud mixture can affect the quality of concrete; thus, it is essential to determine the correct percentage of mud addition to prproducingood quality concrete lining based on concrete K250 requirement while using less sand material. The idea is to obtain the benefits of the mudflow to minimize the effect, for which the mud volume can be managed; thus, the environmental disruption can be minimized.

2. RESEARCH SIGNIFICANCE

The continuous mud eruption in the Lapindo area threatens the surrounding environment, especially considering its longevwhichthat is predicted to last for 31 years. This problem urgently requires the best solutions to bring economic benefits to the community. On the other hand, there is a situation where the availability of material resources for concrete production is getting limited. These two situations make this study significant, for which it can be the empirical basis for the use of Lapindo hot mud as a material for concrete production. It is essential to determine the durability of the concrete produced by using mixed materials to ensure that the products meet the quality standards.

3. MATERIAL AND METHOD

3.1 Material

This study uses an experimental method to create a concrete-based irrigation lining made using Lusi (Sidoarjo hot mud) as a mixture to reduce the use of sand material. The materials consist of Lusi mud collected from the Lapindo mining site in Sidoarjo, split stone from Pandaan, sand from Lumajaand ng, and Cement (Semen Gresik) Type I/PPC.

3.2 Sample Preparation

The concrete lining is made with the addition of the Lusi mixture using 0%, 5%, 15%, and 25% of the weight. Each percentage is formed in 8 cylindrical concrete samples to be tested made with a concrete cylinder mold measuring 13 x 30 cm (Fig.2). Thus, the total concrete sample in this study was 32 units. Lusi is dried in the oven and sieved using a sieve number 200. Sa'diyah et al. [30] explained that Lusi contains 70% water and 30% solids; thus, the drying and sieving processes are crucial to reducing the water content and filtering the material.

3.3 Testing

Observations were conducted by testing the compressive strength of the lining concrete produced. Concrete samples were tested for compressive strength at the age of 28 days using a concrete compression machine (Fig.3) with a capacity of 2000 kN to 3000 kN. The concrete sample is pressed gradually until it breaks, then the compressive force is calculated; the compressive force of the concrete when crushed is divided by the cross-sectional area. The standard compressive strength of concrete is based on the SNI 03-4804-1998 for K250 quality concrete, namely concrete with a minimum compressive strength of 250 kg/cm^2. Figures 2 to 4 demonstrate the process of concrete samples production using the addition of Lusi material. Laboratory analysis using

Microstructure testing includes observations using Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDX) method are also conducted to identify the microstructure and the elements contained in Lusi material.

The method of data analysis consists of the Anova (analysis of variance) with a significance level of 0.05 and regression analysis to determine the relationship between the addition of Lusi material and the compressive strength of the concrete lining produced. Finally, the data analysis is processed in the SPSS statistics program for Windows operating system.

Fig.2 The molding process of concrete materials

Fig.3 Concrete compression machine

4. RESULT AND DISCUSSION

4.1 Characteristics of Mixed Materials

In this study, the discussion of the characteristics of the mixed material is focused on the content of slurry level in the mixed aggregate (fine and coarse) after the addition of the Lusi material. Calculations are carried out using the formula from Sanjaya et al. [31], which is $V_2 : (V_1 + V_2) \times 100\%$. The result demonstrates that the combination of fine and coarse aggregate based on adding Lusi material had an organic content of slurry based on the fine and coarse aggregate samples, namely 0.63%. This level shows that the concrete mix materials meet the requirement based on SNI S-04-1989, which is 5% of the maximum slurry level. Thus, the concrete mix can be processed further to manufacture canal lining concrete for irrigation.

4.2 Final Composition of Concrete Lining

The concrete for irrigation lining was made from a mixture of coarse and fine aggregate. This includes split stone from Pandaan, sand from Lumajang, Cement (Semen Gresik) Type I/PPC, and a mixture of Lusi material that had been dried and sieved. The composition of the concrete mixture is explained in Table 1. After the final composition has been formulated, concrete samples were produced according to the procedures; mixing process, molding, and drying. The concrete specimens were left for 28 days to make sure the structure is solid. At the age of 28 days, the strength of the concrete will reach 99%, which is close to the final strength of concrete that can be achieved one or two years later. In other words, measurements can produce accurate data.

4.3 Micro Structure of Concrete Lining

Microstructure testing includes observations using Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDX) methods. Scanning Electron Microscope (SEM) is an electron microscope that produces an image of a sample by scanning a surface with a focused electron beam with magnification up to a particular scale. The electrons interact with the atoms in the model, generating various signals containing information about the model's surface topography and composition. The making of scanning electron photos is carried out in a laboratory with preparations whose size has been adjusted to the equipment used. This aims to obtain a thin slice of the specimen to make it semi-transparent to electrons.

Table 1 Composition of the concrete mix

Material (Unit)	Composition (%)			
	0	5	15	25
Cement (kg)	377.19	377.19	377.19	377.19
Sand (kg)	709.05	673.60	602.69	531.79
Lusi (kg)	0.00	35.45	106.36	177.26
Split stone 10/120 (kg)	970.48	970.48	970.48	970.48

The result of SEM scanning on two samples are displayed in Figures 4 and 5. Sample 1 is the concrete sample without Lusi mixture and sample 2 is the sample with Lusi. Microstructure-wise, the morphology of the two concrete samples based on the imagery on 250 times magnification demonstrates almost the same results. In other words, samples 1 and 2 had no significant difference in terms of the microstructure.

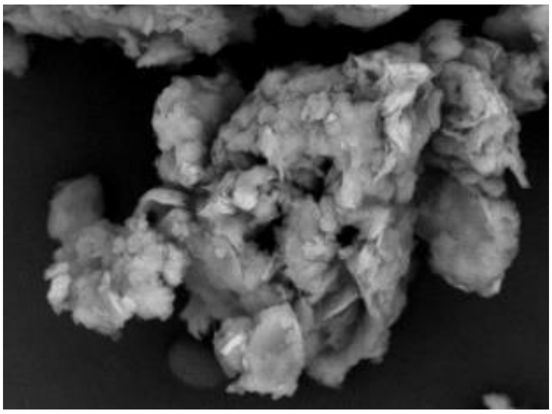

Fig.4. The microstructure of concrete sample 1 on 250 times magnification

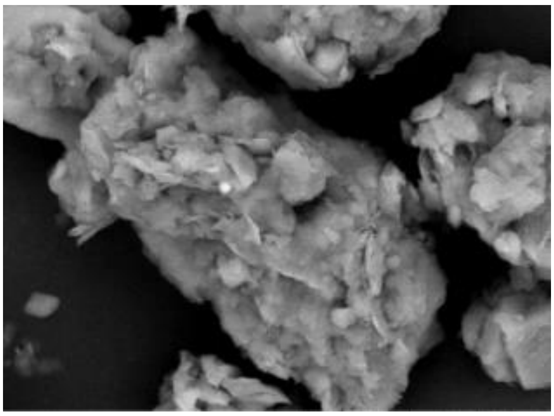

Fig.5. The microstructure of concrete sample 2 on 250 times magnification

Furthermore, the result of the EDX analysis is explained in Table 2. Energy Dispersive X-ray (EDX) is used for chemical elemental materials analysis. The characterization is mainly due to the fundamental principle that each element has a unique atomic structure that allows a unique set of peaks in its electromagnetic emission spectrum.

Table 2 The elements contained in the concrete sample using Lusi mix

Element	Weight %	Weight % σ	Atomic %
Carbon	16.912	2.136	25.003
Oxygen	50.030	1.316	55.527
Sodium	0.982	0.065	0.758
Magnesium	0.953	0.057	0.696
Aluminum	7.542	0.214	4.964
Silicon	16.526	0.446	10.448
Chlorine	1.010	0.055	0.506
Potassium	0.529	0.046	0.240
Calcium	0.703	0.050	0.312
Titanium	0.311	0.056	0.115
Iron	4.502	0.183	1.431

Table 2 displays only the results of the elemental analysis of the concrete mix with Lusi addition. In short, the result of EDX analysis shows that the mix has a high Si element, which validates the assumption that dried Lusi mix can be used to decrease the use of sand. Si is a crucial element required in the production of good concrete [16].

4.4 Compressive Strength of Concrete

The compressive strength determines the durability of concrete to withstand induced damages, which is highly dependent on the capacity of the concrete microstructure to absorb water [32]. In this study, the compressive strength measurement is based on the K250 concrete standard, which represents a minimum concrete compressive strength of 250 kg/cm^2. Concrete has good quality if it has a high compressive strength number.

Table 3 Average compressive strength of concrete

Lusi mixture	Mass (kg)	Compressive strength	
		(MPa)	(kg/cm^2)
0%	12,86	28,238	347,158
5%	12,77	24,225	297,852
15%	12,43	17,056	209,687
25%	12,30	11,798	145,041

The compressive strength is related to the age of the concrete, mainly if it is used as a lining for irrigation canals. Table 3 briefly displays the results of the concrete compressive strength measurements. Table 3 shows that the concrete produced from each grade of the Lusi material mixture has different weights and compressive strengths. The concrete sample with 0% addition of Lusi material has the highest compressive strength, and concrete with 25% Lusi addition has the lowest average score of compressive strength compared to the other samples. This indicates that the compressive strength tends to decrease with the addition of the mud material. Figure 6 demonstrates the relationship between the acquisition of Lusi material and the compressive strength of concrete.

Concrete without a mixture of Lusi material and concrete with 5% Lusi has a compressive strength exceeding the standard of K250 concrete. This means that the concrete produced has good specifications for using a lining for irrigation canals. Meanwhile, along with the decrease in the compressive strength of concrete due to the addition of Lusi material, the compressive strength of concrete has decreased to less than 250 kg/cm^2. Therefore, according to this experiment, the recommended addition of Lusi material for concrete production is 5%. Although the 5% addition seems minor, if this idea is implemented massively, it will help maintain the volume of mud flown at the disaster site at a safe level, and at the same time, significantly reduce the use of sand material.

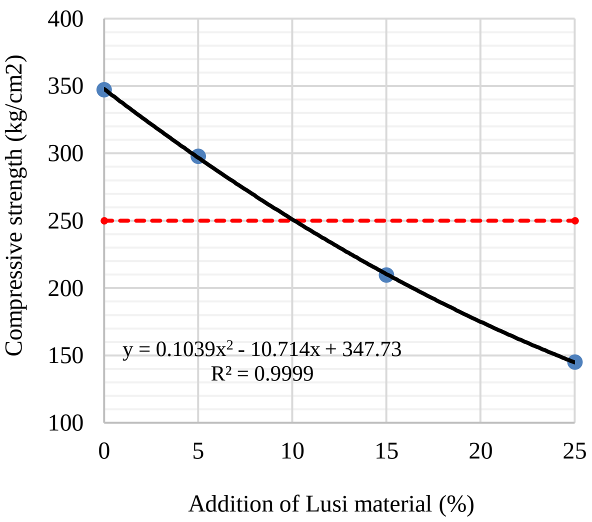

Fig.6. The relationship between the addition of Lusi material and the compressive strength of concrete

Figure 6 demonstrates the negative relationship between the addition of Lusi material and the compressive strength of concrete with an R-square of 0.9999. This means that the addition of Lusi material greatly affects the decrease in concrete's compressive strength (99.99%). A negative relationship indicates that the more Lusi material is added, the lower the compressive strength of the concrete, moving away from the standard. Previously, this pattern of relationship between two variables was also reported by Wiryasa and Sudarsana [33]. This characteristic does not necessarily translate that Lusi material cannot be used as a concrete mixture to reduce the use of sand but indicates that the Lusi can be used as additional material for concrete production at the recommended percentage (5%). As the core objective of this research, an experiment was conducted to determine the appropriate percentage of Lusi material for the manufacture of lining concrete based on the K250 specification (SNI 03-4804-1998).

Mud contains higher organic matter; thus, it has finer properties than sand. This explains why the addition of Lusi material has a negative relationship with the compressive strength of concrete (Fig.6). This condition does not mean that Lusi cannot be used to manufacture good-quality concrete. Mud can be used to reduce the use of sand but at the recommended level to maintain the compressive strength of concrete (250 kg/cm^2). Furthermore, the analysis of the compressive strength of concrete was deepened with a statistical approach through the ANOVA test. The study was conducted to determine the difference in the compressive strength based on each percentage of the Lusi material.

Table 3 Analysis of variance

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	402374.12	3	134124.70	173.883	.000
Within Groups	21597.75	28	771.34		
Total	423971.87	31			

Tabel 4 Least square difference (LSD)

Lusi	Mean±St.Dev	p-value (α 0.05)			
		0%	5%	15%	25%
0%	498.75±32.46	-	0.000	0.000	0.000
5%	427.87±43.14	0.000	-	0.000	0.000
15%	301.25±6.71	0.000	0.000	-	0.000
25%	208.37±11.21	0.000	0.000	0.000	-

Furthermore, the results of the ANOVA test on the compressive strength of concrete with various percentages of Lusi addition demonstrate F-statistics of 173.883 with a significance value of 0.000 ($p < 0.05$). Therefore, there is a significant difference in the compressive strength of concrete based on the various percentages of Lusi material. Since the results of the ANOVA is significant, the post hoc analysis is required to determine whether or not each treatment produces concrete with a considerable difference. The post hoc analysis in this study is the least square difference (LSD).

In general, the results of the LSD test show a significance value of 0.000 (< 0.05); thus, it is confirmed that there are significant differences between all treatments that have been applied. The compressive strength of concrete tends to decrease as the percentage of the slurry mixture increases at a significant rate. These characteristics are also depicted through a regression graph (Fig. 7) which shows the direction of the relationship with a negative sign. The two statistical analyzes produce a clear idea that the use of Lusi material as a mixture in the manufacture of lining concrete should be based on the recommended percentage, which is 5%. If the Lusi mixture follows the recommendation, the utilization of Lusi material will be successful, minimizing the use of sand material and decreasing the environmental disruptions caused by the mudflow. Dagdag et al. [34] explained that Lusi has a significant impact on the environment (rivers and coasts) and harms public health; thus, any idea of mud utilization for any economic purpose is constantly needed.

An example of the successful use of natural materials that were previously only considered waste is the waste of coarse and fine sand from the mining activities of PT. Freeport Indonesia proved to save up to 40% of cement use [33]. The use of mud material from Lumpur Lapindo Sidoarjo has previously been proven to be potential for making paving blocks [35,36,37], filler in the manufacture of asphalt mix [38], cement mix [39,6,10], roof tile [40], and sandpaper [41]. By reflecting on these innovations, the idea of Lusi utilization needs to be further developed to reduce the impact of the disaster on the environment and present potential economic opportunities. Regarding the manufacture of concrete, the use of Lusi material can reduce the need for sand material which has a relatively higher price and is not a renewable natural resource.

5. CONCLUSION

Based on this study, the recommended ratio of Lusi material and sand is 5%:95%. 5% is a safe limit for Lusi addition as the compressive strength of lining concrete is 297.85 kg/cm^2, exceeding the requirement for K250 concrete (250 kg/cm^2). The utilization of Lusi material for concrete production is a good idea that can bring economic benefits and reduce the negative impact of the disaster on the environment. Future studies are suggested to develop an effective treatment to improve the quality of Lusi material before being used as additional material for concrete production, especially regarding the level of organic matter. Therefore, the concrete can be produced with a higher compressive strength by using more than 5% Lusi material.

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