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Sidoarjo Mud: A Potential Cement Replacement Material

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Abstract: This paper presents an experimental and analytical research conducted to study the properties of mortar when treated Sidoarjo mud was added into the mix replacing partially the cement content. The replacements were done at 0, 5, 10, 15, and 20%. Compression, tensile, porosity and Ultrasonic Pulse Velocity (UPV) tests were conducted to evaluate the effect of Sidoarjo mud in mortar. Analyses on the mud were also conducted through X-ray diffraction (XRD), X-ray Fluorescence (XRF), and scanning electron microscope with an energy dispersive X-ray analysis system (SEM-EDX). The results showed that the mud could be used as a cementitious material with optimum ordinary Portland cement (OPC) replacement at 10%.

Keywords: Sidoarjo mud, mortar, cement replacement material

Introduction

Sidoarjo mud has become a major issue when it surfaced from the bowels of the earth and impacted not only to the environment but also to the people at the vicinity. Observations collected indicated that the 27th May 2006 earthquake might have triggered [1] the eruption in Porong, Sidoarjo. Since 29th May 2006 the mud flows out continuously and spreads over the surrounding area. It has now covered more than 400 Ha of productive land and has completely immersed many villages.

The efforts to explore the preliminary finding [2] of the Sidoarjo mud and its potential use in geopolymer concrete have been conducted [3].

By and large improvement of concrete durability [4] and strength are the criteria in focus by many researchers. A large amount of research has been carried out to study both the durability and strength of concrete to obtain high performance concrete.

One of the basic aspects of the production of high strength concrete is the use of supplementary cementing material. Due to growing environmental concerns, the need to conserve energy and resources considerable efforts have been made worldwide to utilize local natural waste.

A study that examines the possibility of utilizing [5] the mud with the purpose of reducing the use of cement and mitigating the social impact of the mud in the environment [6-8] is a commendable effort.

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The mud has degree matrix elements similar to pozzolan chemical compositions. Its natural characteristic, that contains SiO_2 element, can be categorized as a cement replacement material. This is due to their capacity to react with calcium hydroxide (CH) [9] produced during the hydration of Portland cement. It is well known that the compounds formed during this pozzolanic reaction enhance concrete micro structure.

To produce an extremely good concrete the properties such as strength, compressibility, impermeability and resistibility must be taken into consideration. The aim of the study is to establish whether Sidoarjo mud known as hot mud from Jawa Timur, Indonesia, can be used as a supplementary cementitious material for concrete.

Experimental Detail

Figure 1 depicts the experiment conducted in this research that includes mud treatment, preliminary experiment, mix proportion and hardened concrete test.

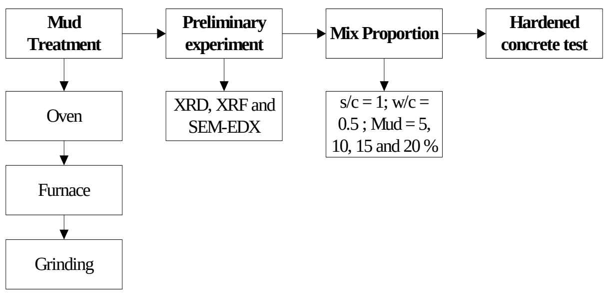

Figure 1. Experimental details

In this work, the solid mud was obtained from Porong, Sidoarjo, Indonesia. Fresh mud was heated up at 105 °C for 24 hours to remove the water content so that when it was burnt it would not produce large amount of smoke. In order to acquire improved quality pozzolanic powder, the mud was burnt until 600^{o}C for one hour duration using electrical furnace. The heat profile of the burning procedure is shown in Figure 2.

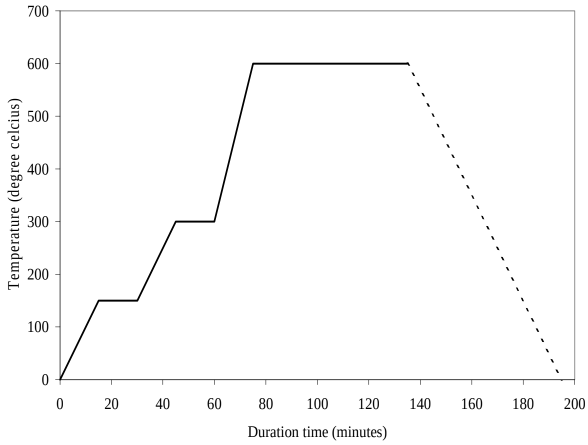

Figure 2: The heat profile for mud burning

Figure 3. The burned mud produced after grinding

Five kg of the mud was then ground (3000 cycles) in a ball mill to increase its fineness. The mud has particle size similar to cement and it could function also as microstructure filler at the interfacial transition zone (ITZ). The ordinary Portland cement (OPC) particle was in the range of 100 micron in size and the mud was sieved to obtain particle which was smaller than 100 micron. The burned mud that was processed by burning and grinding is presented in Figure 3. The presence of silica in the mud was then verified with scanning electron microscope with an energy dispersive X-ray analysis system (SEM-EDX) and X-ray Fluorescence (XRF) equipment.

Energy dispersive X-ray (EDX) is an analytical technique used for the elemental analysis or chemical characterization of a sample. X-ray fluorescence (XRF) is a spectroscopic method that is commonly used for solids in which secondary X-ray emission is generated by excitation of a sample with X-rays. X-Ray Diffraction (XRD) can be used to analyze the crystalline properties of a material. Graph patterns of XRD analysis can show whether the material is in amorphous, partially crystalline, or crystalline state.

To understand the effect of Sidoarjo mud on hardened concrete, various test where conducted in the laboratory. The detail such as sample size, number of sample, age of test and standards are shown in Table 1

Table 2 shows the chemical composition of OPC used in the experiment. Five different mixes with percentage replacement of OPC by Sidoarjo mud at 0, 5, 10, 15, and 20% OPC replacement were adopted. Water cement (w/c) ratio was taken as 0.5 and sand cement (s/c) ratio was capped as 1.

Table 1. The macro structure experimental details

Test	Sample Description			Standard	Unit	Measure	Equipment
	Size (mm)	No	Age (days)				
Strength	50 x 50 x 50	3	3,7,28	BS1881:Part 116:1983	N/mm²	Compression	Compression testing machine (3000KN)
Tensile	100 x 200	3	28	BS1881:Part 117:1983	N/mm²	Split/ Tensile	Compression testing machine (3000KN)
Porosity	1" x 2"	3	28	BS1881:Part 124:1988	%	Ratio of void or air spaces	Vacuum bowl and weighing machine
UPV	50 x 50 x 50	3	3,7,28	BS1881:Part 201:1986	km/s	Integrity	UPV testing machine

Table 2. Chemical properties of OPC

Oxide composition	OPC, weight (%)
Na2O	0.02
MgO	1.43
Al2O3	2.84
SiO2	20.40
P2O5	0.10
K2O	0.26
CaO	67.70
TiO2	0.17
Fe2O3	4.64
SO3	2.20
SO2	0.16

Results and Discussions

Microstructure Analyses

Table 3 and Table 4 show the chemical properties of Sidoarjo mud before and after burning that were identified using SEM-EDX and XRF equipment respectively. Whilst Figure 3a and 3b show the SEM micrograph of mud before and after burning. Both mud samples have similar smooth, dense and compacted surface. Figure 4 describes the properties of mud in term of its amorphousness.

Table 3. The results achieved by SEM-EDX

Element	Before burning, (%-mol)	after burning, (%-mol)
C	15.2	12.7
O	45.1	51.7
Na	0.9	0.9
Mg	1.0	1.1
Al	9.4	8.1
Si	19.6	21.4
Cl	0.7	0.6
K	1.5	0.3
Ca	1.1	1.0
Ti	0.7	1.7
Fe	4.8	0.4
Total	**100.0**	**100.0**

Table 4. The results achieved by XRF

Oxides	before burning, (%)	after burning, (%)
CaO	4.897	4.692
SiO2	54.9	56.08
Al2O3	20.44	20.64
Fe2O3	10.64	9.616
K2O	2.352	2.271
MgO	1.76	1.8
SO3	1.31	2.01
MnO	0.213	0.202
ZnO	0.0174	0.0149
Rb2O	0.01	0.0095
Cl	1.14	0.611
P2O5	1.06	0.927
Br	0.008	0
TiO2	1.16	1.06
ZrO2	0.0231	0
CuO	0	0.0028
SrO	0.07	0.0653
Total	100	100

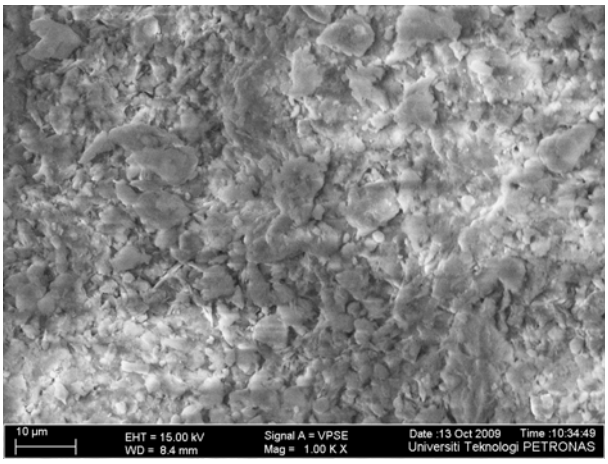

Figure 3a. SEM micrograph of mud before burning

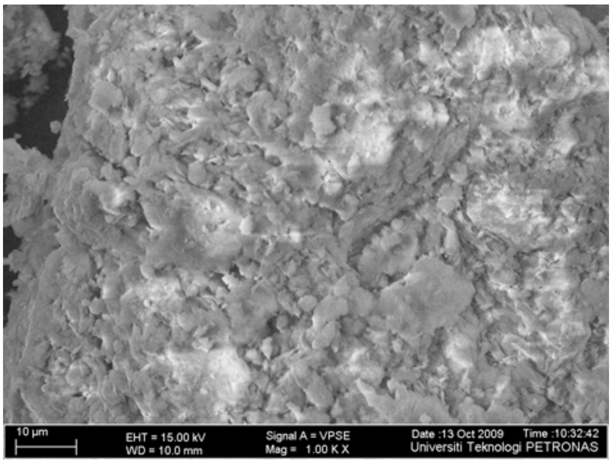

Figure 3b.. SEM micrograph of mud after burning.

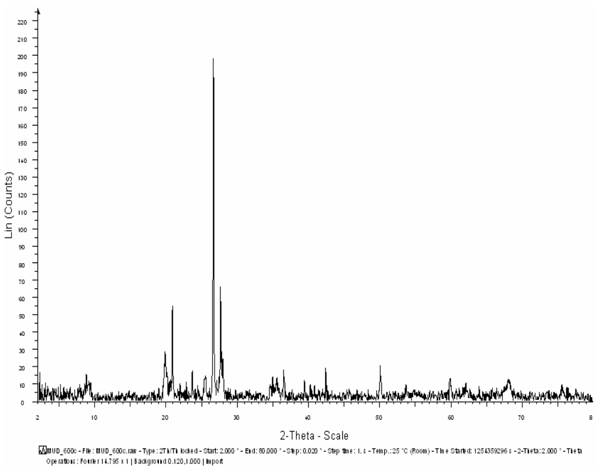

Figure 4. XRD result of mud after burning

Compressive Strength

The strength development of mortar containing various percentages of Sidoarjo mud was monitored at ages 3, 7, and 28 days. Figure 5 shows the compressive strength result of the various mix proportion plotted against time.

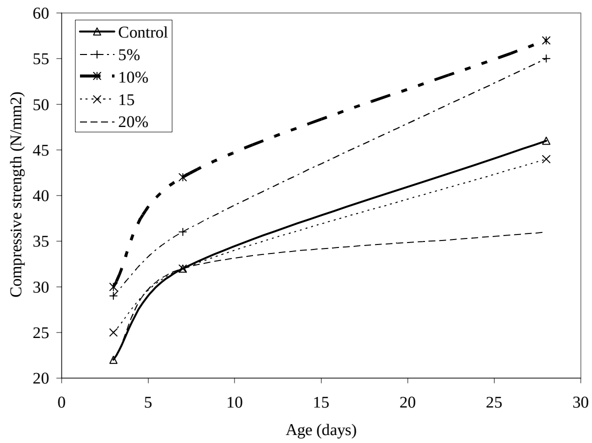

Figure 5: Compressive strength development against time

It can be seen that the concrete strength is affected by the percentage of mud inclusions. It is evident that 10% of mud reacted well with the mixture of mortar and depict higher compressive strength compared to all other types of mortar at all ages. The 5% mixture also showed higher compressive strength compared to OPC samples but on the contrary lower compressive strengths were obtained for 15% and 20% replacement levels. At 28 days percentage differences, with respect to OPC samples of about 30%, 20%, -5%, -30% were obtained for 10%, 5%, 15% and 20% replacement respectively. Judging from the results obtained for 5% and 10% replacements it can be concluded that the mud can be used as a cement replacement material.

Tensile Strength

Figure 6 shows the effect of mud on tensile strength of concrete. It is evident that Sidoarjo mud concrete regardless of percentage replacement showed better tensile strengths compared to normal OPC mortar. It was also found that 10% replacement gave the highest tensile value i.e. 9.3% higher than control sample. The samples with 5%, 15% and 20% mud replacements showed 5.8%, 5.8%, 4.0% increase compared to normal concrete respectively. It is believed that chemical contents such as calcium, silica, and alumina were instrumental in enhancing the cement reaction hydration process.

Porosity

The technique of vacuum saturation is conducted to measure the porosity of the mortar. Experts have widely agreed for decades that the use of pozzolana or supplementary cementing materials (SCM) can reduce porosity. Figure 7 shows that the mud reduces the void ratio in the mixture. During hydration process, calcium hydroxide reacted with the pozzolana and increased the interlocking capability in the mixture. It is evident that this mud can reduce the void in the mixture and 10 % replacement seems to be giving the least porosity. A reduction of porosity of about 6% can be seen from the 10% inclusion whereas the other percentage inclusions did not have significant difference compared to OPC samples.

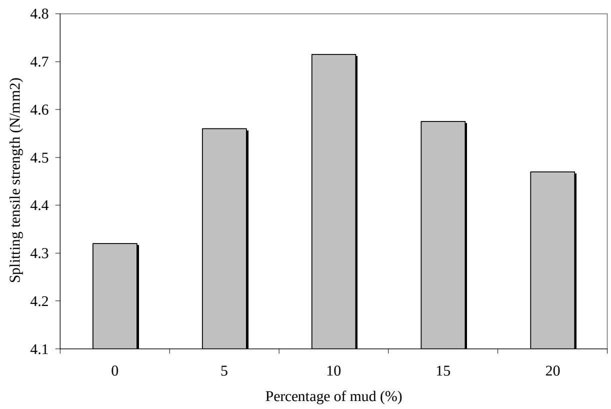

Figure 6. Tensile strength at 28 days

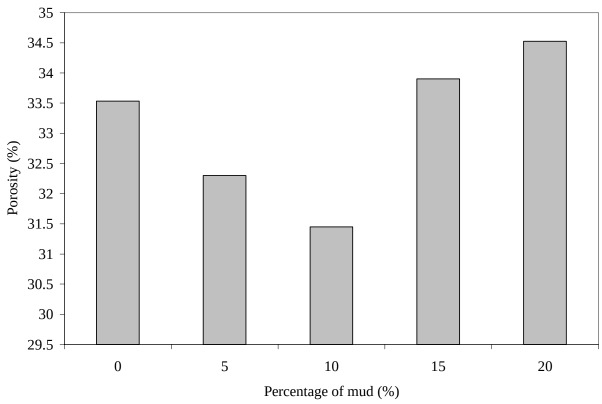

Figure 7. Porosity level

Integrity

Figure 8 shows the UPV test results for the various percentages of mud replacements. Again it was found that 10% replacement showed the best result even though the difference is very small (about 1.8%) as compared to control OPC sample. After 10% replacement, UPV values decreased with increasing mud replacement as it occurred for compressive strength.

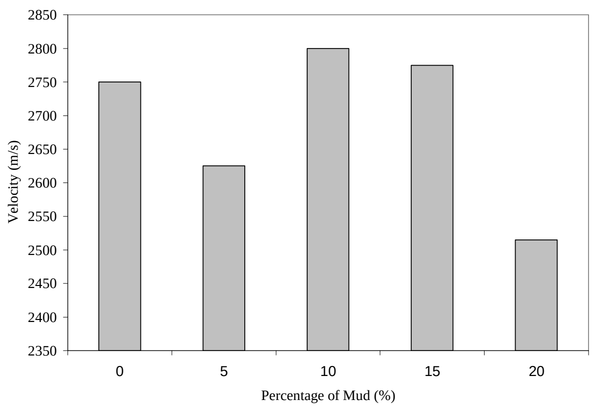

Figure 8. UPV test results

Conclusion

In conclusion, it can be confirmed that treated Sidoarjo mud from Porong, Sidoarjo, Jawa Timur, Indonesia can be utilized as a cement replacement material with 10% replacement as the optimum value. Sidoarjo mud can improve the compressive strengths, integrity and able to reduce the porosity of mortar. Nevertheless, its influences on tensile, porosity and integrity are small as compared to compressive strength. Utilization of this material, as cement replacement material, that is available in abundance in Sidoarjo can not only mitigate social and environmental problems but also improve concrete properties.

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