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EFFECTS OF STICKY RICE ON COMPRESSIVE STRENGTH OF CEMENT STUCCO CONTAINING LIME AND SLAG

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Abstract: As the concept of green building becomes increasingly popular, it is beneficial to find an eco-friendly stucco with better mechanical property and durability. As a traditional organic admixture, sticky rice has been widely used in the construction of ancient Chinese architectures, and it has been demonstrated that adding small quantity (up to 1%) of sticky rice can significantly improve the compressive strength of lime mortar. This paper studies the 56-day compressive strength of cement-based stucco as affected by sticky rice slurry, lime and slag contents. The results show that the 56-day compressive strength of stucco decreased with lime and sticky rice (higher than 1%). The highest strength was achieved with 1% sticky rice, 10% lime and 30% slag.

1 INTRODUCTION

Sticky rice mortar is one of the most widely used building materials in ancient times. It was first found applied to the brick tombs of Deng County, Henan Province, during the Northern and Southern Dynasties, Yang *et al*. (2010). Archaeologists detected sticky starchy substances in the cementation material of the tomb. In the third century, the application of sticky rice mortar has already become a relatively mature technology, Peng and Jackson (2015). From the archaeological findings, sticky rice mortar is mainly used for tombs, urban construction and water conservancy projects, Qiu (1980). Today, many ancient buildings using sticky rice mortar, such as the ancient city walls in Nanjing and a Qing Dynasty stone pagoda located in Baohe Town of Chongqing, which was built in the 16th century with a height of 10 meters and an inclination of more than 45°, still have high compressive strength, despite the erosion of wind and rain, Song (2008). It has been found that the sticky rice slurry acts as a biomineralization templating agent in the hydration reaction of the cementitious material, which guides the size, shape and structure of the crystalline particles, Wei *et al*. (2012). In this process, the particles of the sticky rice paste and the cementitious material distribute evenly, and wrap each other, making the structure of the hydration products denser. This dense microstructure contributes to higher sticky rice mortar compressive strength and surface hardness of the micro-based foundation, Zeng *et al.* (2008). Similar typical organic / inorganic composite structures are found in bones and shells of animals as well. It was also found that the alkaline environment formed by the alkaline materials can inhibit the growth of bacteria and has a preservative effect on the sticky rice paste, which can improve the durability of the material, Yang *et al.* (2010). The study of contemporary applications of sticky rice mortar is of significance in improving the strength of the material and the durability of the structures where this material is used in small quantity (up to 1%). Furthermore, studies have found that after the slag was added to the sticky rice mortar, the process of the biomineralization reaction was accelerated, and the microstructure of the mortar became much denser, Qiu (2014). As an industrial waste, slag can chemically react with cement and lime, and its utilization can also reduce environmental pollution.

As a durable and inexpensive building material for inner and exterior walls, cement-based stucco containing lime and other cementitious material such as slag and fly ash is gaining popularity during the last decade. However, few studies have been done to optimize the mix proportion. Moreover, incorporating sticky rice might be as beneficial to stucco as it is to mortar. In this paper, the effect of sticky rice, lime, and slag on cement-based stucco will be studied from the perspective of improving the compressive strength and durability of stucco.

2 MATERIAL AND EXPERIMENTAL METHODS

2.1 Material

The materials used for the stucco mixture were the following:

- Lime: High calcium hydrated lime with a calcium content of 48% and a neutralizing value ($CaCO_3$) of 130%;
- Slag: Ground granulated blast-furnace slag which meets the requirements of CSA A3001;
- Cement: General Use Portland Cement which meets the requirements of CSA A3001;
- Sticky rice slurry: The sticky rice flour comes from Golden Panda Inc. To make the sticky rice slurry, sticky rice flour and water were mixed together with a sticky rice/water ratio of 0.1. The mixture was stirred and poured into a rice cooker and boiled for an hour. Water was added regularly during this process to keep the water level unchanged.
- Plasticizer: superplasticizer which meets the requirements of ASTM C494;
- Water: Tap water.

2.2 Mix proportion and nomenclature

In this study, the water to cementitious material ratio was set at 0.47, and the cementitious material to sand ratio was set at 0.5. Based on the total mass of cementitious materials, three different ratios of sticky rice (1%, 2% and 3%), slag (15%, 30% and 50%), and lime (10%, 20% and 30%) were chosen for this study. The rest of the cementitious material was Type GU Portland cement.

2.3 Preparation of specimens

Workability is an important parameter in stucco applications. If the mix is too dry and harsh, it would be difficult to place; if the mix is too fluid, segregation can occur. The flow diameter, as measured following the procedure of ASTM C1437, was controlled to 260 ± 10 mm by adding appropriate amounts of superplasticizer for all the mixes in this study.

For each mix, three cubes of 50x50x50 mm were prepared following the procedure of ASTM C109. After 24 hours, the moulds were removed and the specimens were wrapped with plastic sheet and placed in a curing chamber at 23 ± 1°C. The test age was set to 56 days as the mixes contain large amount of cementitious materials.

2.4 Compressive strength test

The procedure of ASTM C109 was followed to perform compression tests using an ELE compression machine with a capacity of 2000 ±0.05 kN. The load was then applied at a rate of 0.02 MPa/s.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Results of compressive strength tests

The compressive strength of each specimen at 56 days is shown in Table 1. The average compressive strength X, the standard deviation S and the coefficient of variation CV (= S/X) are also presented. It can be seen that the results are very consistent for all the mixes with CV values under 2% in most cases.

Table 1: Compressive strength (MPa) at 56 days

Mix	Compressive strength			Average	S. dev.	CV = S/X
	X_1	X_2	X_3	X	S	(%)
R1L10S15	50.1	50.8	51.4	50.7	0.62	1.2
R1L10S30	58.3	57.2	57.6	57.7	0.57	1.0
R1L10S50	48.9	48.1	48.6	48.5	0.42	0.9
R1L20S15	44.3	45.4	45.2	45.0	0.61	1.3
R1L20S30	44.3	44.7	45.1	44.7	0.45	1.0
R1L20S50	43.6	43.1	44.3	43.7	0.56	1.3
R1L30S15	42.1	42.9	42.0	42.3	0.48	1.1
R1L30S30	42.1	41.5	40.6	41.4	0.75	1.8
R1L30S50	33.3	33.6	32.9	33.2	0.34	1.0
R2L10S15	44.3	44.9	45.4	44.9	0.57	1.3
R2L10S30	49.9	50.2	51.4	50.5	0.80	1.6
R2L10S50	47.6	47.7	48.8	48.0	0.65	1.4
R2L20S15	41.7	42.0	43.4	42.4	0.94	2.2
R2L20S30	40.7	39.7	40.2	40.2	0.48	1.2
R2L20S50	43.9	43.9	42.1	43.3	1.06	2.4
R2L30S15	42.4	42.8	42.2	42.5	0.32	0.8
R2L30S30	39.9	40.1	39.4	39.8	0.36	0.9
R2L30S50	34.4	35.2	34.2	34.6	0.52	1.5
R3L10S15	43.1	42.6	41.8	42.5	0.63	1.5
R3L10S30	44.7	42.9	43.3	43.6	0.99	2.3
R3L10S50	41.9	40.9	41.1	41.3	0.56	1.3
R3L20S15	42.4	41.8	42.3	42.2	0.36	0.9
R3L20S30	45.3	47.2	46.2	46.2	0.96	2.1
R3L20S50	47.7	45.8	46.2	46.6	0.99	2.1
R3L30S15	44.1	43. 9	43.8	43.9	0.19	0.4
R3L30S30	43.5	44.6	41.6	43.2	1.51	3.5
R3L30S50	37.2	39.8	39.3	38.7	1.36	3.5
R0L10S30	52.7	53.8	53.1	53.2	0.54	1.4

Nomenclature used: letters R, L and S are short for sticky rice, lime and slag respectively. The number following each letter represents the ratio in percentage.

3.2 Effect of lime on compressive strength

To illustrate the effects of lime, the stucco's 56 day compressive strengths containing 1% sticky rice are shown in Figure 1. It can be observed that the strength decreased as the lime proportion increased for all the three groups (S15, S30 and S50). The stuccos achieved the highest strength with 10% lime. The same trends were observed for nearly all groups with other sticky rice proportions (2% and 3%). Similar results were reported by Pandey and Sharma (2000) for mortars. It can be concluded that increasing lime proportion is not beneficial in terms of 56 day compressive strength of stucco.

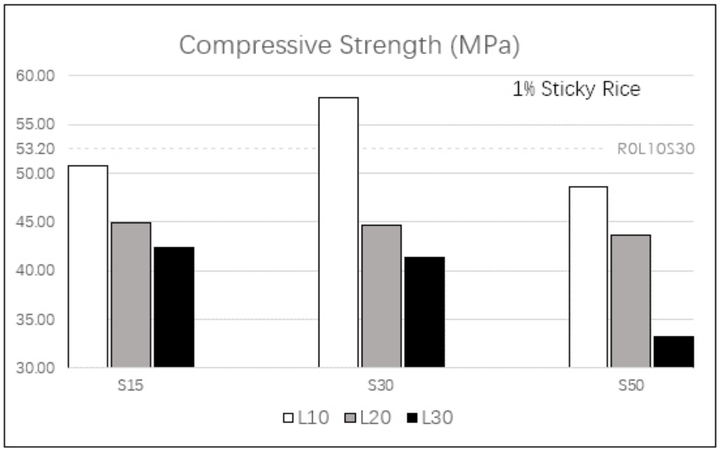

Figure 1: Effect of lime on 56-day compressive strength

3.3 Effect of slag on Compressive strength

Figure 2 shows the stucco's 56-day compressive strength of mixes containing 10% lime. Within each of the three groups (R1, R2 and R3), the stucco's compressive strengths increased when the slag proportion increased from 15% to 30%, but decreased when the slag proportion increased from 30% to 50%. The highest compressive strength were achieved with 30% slag. This result is consistent with the findings of Liu (2015), where he reported that when replacing 30% of cementitious material with slag, the compressive strength increased at first, and then declined when the replacement ratio reached 45%. Furthermore, the highest compressive strength of each group dropped with higher proportions of sticky rice.

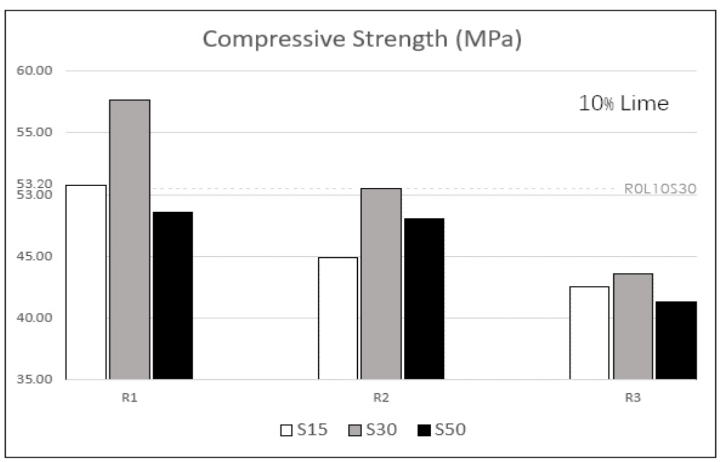

Figure 2: Effect of slag on 56-day compressive strength

3.4 Effect of sticky rice on compressive strength

Figure 3 shows the stucco's 56 day compressive strength of specimens, as affected by sticky rice proportion, for mixes containing 10% lime. As shown in the figure, the compressive strength gradually decreased as the sticky rice proportion increased from 1% to 3%, for all the three groups (S15, S30 and S50). The stucco achieved the highest compressive strength with 1% sticky rice. Similar results were also observed for the other groups containing 20% and 30% lime. This is in accordance with previous findings reported by Peng and Jackson (2015) which concluded that mortar with 1% rice had the highest compressive strength at 28 days, and they also concluded that sticky rice contributed to refining the calcite grain size and microstructures. To confirm this finding, one more mix (R0L10S30) were tested and the results are shown in Table 1 and Figure 3. As compared to the mix R1L10S30, adding 1% sticky rice improved the 56-day compressive strength by about 8%.

It can also be seen that the mixes containing 30% slag achieved the highest strength among the three groups.

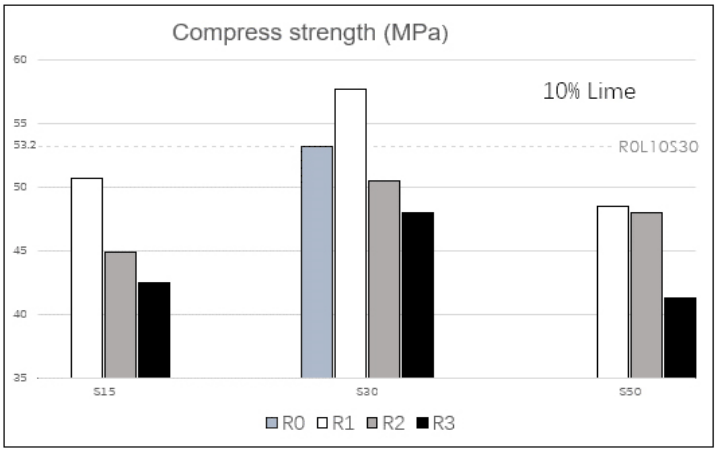

Figure 3: Effect of sticky rice on 56-day compressive strength

From Table 1, it can be observed that, among all the mixes studied, the highest compressive strength was achieved with the mix R1L10S30 which contains 1% sticky rice, 10% lime and 30% slag. This mix is considered as the optimal for this study and will be used for field tests in future studies.

4 CONCLUSIONS

From the findings of this study, the following conclusions can be drawn:

1. Cement-based stucco mixes with reasonable workability can be formulated with lime, slag and sticky rice slurry.
2. The 56-day compressive strength decreased as the lime proportion increased.
3. The 56-day compressive strength increased when the slag proportion increased from 15% to 30%, but decreased when the slag proportion increased form 30% to 50%. The highest compressive strength was achieved with 30% slag.
4. The 56-day compressive strength gradually decreased as the sticky rice proportion increases from 1% to 3%. It is therefore recommended to not use sticky rice with a dosage higher than 1%.
5. The highest 56-day compressive strength was achieved with the mix containing 1% sticky rice, 10% lime and 30% slag.

Further investigations need to be done for the long-term durability of such mixes.

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