Journal of Materials and Construction
ISSN 2734-9438
Website: www. jomc.vn

Rainfall erosion of natural fibers cement treated mud

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KEYWORDS

Rainfall erosion
Mud
Natural fiber
Soil loss

ABSTRACT

An This study evaluated the possible application of inexpensive mud stabilization treatments for the purpose of reducing soil erosion. The soil erosion was investigated by measuring soil loss over the surface of compacted specimens made by natural fibers cement treated mud exposed to a rainfall test sequence. The compacted specimens were made by adding 5 kg/m^3 to 50 kg/m3 cement and 0 kg/m^3 to 20 kg/m^3 natural fibers to 40 % to 60 % water content mud. The results showed that the increasing of either cement content or natural fibers content reduced the soil erosion from 50 % to 80 %. Furthermore, a numerical function was developed to predict the value of soil loss of the treated mud based on the ratio of cement content, natural fibers content and initial water content. experimental push-out test was carried out on 12 specimens in 6 groups to investigate the mechanical behavior of shear connectors in cold-formed steel-concrete composite beams. Specimen groups have differences in rivet spacing, shear connector spacing, tab aspect, and rebar through shear connectors. The mechanical behavior was evaluated through quantities such as shear resistance, relative slip between the steel beam and concrete slab, and failure modes. The results show that screw significantly affects the mechanical behavior of shear connectors in cold-formed steel-concrete composite beams.

1. Introduction

Soil erosion – the loosening, detachment, and transportation of soil particles from their initial position – can generally be attributed to natural processes such as rainfall, runoff, wind, and landslides, as well as to man's activities which alter the natural protective cover of the ground surface [1]. Soil detachment is the first step in the process. It is a mechanical process that requires energy. Raindrop erosion is recognized as being responsible for four effects: disaggregation of soil particles, minor lateral displacement of soil particles, splashing of soil particles into the air, selection or sorting of soil particles by raindrop impact, which may occur as results of the forcing of fine particles into soil voids causing the infiltration rate to be reduced and the splashing selection of detached soil particles.

In previous studies, soil losses decreased with increasing soil particles size [2, 3]. Soil loss through erosion was significantly lowest in the kaolinitic, highest in the montmorillonitic, and intermediate in the non-phyllosilicate soils [4-8]. Also, the splash erosion was increased with the increase in rainfall intensity [9, 10].

The mechanism of soil detachment by raindrop impact could be related to the soil's shear strength and surface and thickness of the film of water covering the surface. A drop strikes at the early stages of impact and then spreads out in all directions at variable heights.

The penetration and spread depend on the soil's surface condition, especially water content. The soil under the impact area is strained vertically. The magnitude of this strain is proportional to the magnitude of the applied load and the area of its application as determined by raindrop size and velocity and by soil deformation characteristics as determined by its shear strength [11, 12]. As soil shear strength increases, the depth and the total volume of the soil detachment caused by the raindrop decreases. When the shear strength of soil increases, the soil becomes more resistant to deformation under applied forces, compressive stresses due to raindrop impact are transformed to shear stresses along with the soil-water interface. The amount of splash soil depends on soil deformation during the early stages and on the cohesive forces resisting the shear stresses. Fig. 1 shows the schematic diagram of the splash mechanism.

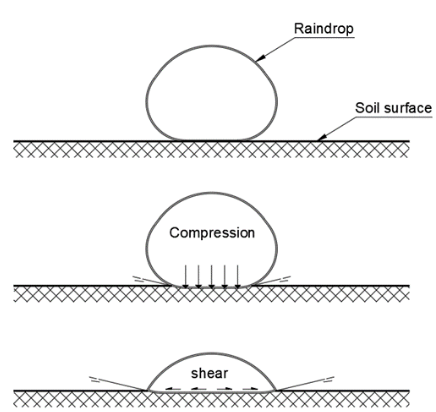

Figure 1. Schematic diagram of splash mechanism.

A setup on natural rainfall simulation is not possible due to physical limitations such as fall height, the terminal velocity and kinetic energy of artificial drops [10]. Few commercial suppliers

* Corresponding author,
Received 18/04/2023, explanation 17/5/2023, Accepted 11/06/2023
Link DOI: https://doi.org/10.54772/jomc.v13i01.511

of rainfall simulators, so it usual for research workers to build their own [13]. However, a considerable amount of literature reports the building and testing of rainfall simulators. Large simulators are expensive and need teams of trained operators, so it is outside the scope of this study, which will look at some inexpensive and straightforward simulators.

The main objective of this study is to investigate the relative erosion behaviors of natural fiber-cement-reinforced mud under artificial rainstorm. Further, an empirical equation to predict the soil detachment will be discussed.

2. Materials and procedures

The remolded mud was reinforced by adding rice straw (RS) fibers and cement. The particle size distribution and mechanical properties of the mud are presented in Fig. 2 and Table 1, while the mechanical properties of rice straw fibers are listed in Table 2. According to the unified soil classification system, the soil type was classified as clay with high plasticity (CH).

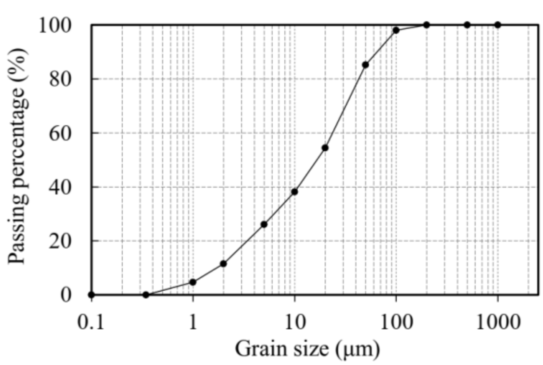

Figure 2. Particle size distribution of sludge.

Table 1. Mechanical properties of mud.

Properties	Value
*D*50 (μm)	17.2
Dry density (kg/m^3)	2467
Liquid limit (*LL*, %)	46.1
Plastic limit (*PL*, %)	29.4
Plastic index (*PI*, %)	16.7
Optimum water content (%)	28.4

Table 2. Rice straw fiber properties.

Properties	Values	Unit
Water absorption	290-310	(%)
Bulk density	30-50	(kg/m^3)
Moisture	3-6	(%)
Length	13.2 ± 6.3	(mm)
Width	0.2 ± 0.1	(mm)
Tensile strength	4.2-246.2	(MPa)

Laboratory rainfall apparatus was designed to imitate the effects of rainstorms on the erosion of the reinforced-mud. Fig. 3 is a sketch of the rainfall apparatus. The apparatus was set to 1.8 meters in drop-falling height. The raindrop formers were optimally spaced in equilateral triangular configurations to obtain an effectively uniform distribution of raindrops over the area exposed to rainfall. The rainfall intensity was controlled by regulating the flow through the drop formers using a needle valve in the water supply line.

The testing procedure is described as follows and shown in Fig. 4.

- Distilled water was added to the oven-dried mud to achieve an initial water content.
- Compose modified-mud pastes by inclusion of rice straw fibers and cement into the wet mud.
- Securely cure the modified-mud at 20 ^{0}C for 3 days in container to ensure no water evaporation.
- Make specimens by compaction method.
- Securely cure the specimens for the next 7 days at 20 ^{0}C.

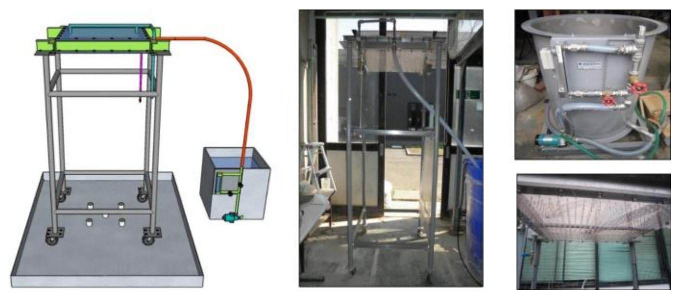

Fig. 3. Rainfall simulator apparatus.

The soil specimen sizes were set to 5 cm in diameter and 5 cm in height. It was designed to get effectively soil loss based on considering two effects [14]:

- Rim effect (effect of boundary of specimen): when the specimen surface is lower than its container, the specimen becomes more difficult to be splashed out.
- The wash-off effect: describes the effect of the water layer thickness on the specimen surface of splash cup following by soil loss caused by surface run-off. If the size of specimen becomes larger, the run-off water velocity on the surface of specimen decreased. It becomes more difficult to wash-out the water. As results, the thickness of water layer on the surface gets thicker and it reduces the effect of rainfall.

The impact energy of raindrops on soil erosion could be shown in the term of kinetic energy [15]. The kinetic energy can be measured by several methods such as laser distrometer, optical spectro Pluviometer, and empirical functions. In this study, it is difficult to get laser distrometer and optical spectro Pluviometer to measure kinetic energy. Moreover, the empirical function of kinetic energy depends on many factors including raindrop diameter and terminal velocity of raindrops [16]. Therefore, in this study, the rainfall intensity and kinetic energy are set as a constant value. The testing conditions are changed by changing cement content, rice straw fibers content, and initial water content of remolded mud. The rainfall intensity was set to I = 500 mm/h. The raindrop size was approximately 3 mm.

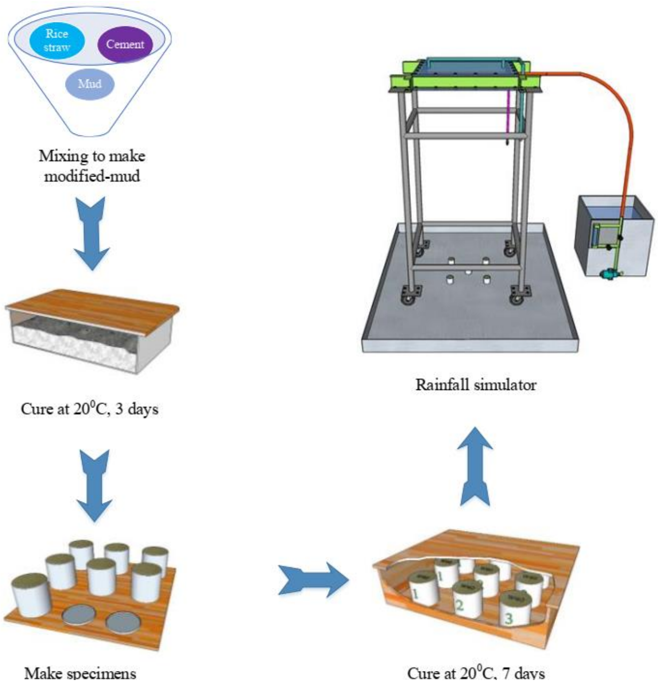

Fig. 4. Procedure of the rainfall simulator test.

3. Results and discussions

Table 3 shows the testing conditions and Fig. 5 shows the results of rainfall erosion tests. From the results, the soil loss was decreased with increasing of cement content. It was because the shear strength of the modified-mud was increased by inclusion of cement. These results were similar to the results in previous research [11, 12]. Moreover, an increase in rice straw fibers content, the soil loss decreased. This is because the rice straw fibers absorbed free water content in the remolded mud, and as a result the density of the modified mud increased under compaction. Thus, the shear strength of the modified-mud also increased. Furthermore, by adding rice straw fibers, the specimen's surface rate affected by raindrops decreased. Because of apparatus limitation, the other rainfall characteristics such as kinetic energy, fall velocity, and intensity changing were not investigated. Also, the rainfall intensity I = 500 mm/h seems more significant than natural rainfall in Vietnam [17] (usually between 100 – 300 mm/h).

That is because of the limitation of the raindrop fall height of the experiment's apparatus. As a result, the rainfall terminal velocity is less than natural rainfall. However, the results could be used for studying the relative changing of soil loss of fiber-cement-reinforced mud. And, more studies should be carried out to determine the difference between artificial and natural rainfall.

Table 3. Testing conditions.

Initial water content (%)	Amount of cement (kg/m^3)	Amount rice straw fibers (kg/m^3)
	5	0, 5, 10, 20
4 0		0, 5, 10, 20
	15	0, 5, 10, 20
	25	0, 5, 10, 20
6 0		0, 5, 10, 20
	35	0, 5, 10, 20
	40	0, 5, 10, 20
8 0		0, 5, 10, 20
	50	0, 5, 10, 20

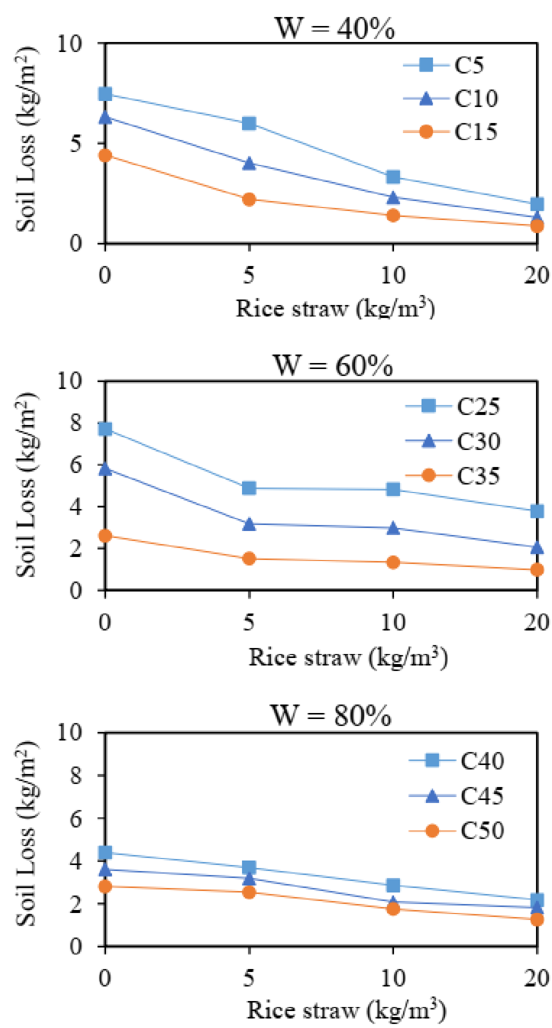

Fig. 5. Rainfall erosion test results.

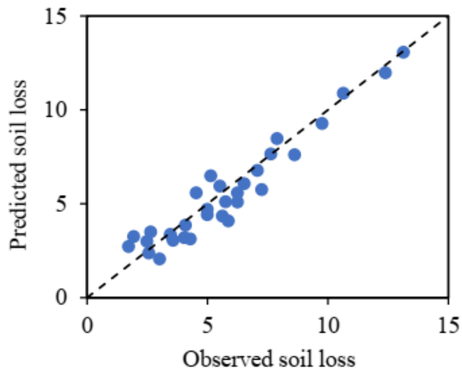

Fig. 6. Predicted and observed soil loss data.

Furthermore, a numerical model was developed to predict the value of soil loss for the modified-mud. The factors which affected to the soil loss value were the initial water content of mud (w), amount of cement content (C), and amount of rice straw fiber content (RS). The combining effects of these parameters could be seen in two factors such as the ratio of C/w and RS/w. Second order two variables polynomial formula was applied. The formula is described as follows. The constraint was p-value ≤ 0.05. Fig. 6 shows the predicted and observed soil loss data.

$$SL = 14.154 - 106.9\frac{C}{w} - 428.1\frac{RS}{w} + 3432\left(\frac{RS}{w}\right)^2 + 2953\frac{C}{w}\times\frac{RS}{w} \quad (1)$$

Where: SL: dried-soil loss (kg/m^2), C: cement content (kg/m^3), RS: rice straw fiber content (kg/m^3), w: initial water content of mud (%).

4. Conclusions

In the study, rainfall erosion characteristics of rice straw fiber-cement-reinforced mud were investigated. Based on the experimental data, some conclusions could be drawn.

- With an increasing of either cement content or rice straw fiber content, the soil loss of the modified mud reduced due to it's the increase of shear strength.
- A numerical function was developed to predict the value of soil loss of the modified-mud. The factors which affected to soil loss value were the ratio of C/w and RS/w.

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