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Enhance Biyagama water treatment plant sludge properties with natural and synthetic binders

Himahansi Galkanda
Department of Civil Engineering
University of Moratuwa
Moratuwa, Sri Lanka
himahansi.galkanda@gmail.com

Harsha Galabada
Department of Civil Engineering
University of Moratuwa
Moratuwa, Sri Lanka
hyasasiri@yahoo.com

P. Dhammika Dharmarathna
Department of Civil Engineering
University of Moratuwa
Moratuwa, Sri Lanka
makway.cons@gmail.com

Malsha Mendis
Department of Civil Engineering
University of Moratuwa
Moratuwa, Sri Lanka
malsharesearch@gmail.com

Renuka Nilmini
Department of Materials and
Mechanical Technology
University of Sri Jayewardenepura
Homagama, Sri Lanka
nilminil@sjp.ac.lk

Rangika Halwatura
Department of Civil Engineering
University of Moratuwa
Moratuwa, Sri Lanka
rangikauh@gmail.com

Abstract—Alum sludge is an inevitable waste product produced in the drinking water treatment process. In the Biyagama water treatment plant the sludge generation is estimated as 10 m³ per day. Shrinkage was identified as the main drawback of the sludge to use as a construction material. According to the historical evidence, natural binders were added to soil mixtures to overcome the shrinkage. Therefore, this study was conducted to identify the performances of both natural and synthetic binders to enhance the properties of Biyagama water treatment plant sludge to overcome the shrinkage. In the study styrene acrylic binder as the synthetic binder and extractions of Dawulkurundu leaf, Bhoomi bark, and Bael fruit as the natural binders were selected. In the first phase of the study, natural binders were prepared and the synthetic binder was purchased from the market. In the second phase of the study, sludge mixtures were prepared by mixing with binders in a mechanical mixer. The initial moisture content of each mix was measured according to the oven-dry method and an observational shrinkage test was conducted. Results indicated that both natural and synthetic binders affect the shrinkage in different ways according to the binder type, while increasing the adhesiveness of the mix. Different crack patterns were observed according to the binder type and the binders increased the adhesiveness of the mixture. It is concluded that both synthetic and natural binders enhanced the properties of Biyagama water treatment plant sludge, and further studies should be conducted to finalize the optimum mixing ratios of each binder type.

Keywords—Biyagama water treatment plant sludge, natural binders, observational shrinkage, synthetic binders

I. INTRODUCTION

Water is one of the basic needs of humans, as well as the main requirement of all living creatures. It was estimated that a human can survive only for three days without drinking water. The average water requirement of humans has differed with biological factors, such as age, gender, weight, etc., and with climatic factors [1]. The average water requirement is higher in hot climatic zones compared to the temperate climatic zone. As a tropical country, the Sri Lankan average drinking water requirement per person is much higher. Access to a sufficient amount of drinking water with the required quality is important for humans, physiologically as well as psychologically, because, water is a basic requirement for the effective maintenance of metabolic activities of the human body [2]. Therefore, secure access to a sufficient amount of clean drinking water is one of the main responsibilities of the country [3, 4].

Sri Lanka is a country, rich with high-quality natural water resources compared to the other countries in the world. But with urbanization and industrialization, access to safe water is restricted in most of the urban areas of the country at present. Therefore, the Sri Lankan government has to provide sufficient, safe drinking water to the residences in urban areas of the country. The national water supply and drainage board (NWSDB) is responsible for the drinking water supply of the country [5]. The NWSDB provides its service along with 323 major, medium, and small water supply schemes operated all over the country [6]. In the water supply schemes, water from surface water reservoirs were collected and treated to achieve drinking quality through water treatment plants before the distribution. Water treatment is important because impurities such as sand, silt, clay, humic particles, and other contaminants are suspended in surface water as a result of surface runoff and effluent discharge from urban and industrial sources [7].

Drinking water treatment plants (DWTP) consist of processes of coagulation, flocculation, sedimentation, filtration, and disinfection [7]. In the coagulation process chemical coagulants; such as alum (KAl(SO₄)₂), lime (Ca(OH)₂), and polymers, are usually added to remove colloidal and suspended impurities such as sand, silt, clay, and humic particles. Flocculation and sedimentation processes let the sludge, consisting of organic and suspended matter, coagulant products, microorganisms, and chemical elements, settle and be removed in the filtration process. In the disinfection process treated water is disinfected by adding chlorine (Cl₂). The sludge is an inevitable waste product generated in DWTP [8].

Biyagama DWTP consists of two intake structures, a raw water regulation tank, a mixing chamber, six flocculators/clarifiers, eight filters, and a clear water/contact tank. The plant collects raw water from the Kelani River and produces 180,000 m³ of drinking water per day, which covers 1,000,000 of the population. The plant has a sludge treatment plant to dewater the sludge and to remove solid sludge. The sludge treatment plant consists of two wash water recovery tanks, a sludge balancing tank, a sludge thickener tank, a thickener sludge tank, and two sludge decanters. In the sludge treatment plant, water is recovered from sludge and feedback to the DWTP. The dewatered solid sludge generation is estimated at 10 m³ per day.

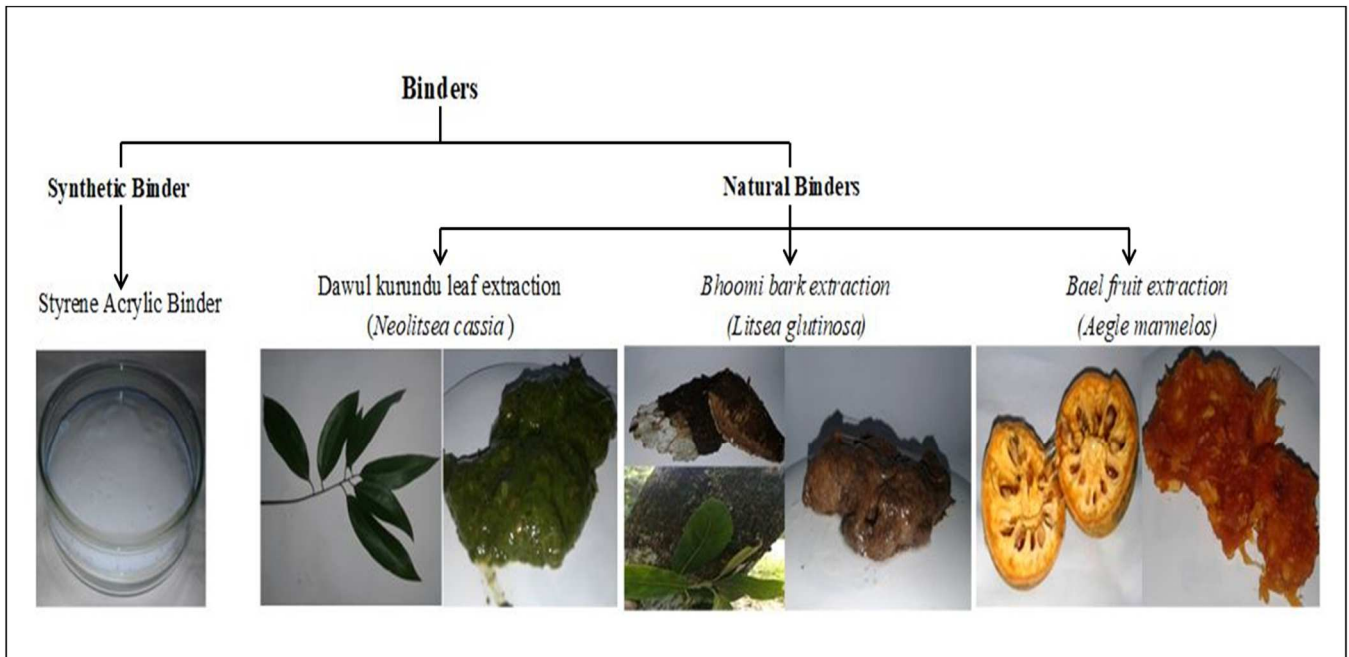


Fig. 1. Binders used in the study

DWTP sludge is categorized under nonhazardous industrial waste [9, 10]. Although it is nontoxic, discharge to water bodies is prohibited due to the undesirable formation of mud deposits which creates potential disturbances to the aquatic biota and the water reservoirs [11]. Most of the countries use the dewatered DWTP solid sludge in land fillings [12]. Biyagama DWTP solid sludge is also sent for land fillings but with time the solid sludge generation of the plant is increasing due to the increasing production of the plant. As the sludge is an inevitable waste product of the plant, a sustainable solution should be found for the increasing amount of dewatered solid sludge generation [13].

DWTP sludge was identified as a fine material made with organic and suspended matter, coagulant products, microorganisms, and chemical elements, similar to mud in texture. In the construction industry, mud can be identified as an effective construction material from prehistoric times [14,15]. Even today, mud is a very popular construction material in the construction industry. Mud is used as a construction material in brick production, mud concrete block and cement stabilized earth block, roof tile production, wall construction, rammed earth walls, and mud concrete walls [16-18]. Therefore, the DWTP sludge can be used as an alternative raw material to mud, to use as a construction material after identifying the properties of the sludge.

According to the literature it was found that shrinkage of the drinking water treatment plant sludge was the major drawback when it was incorporated in construction material production process [18]. According to the historical evidences, it was found that natural additives such as natural polymers, binders, fibers, etc. were added to soil mixtures to overcome the shrinkage as shown in Table I [19]. Therefore, this study was conducted to identify the performance of both natural and synthetic binders to enhance the properties of Biyagama water treatment plant sludge to overcome the shrinkage.

TABLE I. HISTORICAL EVIDENCES OF USE OF NATURAL POLYMERS AS ADDITIVES IN SOIL MIXTURES

Source	Soil Plaster Type	Country	Additives
[20]	Exterior and Interior Plaster in Caves	Bhaja Caves, India	Raw soil, slaked lime, rice husk, and proteinaceous adhesive
[21]	Wall Plaster	Mali and African Countries	Wet mud fermented with rice husks and proteins (milk and animal blood)
[22]	Blood Lime Plaster	Europe, China, and Mexico	Animal blood and lime
[23]	Plaster of Sigiriya Fresco	Sri Lanka	Paddy husk and coconut fiber

A binder is any material or substance that holds or draws other materials together to form a cohesive whole mechanically, chemically, by adhesion, or by cohesion. Therefore, binders can tightly bind clay particles of the sludge to overcome the shrinkage. Binders are loosely classified as organic (bitumen, animal and plant glues, polymers) and inorganic (lime, cement, gypsum, liquid glass, etc.) [24,25]. In this study, three natural binders extracted from plant materials and one synthetic binder were selected as shown in Fig.1.

Shrinkage can be measured as volumetric shrinkage and observational shrinkage as shown in Fig. 2 [26,27]. Observational shrinkage is considered as the shrinkage after the application of a mixture as a thin layer. Observational shrinkage is determined by comparing the crack formation on the surface before and after. According to the observational shrinkage test results, the adhesiveness of the mixture can be analyzed. The crack pattern and the severity of the cracks demonstrate the bonding pattern of the particles present in the mixture (internal bonding), while the bonding strength to the base demonstrates the adhesiveness of the

mixture [28,29]. Therefore, this study was conducted to identify the performances of both natural and synthetic binders to enhance the properties of Biyagama water treatment plant sludge to overcome shrinkage. In the study, mixtures were prepared by mixing different binders, both natural and synthetic, and an observational shrinkage test was conducted to analyze the effect of binders on the sludge properties.

II. MATERIALS AND METHODS

In the first phase of the study natural binders were extracted. Dawulkurundu leaves were crushed and blended with a small amount of water in a mechanical blender and the Dawulkurundu leaf extract was prepared. Bael fruit was extracted which included Bael resin. The bark of the Bhoomi tree was cut into pieces and blended with a small amount of water to prepare the Bhoomi bark extract. Styrene acrylic binder was the selected synthetic binder for the study and it was purchased from the local grocery store.

In the second phase of the study, five sludge mixtures were prepared by mixing with the binders according to the mix design shown in Table II using a mechanical mixer. After the preparation of sludge mixtures, tests were conducted to measure the initial moisture content of each mix and for the observational shrinkage test.

TABLE II. MIX DESIGN

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
Sludge	X	X	X	X	X
Styrene Acrylic Binder	-	X	-	-	-
Dawulkurundu Leaf Extract	-	-	X	-	-
Bhoomi Bark Extract	-	-	-	X	-
Bael Fruit Extract	-	-	-	-	X

A. Moisture Content Test

Initial moisture content and the solid content of the samples on a weight basis were tested according to the oven-dry method [30]. The wet weight (W_w) of each sample was measured and the samples were oven-dried at 110 °C temperature. After 24 hours the dry weight (D_w) of each sample was measured. Moisture content (MC) and the solid content (SC) of each sample was calculated according to the equations (1) and (2).

$$MC (\%) = 100 (W_w - D_w) / W_w \quad (1)$$

$$SC (\%) = 100 - MC \quad (2)$$

B. Observational Shrinkage Test

Shrinkage can be measured as volumetric shrinkage and observational shrinkage as shown in Fig. 2. Observational shrinkage is considered to be the shrinkage after application of a mixture as a thin layer on a base. Observational shrinkage is determined by comparing the crack formation

on the surface before and after. According to the the observational shrinkage test results, the adhesiveness of the mixture can be analyzed. The crack pattern and the severity of the cracks demonstrate the bonding pattern of the particles present in the mixture (internal bonding), while the bonding strength to the base demonstrates the adhesiveness of the mixture.

The sludge mixtures were applied as thin layers in an area of 8 inch x 8 inch and 2 mm thickness on cement sand plaster panels for the observational shrinkage test. Samples were air-dried for 24 hours and the crack patterns were observed.

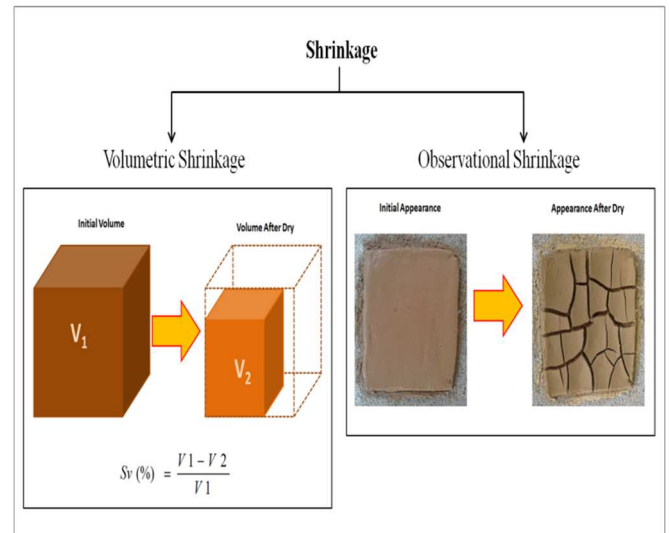


Fig. 2. Tests used to determine the shrinkage

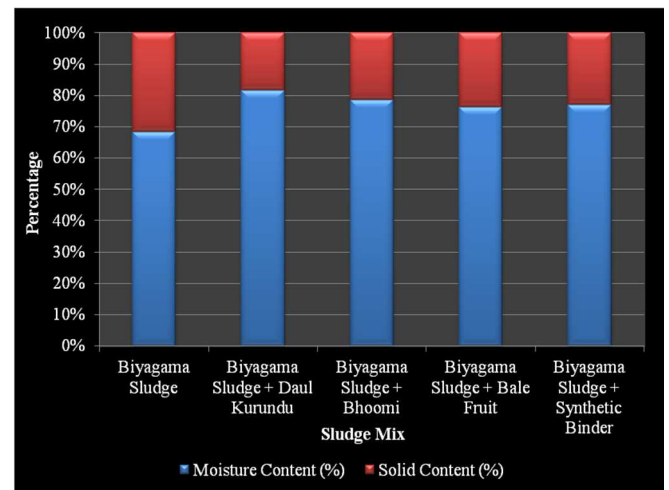


Fig. 3. Moisture and Solid content variation of sludge mixtures according to the Moisture Content Test Results

Mix	Sludge	Binders			
		Styrene Acrylic Binder	Dawul kurundu leaf extraction	Bhoomi bark extraction	Bael fruit extraction
Moisture content of the mix	68.38	77.01	81.51	78.64	76.13
First Appearance					
Observational Shrinkage After 24 hours					

Fig. 4. Observational Shrinkage Test Results

III. RESULTS AND DISCUSSION

A. Moisture Content

Moisture content test results are shown in Fig. 3; and the moisture content and solid content vary as shown in the graph. Compared to the raw sludge, addition of binders increased the moisture content while reducing the solid content in each sample as shown in the Fig. 3.

B. Observational Shrinkage Test

Observational shrinkage test results were shown in Fig. 4. Cracking, patterns differed with the binder type. It took 24 hours to completely dry the material at which the observations were taken. When the sludge was applied in the raw condition, it was completely cracked without binding to the panel surface after 24 hours. The rest of the mixtures prepared by mixing with binders were cracked with different crack patterns according to the binder type after 24 hours. However, the mixtures with binders were bound to the panel more tightly than that of the raw sludge. The presence of a binder reduced the severity of the cracks compared to the raw sludge, and increased the adhesiveness.

IV. CONCLUSION

Biyagama water treatment plant sludge properties can be enhanced by adding both natural and synthetic binders; although the addition of binders resulted in an increase of moisture content of the mix compared to the raw sludge. Binders reduced the severity of the cracks; and crack patterns differed with the binder type. Additions of binders improved the adhesiveness of the sludge mixture compared to the raw sludge. Further studies should be conducted to identify the most effective binder type and the optimum binder percentage to finalize the sludge mixture with optimum adhesiveness and low shrinkage properties, which can be used as a raw material in the construction material production process.

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