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ARTIFICIAL BEACHROCK FORMATION THROUGH SAND SOLIDIFICATION TOWARDS THE INHIBIT OF COASTAL EROSION IN BANGLADESH

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ABSTRACT: Erosion is a great problem in the coast areas of Bangladesh. The present study was conducted through literature survey to evaluate the prospects of making artificial beachrock through sand solidification for the protection from coastal erosion in Bangladesh. On average, recession through erosion due to sea level rise (SLR) in the coast of Bangladesh will occur 0.87m per 1cm rise in sea level. Artificial beachrocks have the potentials to inhibit coastal erosion. Beachrock is a type of sedimentary deposit that generally occurs on tropical and subtropical beaches as a result of intertidal lithification of loose beach sands and gravels by carbonate cementation. Chemically, beachrock around the world differs in composition but mainly it composed of $CaCO_3$ and SiO_2. Beachrocks are cemented by high Mg calcite (HMC) with the influence on precipitation from seawater and/or seawater evaporation (PSW) and on surface microorganisms, bacterial ureolysis. On 30 ^{0}C curing temperature which is similar to the average temperature in Bangladesh beach sand solidified 5 to 8 MPa unconfined comprehensive strength (UCS) in 28 curing days using the ureolytic bacteria (*Pararhodobacter* sp.). It is concluded that it may be possible to manufacture artificial rocks through sand solidification similar to beachrocks for erosion control purposes in Bangladesh.

Key words: Coastal Erosion, Artificial Beachrock, Sand Solidification, Ureolytic Bacteria

1. INTRODUCTION

Coastal erosion is the great problem throughout the world. Some islands in the world are in danger of being submerged due to erosion and sea level rise as impact of climate change. Erosion in the coastal area of Bangladesh is a big point of concern. Heavy discharge currents through the GBM (Ganges-Brahmaputra-Meghna) river system, wave action due to strong southwest monsoon winds, high astronomical tides, and storm surges in the Bay of Bengal are the main causes of erosion in the coastal area of Bangladesh [1]. Superimposed on these causes, sea level rise (SLR) has a long-term effect on coastal erosion in the country. It is predicted that 17% of the total land of the country will be submerged if sea level rise up to 1.0 meter by 2100 and also predicted that sea level rise between 0.18 to 0.79 meters will lead to salinity intrusion and coastal flooding [2].

Manmade (artificial) beachrocks have the potential to inhibit coastal erosion [3], [4]. Beachrocks are coastal deposits cemented mainly by calcium carbonate cement; these deposits are found in the tidal and intertidal zone of sandy beaches in tropical and subtropical regions [3], [4]. Cox's Bazar sea beach of Bangladesh, the longest continuous beach of the world, is such types of sandy beach located subtropical region. Therefore this beach has the potentiality to the formation of man-made (artificial) beachrock. Considering the use of man-made rock in order to preserve such submerged-looking islands above sea level, Danjo and Kawasaki; and Danjo *et al*., conducted several study in Okinawa and Ishikawa, Japan [5], [6], [7]. They found sufficient information to build man-made beachrock. Danjo *et al.* perform coral sand solidification test using ureolytic bacteria (*Pararhodobacter* sp.) and found this type of bacteria has the ability to solidify coral sand precipitating $CaCO_3$ [8]. Considering this importance such type of study is also essential in Bangladesh, as the most vulnerable country to climate change, to inhibit the coastal erosion due to sea level rise. Therefore the objectives of the present study were to evaluate the prospects of making artificial beachrock through sand solidification for the protection from coastal erosion in Bangladesh.

2. METHODS

Data and information were gathered on (a) coastal erosion in Bangladesh, (b) beachrocks, its (c) properties and (d) formation mechanism; since this information would be essential for the manufacturing of artificial rock for the protection of coastal erosion. Information in this study was

obtained from literature survey of related works. Quantitative scenario of coastal erosion in Bangladesh was shown in the gathered information. Regional information for the substances contained in beachrocks, their cement components etc. were collected and compared. Information on the chemical composition of beachrock and its physical and mechanical properties as well as formation mechanism were also compiled.

3. RESULTS AND DISCUSSIONS

3.1 Coastal Erosion in Bangladesh

In [9], [10], [11] studied coastal erosion and accretion activities in Bangladesh. Heavy discharge currents through the GBM (Ganges-Brahmaputra-Meghna) river system, wave action due to strong southwest monsoon winds, high astronomical tides as well as sea level rise (SLR), and storm surges in the Bay of Bengal are the main causes of erosion in the coastal area of Bangladesh [1]. Erosion due to SLR has been discussed by Islam *et al.* at his study which was done under the U.S. Country Studies Program, and some of the salient features of the study are presented there [11]. The study was based on the erosion formula given by Bruun [12].

$$x = ab/(e + d) \quad (1)$$

Where *x* is the shoreline recession due to SLR, *a* is the rise in water level due to SLR, *e* is the elevation of the shore, and *d* is the depth of water at a distance *b* from the coastline.

Islam *et al.* applied the formula to the eastern region [11], where the longest continuous sandy beach situated, of Bangladesh (Fig. 1); the study area is bounded by 20^0 $40^/$ N and 22^0 $13.5^/$ N latitudes and 91^0 $45^/$ E and 92^0 $2^/$ E longitudes. Islam *et al.* also conducted a field survey at 21 different locations along the coast with profiles being perpendicular to the coastline to measure the values of the parameters [11]. The recession distances were calculated for these points under 3 values of SLR - 0.30, 0.75, and 1.00m. He found, for 0.30m SLR, the recession varies from 0.18 to 0.39mcm^{-1} (meaning that the shoreline will recede 0.18 to 0.39m per 1cmrise in SLR); for 0.75m, the range is 0.41 to 0.91mcm^{-1}; and for 1.00 m, 0.58 to 1.30mcm^{-1}. On average, a recession of 0.87m occurs per 1cm rise in sea level. That is, recession distance through erosion due to SLR is about 87 times of the SLR. The results agree reasonably well with others; for example, 100 times for the Florida coast [12] and 60 to 80 times for the Belgium-to-Denmark coast [13].

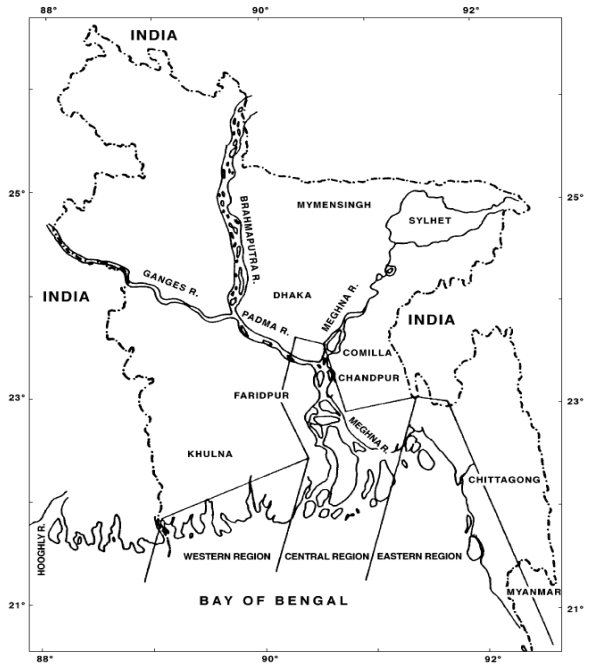

Fig. 1 Map of Bangladesh showing coastal area and the major river system [11]

3.2 Beachrock and Coastline Protection

Beachrocks, which are formed naturally on beaches, have attracted attention as a model for artificial rocks. Danjo and Kawasaki proposed a new method to protect coastlines from erosion – the use of artificial rock that auto-repairs by means of sunlight, seawater, and bacteria [3]. Their model of artificial rock is beachrock. Beachrock is a type of sedimentary deposit that generally occurs on tropical and subtropical beaches as a result of intertidal lithification of loose beach sands and gravels by carbonate cementation [14]. The Association for Geological Collaboration in Japan [15] defined beachrockare as follows:

"An extremely recent, consolidated, calcareous rock occurring in the intertidal zone on sandy beaches. It comprises multiple layers, each around 1–60 cm thick, and runs roughly in the same direction as the beach, at an oblique angle of $5–7^0$ to the sea. It forms a cuesta shape, with the landward side having an acutely angled face. Its overall thickness is about 1.0 m, and may be separated into two or more bands. The cement material may be calcareous or may contain iron, and the non-cement substances may be any material, regardless of the grain size or substance. Beachrocks are found on beaches in tropical and sub-tropical zones. In the seas around Japan they can be found in the Nansei Island group, which is southwest of the mainland."

Beachrocks around the world have been reported to form over several thousand years [16]

owing to interactions among sand supply, cement precipitation from seawater and coastal erosion by ocean waves [3]. Therefore, it may be possible to slow down the erosion of coasts by making man-made beachrock from coastal sands. Because this artificial rock is made of local materials, it has the potential to be an eco-friendly product [3].

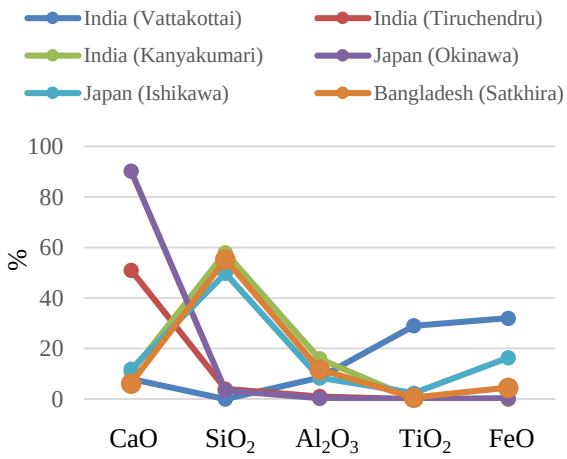

Fig. 2 Beachrock compositions around the world [6], [17]

3.3 Properties of Beachrock

Over 90 % of beachrocks are distributed between the proximity of 40^0N latitude and the Tropic of Capricorn, and that their formative periods range from 26,000 years to just a few decades ago [18]. Beach of Bangladesh located between $20^035'$ N to $22^050'$ N latitude and $89^006'$ E to $92^021'$ E longitude. There is no relation between the formative age of beachrock and latitude [6]. Chemically, beachrock around the world differs in composition (Fig. 2). Beachrock at Tiruchendur, India mainly consists of Ca. In contrast, the beachrock in Vattakottai, India, is mainly Si- and Al-rich and that in Kanyakumari, India, is mainly Fe- and Ti-rich [6] where Bangladesh is Si rich (Fig. 2). The main components of beachrocks and surrounding material are calcium carbonate or silica [18].

3.4 Properties of Beachrock and Sand in Bangladesh and Asian Countries

The proportion of $CaCO_3$ in beachrocks was around 90 % while the other portions consisted of SiO_2, and Al_2O_3 in the Gulf of Mannar, India [19]. The beachrocks in Bangladesh are mainly composed of calcium carbonate or silica, similar to the beachrocks in Japan (Table 1). Coral sand are also found in the St. Martin beach in Bangladesh.

Table 1 Compositions of some beachrocks in the Asian countries

Location	Component materials of the beachrock	Main minerals of the beachrock	Component materials of the cement	Reference
Sumuide, Nago, Okinawa, Japan		Aragonite, Mg-calcite	Mg-calcite	[20]
Sosogi, Wajima, Ishikawa, Japan	Sand, gravel, plastic piece, glass piece, iron chain		Si,Al	[21]
Suzu, Ishikawa, Japan	Shell sand, foraminifer, sand, gravel	Quartz, feldspar, $CaCO_3$	$CaCO_3$	[22]
Vattakottai, India		Calcite, aragonite, quartz, heavy minerals		[23]
Cox's Bazar, Bangladesh	Sand, silt, clay			[24]
St. Martin, Bangladesh	Calcareous coral sand, broken coral or limestone			[24]

3.5 Formation of (Artificial) Beachrock

With regard to the origin of beachrocks, two contrasting theories were proposed: one cited seawater as the source for beachrocks [25], [26] and the other claimed that land-based water such as groundwater or spring water was the source [27], [28]. Opinions were divided between these two theories; and at the time, there was more support for the theory of seawater as the source for beachrock formation [26]. In this regards Danjo and Kawasaki [3] examined a formation mechanism of beachrock in Okinawa, Japan, because understanding this mechanism is an important step in making artificial beachrock. They focused on the cement formation mechanism of beachrock, which occurs in the intertidal zone. Cement type and content have the potential to influence the strength of the material; hence, detailed knowledge of beachrock cements is valuable for producing a man-made equivalent [3]. Beachrocks are cemented by high Mg calcite (HMC) have been reported at 16 sites around the world [7], [29]. Danjo and Kawasaki [3] focused investigation into the formation mechanisms of the beachrock cements on the influence of precipitation from seawater and/or seawater evaporation (PSW), and on surface microorganisms. They found in Okinawa, Japan that the evaporation of seawater and/or the urease activity of microorganisms might have resulted in the precipitation of high Mg calcite (HMC), leading to formation of beachrock.

3.6 Beachrock Formation Through Sand Solidification

In order to create an artificial rock Danjo *et al.*, conducted solidification test on coral sand of Okinawa, Japan [8]. They performed Syringe Solidification Test and Column Solidification Test using the ureolytic bacteria (*Pararhodobacter* sp.), isolated from the soil near beachrock in Sumuide, Nago, Okinawa, Japan. They used coral sand from Okinawa, Japan in their experiment because the beachrock that had previously been investigated in relation to its formation mechanism was composed mainly of coral sand and $CaCO_3$ cement. They also used artificial seawater (made artificially in the laboratory mixing Akuamarine powder which produced by Yashima Drug Company, Osaka, Japan with distill water) to recreate a condition similar to that in which the original beachrock was formed.

In Syringe Solidification Test, the unconfined compressive strength (UCS) of the samples was up to 6.0 after 28 days curing time at 30 ^{0}C which was larger than that at room temperature, 23±1 ^{0}C. The UCSs increased with curing time, UCS in 28 days is higher than the 14 days (Table 2). The estimated UCSs in Column Solidification Test were 6.7MPa after 28 days curing time (Table 2). UCSs of the specimens tended to increase exponentially with time [8]. In addition, there is no procedural difference in the Syringe Solidification Test and Column Solidification Test. The only difference between these two tests in their sample size, in Syringe Solidification Test (diameter 2.5cm × height 7cm) and Column Solidification Test (diameter 5cm × height 11.5cm), its sand as well as solution volume.

Table 2 UCS of sand solidification test with curing time and temperature [8]

Test	UCS (MPa)	Curing time (Day)	Curing temperature (^{0}C)
Syringe	0.5 – 0.7	14	23±1
Solidification	1.8 – 2.2	14	30
Test	3.0 – 6.0	28	30
Column	0.7	10	30
Solidification	1.0	14	30
Test	2.2	21	30
	6.7	28	30

The microorganism used by Danjo *et al.* was *Pararhodobacter* sp., a ureolytic bacterium which was isolated from the soil near beachrock in Sumuide, Nago, Okinawa, Japan [8]. By *Pararhodobacter* sp., carbonate precipitated on coral sand which is similar to the beach sand in Bangladesh (Fig. 2 and Table 1). The mean annual temperature of the surface water of the Bay of Bengal in Bangladesh is about 28^{0}C where the maximum temperature is observed in May (30^{0}C) and the minimum (25^{0}C) occurs in January-February [30], which is similar to the optimum temperature for $CaCO_3$ precipitation by *Pararhodobacter* sp. The surface water salinity in the coastal parts of the Bay of Bengal oscillates from 10 to 25 ppt (parts per thousand, i.e. grams per kilogram of sea water) [31]. Dissolved oxygen (DO) concentration on surface sea water in the coastal Bay of Bengal in Bangladesh, ranges from 4.56 to 6.24 mg/L [31]. This salinity as well as DO would be suitable for the optimum growth of the *Pararhodobacter* sp., saline water bacteria. Therefore, it has the potentiality for the sand solidification using *Pararhodobacter* sp. in Bangladesh.

3.7 Prospect of Beach-sand Solidification in Bangladesh

Based on formation methods observed for Okinawa, Japan, artificial beachrock is cemented by HMC using microorganisms with urease activity, organic matter such as citrate and malate,

nutrient sources, $CO(NH_2)_2$, artificial seawater and sand [32]. Silica sand and coral sand are found in the beaches in Bangladesh (Table 1) though their ratio (%) is not calculated due to unavailability of data. The sand properties of beach in Bangladesh are similar to the Japan which would be very much suitable for sand solidification. The daily-averaged temperatures at Nago, Okinawa each month from 1967 to 2013 each year were 20.8–23.0 ^{0}C [33]. The daily average temperature of the beach areas (southern part) of Bangladesh from 1995 to 2012 was 24 to 30 ^{0}C [34].The curing temperatures, 23±1 and 30 ^{0}C, for expected UCSs can be regarded as the daily-averaged temperatures each year in Bangladesh. Water of Bay of Bengal is also typical sea water and this water would be suitable for sand solidification. It is therefore, also in Bangladesh this sand solidification would be considered (that $CaCO_3$ precipitates at 30 ^{0}C) to the formation of artificial beachrock.

4. CONCLUSIONS

This bibliographical study reported above indicated that the information are useful for the creation of artificial rocks that are modeled on beachrocks. In the future, it may be possible to manufacture artificial rocks through sand solidification similar to beachrocks for erosion control purposes in Bangladesh. Manufacturing of artificial rocks using compositional substances that are as similar as possible to those in beachrocks, and that follow the same formation process.

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