Formation of artificial beachrock towards inhibit of coastal erosion in Bangladesh: a review

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ABSTRACT

Erosion in the coastal area of Bangladesh is a big point of concern. The present study was conducted to find out the protective measure from coastal erosion in Bangladesh as well as evaluate the prospects of the formation of artificial beachrock. This study was conducted based on literature survey of related works. In the coast of Bangladesh, average recession through erosion will occur 0.87m due to per 1cm sea level rise. Beachrock as well as artificial beachrocks have the potentiality to prevent such coastal erosion. Beachrock is a type of sedimentary deposit that generally occurs on the tropical and subtropical beaches as a result of intertidal lithification of loose beach sands and gravels by carbonate cementation. Beachrock in the world differs by their chemical composition but it composed mainly of CaCO_3 , SiO_2 and Al_2O_3 . Usually, beachrocks are formed by the cementation of CaCO_3 precipitation with the influence of seawater and/or seawater evaporation as well as surface microorganisms. From the knowledge of natural beachrock formation as well as sand properties, in the future, it may possible to manufacture artificial beachrocks similar to beachrocks for erosion control purposes in Bangladesh.

Keywords: Artificial beachrock, coastal erosion, carbonate cementation, seawater, surface microorganism

1 INTRODUCTION

Some islands in the world are in danger of being submerged due to erosion and sea level rise as impact of climate change. Bangladesh, the largest delta of the world, is the most vulnerable country to the impact of climate change. 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 (Cruz *et al.*, 2007). 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 (Ali, 1999). Superimposed on these causes, sea level rise (SLR) has a long-term effect on coastal erosion in the country.

Artificial beachrocks (manufacture artificially in the natural condition) have the potential to inhibit coastal erosion (Danjo and Kawasaki, 2013a and Danjo *et al.*, 2013a). 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

(Danjo and Kawasaki, 2013a and Danjo *et al.*, 2013a). 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 artificial beachrock. Considering the use of artificial rock in order to preserve such submerged-looking islands above sea level, Danjo and Kawasaki (2012a, 2012b) and Danjo *et al.* (2012) conducted several study in Okinawa and Ishikawa, Japan. They found sufficient information to build artificial beachrock. Considering this importance such type of study is also essential in Bangladesh, as most vulnerable country to climate change, to inhibit the coastal erosion due to sea level rise using artificial rock.

Therefore the objectives of the present study were to find out the protective measure for coastal erosion in Bangladesh and to find the prospects of the formation of artificial beachrock.

2 METHODS

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

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

3 RESULTS AND DISCUSSIONS

3.1 Coastal erosion in Bangladesh

Pramanik (1983), MCSP (1992), and Islam *et al.* (1999) 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 (Ali, 1999). Erosion due to SLR has been discussed by Islam *et al.* (1999) at his study which was done under the U.S. Country Studies Program, and some of the salient features of the study are presented here. The study was based on the erosion formula given by Bruun (1962).

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

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.

Fig. 1. Map of Bangladesh showing coastal area and the major river system (Islam *et al.*, 1999)

Islam *et al.* (1999) applied the formula to the eastern region, where the longest continuous sandy beach situated, of Bangladesh (Fig. 1); the study area is bounded by $20^{\circ} 40' N$ and $22^{\circ} 13.5' N$ latitudes and $91^{\circ} 45' E$ and $92^{\circ} 2' E$ longitudes. Islam *et al.* (1999) 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. 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 1cm rise in SLR); for 0.75m, the range is 0.41 to 0.91mcm^{-1} ; and for 1.00m, 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 (Bruun 1962) and 60 to 80 times for the Belgium-to-Denmark coast (Hekstra 1989).

3.2 Coastline protection through beachrock

Natural beachrocks, which are formed naturally on beaches, have attracted attention as a model for artificial rocks. Danjo and Kawasaki (2013a) proposed a new method to protect coastlines from erosion – the use of artificial rock that auto-repairs by means of sunlight, seawater, and bacteria. 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 (Ginsburg, 1953). The Association for Geological Collaboration in Japan (2000) defined beachrock 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 $5-7^{\circ}$ 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 subtropical zones. In the seas around Japan they can be found in the Nansei Island group, which is southwest of the mainland.”

Around the world beachrocks have been reported to form over several thousand years (Vousdoukas *et al.*, 2007) owing to interactions among sand supply, cement precipitation from seawater and coastal erosion by ocean waves (Danjo and Kawasaki, 2013a). 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 (Danjo and Kawasaki, 2013a).

3.3 Beachrock properties

More than 90 % of beachrocks are distributed between 40° N latitude and the Tropic of Capricorn, and that their formative periods ranges from 26,000 years to just a few decades ago (Danjo and Kawasaki, 2013b). Beach of Bangladesh located between 20°35' N to 22°50' N latitude and 89°06' E to 92°21' E longitude. But there is no relation between the formative age of beachrock and latitude (Danjo and Kawasaki, 2012b).

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 (Danjo and Kawasaki, 2012b) where Bangladesh is Si rich (Fig. 2). The main components of beachrocks and surrounding material are calcium carbonate or silica (Danjo and Kawasaki, 2013b). The proportion of CaCO₃ in beachrocks was around 90 % while the other portions consisted of SiO₂, and Al₂O₃ in the Gulf of Mannar, India (Sahayam *et al.* 2010). The beachrocks in Bangladesh are mainly composed of

calcium carbonate or silica, similar to the beachrocks in Japan and the world (Table 1).

Fig. 2. Beachrock compositions around the world (Danjo and Kawasaki, 2012b)

Table 1. Compositions of some beachrocks in the world

Location	Component materials of the beachrock	Main minerals of the beachrock	Component materials of the cement	Reference
Sumuide, Nago, Okinawa, Japan		Aragonite, Mgcalcite	Mg-calcite	Danjo <i>et al.</i> (2013b)
Sosogi, Wajima, Ishikawa, Japan	Sand, gravel, plastic piece, glass piece, iron chain		Si, Al	Ogasawara <i>et al.</i> (2004)
Suzu, Ishikawa, Japan	Shell sand, foraminifer, sand, gravel	Quartz, feldspar, CaCO ₃	CaCO ₃	Azuma <i>et al.</i> (1982)
Grand cayman	Algae, mollusk, organic material, coral grains			Moore (1973)
Heron Island	Carbonate grains			Webb <i>et al.</i> (1999)
Vattakottai, India		Calcite, aragonite, quartz, heavy minerals		Ravisankar and Rajalakshmi (2007)
Cox's Bazar, Bangladesh	Sand, silt, clay			Brammer, 1996
St. Martin, Bangladesh	calcareous coral sand, broken coral or limestone			do.

3.4 Beachrock formation

Regarding the origin of beachrocks, two contrasting theories were proposed: one cited seawater as the source for beachrocks (Tanaka 1983, 1990) and the other claimed that groundwater or spring water was the source (Yonetani 1963, 1966). 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 (Tanaka 1990). In this regards Danjo and Kawasaki (2013a) examined a formation mechanism of

beachrock in Okinawa, Japan, understanding this natural formation mechanism of beachrock is an important step to 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 would be valuable for producing an artificial equivalent (Danjo and Kawasaki, 2013a). Beachrocks are cemented by high Mg calcite (HMC) have been reported at 16 sites

(Vousdoukas *et al.*, 2007 and Erginal *et al.*, 2010) around the world. Danjo and Kawasaki (2013a) 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. 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, $\text{CO}(\text{NH}_2)_2$, artificial seawater and sand (Danjo and Kawasaki, 2014). With respect to PSW, Raz *et al.* (2000) reported that to better understand the depositional process of high-magnesian calcitic skeletons, they studied the CaCO_3 precipitates formed from solutions with Mg/Ca ratios ≥ 4 . In addition, according to experiments by Kitano and Kanamori (1966), sodium citrate and sodium malate favor the precipitation of MC, whereby an increase in concentration of magnesium ion and these organic materials cause formation of Mg-rich calcite.

The sand properties of beach in Bangladesh are similar to the Japan, Silica sand and coral rich (Table 1), which would be very much suitable for artificial beachrock formation.

4 CONCLUSIONS

This bibliographical study has enabled us to gather information that should prove useful for the creation of artificial rocks that are modeled on beachrocks. In the future, it may possible to manufacture artificial rocks similar to beachrocks for erosion control purposes and it may also be possible 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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