Preliminary study on use of biopolymers in earthen construction

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ABSTRACT: Biopolymers are known to achieve significant soil stabilisation when working with small quantities. There have been studies understanding their effects on permeability, strength, compressibility and durability, however, there are few studies exploring their potential as stabilisers in earthen construction. An earthen material is typically stabilised with energy consuming stabilisers like cement to enhance durability, and biopolymers could be viable green alternatives. Based on recently established understanding of mechanical behaviour of biopolymer-treated earthen construction materials, the preliminary study described here was undertaken to understand their effects on durability. In this study, two biopolymers, namely guar and xanthan gums, were used as stabilisers to treat earthen construction materials and tested for their durability performance through erosional and immersion tests. The treated materials performed satisfactorily in erosional tests, while only xanthan gum treated material performed well in immersion tests. Elementary X-Ray Computed Tomography scans were undertaken on biopolymer treated materials at 7 and 28 days after manufacture. It was observed that there was particle re-arrangement from 7 to 28 days and this was more evident for guar gum treated soil.

1 INTRODUCTION

The growing interest in sustainable engineering has led to the emergence of bio-stabilisation methods enabling sustainable soil stabilisation. Biopolymers have proved most popular, due to simplistic application procedures and enhanced stabilisation effects. Only in the past decade, have these materials been introduced in geotechnical applications to improve soil properties. It has been reported that when added in small quantities biopolymers have reduced soil permeability (Bouazza et al. 2009; Aminpour & O'Kelly 2015), increased shear strength (Cabalar & Canakco 2011; Chang et al. 2015), improved compressibility (Latifi et al. 2016) and enhanced durability (Qureshi et al. 2017). Biopolymers may prove to be an exciting alternative to energy consuming stabilisers like cement which have been popularly used in stabilised earthen construction.

As a compacted unsaturated soil, the mechanical behaviour of earthen construction can be understood in terms of unsaturated soil mechanics (Jaquin et al. 2009). However, in its lifetime, earthen construction is subjected to different environmental conditions than a natural unsaturated soil which can affect the strength of the material. The variations of strength can be linked to the variation of the induced suction due to drying and wetting cycles (Jaquin et al. 2009; Beckett & Augarde 2012; Al Aqtash & Bandini 2015). Therefore, it can be concluded that suction plays an important role in the strength and durability of earthen construction material. Though this understanding has been arrived for unstabilised earthen construction, similar approaches may be adopted to stabilised materials. With this approach in mind, the authors have initiated a research project to explore the possibility of using biopolymers as stabilisers in earthen construction.

2 BACKGROUND WORK

Biopolymers are naturally occurring polysaccharides which have a large number of hydroxyl groups which readily react with water to form long chains of "hydrogels". On dehydration, the water molecules tend to escape from polymer chains leading to the formation of complexes of linked polymer chains. In addition, during drying, the hydrogels transform from what is termed a "rubbery" to a "glassy" state (Eichler et al. 1997; Ayeldeen et al. 2016). When introduced in soils, biopolymers interact with soil particles and free water in the soil matrix leading to complex networks of polymer chains binding soil particles through hydrogen and/or ionic bonding depending on the intrinsic properties of the biopolymer used (Chudzikowski 1971; Katzbauer 1998). Though these biopolymers have been previously used in soil stabilization work, only recently it has been suggested as a stabiliser for earthen construction material.

Aguilar et al. (2016) and Nakamatsu et al. (2017) stabilised earthen construction material using biopolymers such as chitosan and carrageenan at 3.0 and 2.0% concentrations respectively. In these studies, compressive strength tests were performed on cylindrical specimens of 34mm diameter and 71 mm height, while flexural strengths were obtained from prismatic beam samples of 42 x 44 x 125mm. Mechanical testing was undertaken at 14 days for air cured specimens. Erosional tests were also performed on cylindrical specimens to assess durability. It was reported that the addition of biopolymer led to improved mechanical and durability performance for the treated earthen material. Very recently, the authors here undertook a study to understand the mechanical behaviour of biopolymer treated earthen construction materials (Muguda et al. 2017). In this study, reconstituted soil suiting the requirements of earthen construction was treated with two biopolymers namely guar gum and xanthan gum. Cylindrical specimens (38mm diameter by 76mm height) were tested in unconfined compression, and "bowtie" specimens were tested in tension using the procedure outlined in Stirling et al. (2015). Biopolymer content was added in a range of 0.5-3.0% of dry unamended soil. All the samples were statically compacted to achieve the initial dry density of 19.62 kN/m^3 having a porosity of 16.98% and pore void volume of 14.63 cm^3. However, due to the addition of biopolymer there was a slight variation in the initial dry densities achieved and corresponding porosity and pore space volume values. All the samples were left to air dry at a relative humidity of 50% and temperature of 21^{0}C and then tested at 7 and 28 days. For comparisons, similar tests were carried on unamended samples and samples with 8% cement. As noted by Zhao (2014) and Cao et al. (2017), presence of biopolymer has a significant effect on the soil suction so it was imperative to measure suction during the strength tests. Hence, total suction was measured using a WP4C potentiometer for the soil portions remaining after the completion of strength tests. Fig 1 shows the variation of compressive, tensile and suction with varying stabiliser content for both biopolymers. It was observed that the addition of biopolymer at any stabiliser content for both guar gum and xanthan gum increased the suction. However, compared to the 7-day suction, the suction in the guar gum treated specimen at 28 days had reduced, while this was opposite for xanthan treated specimens. Also, it was noted that both biopolymers showed different compressive and tensile strength behaviour. For guar gum, compressive strength increased at 28 days while the tensile strength decreased. In case of xanthan gum, there was a slight reduction in compressive strength, while the tensile strength increased at 28 days. The above differences in the compressive and tensile strengths and suction changes was linked to the soil-water-biopolymer interactions which are dependent on the intrinsic properties of the respective biopolymer. As a neutral polysaccharide with large hydroxyl groups, guar gum would form network of hydrogels between soil particles and free water via hydrogen bonding (Chen et al. 2013). At 7 days, these hydrogels (predominantly in a rubbery elastic state) contribute to higher suction. Once these hydrogels transform to a glassy state, the suctions tend to reduce. The increased compressive strength at 28 days is therefore attributed to the network of hydrogels in a glassy state. As a chemically weaker bond, the hydrogen bonding may not contribute much to tensile strengths.

Xanthan gum is an anionic polysaccharide which will have ionic bonding with soil particles in addition to hydrogen bonds (Chen et al. 2013). Similar to guar gum, at 7 days, the combination of suction and hydrogel bonding appears to contribute to both compressive and tensile behaviour of xanthan treated soils. However, unlike guar gum, the ionic bonding of hydrogels appears to contribute to the increased suction and tensile strengths at 28 days. The above understanding gives an insight on the mechanical behaviour of biopolymer treated earthen construction materials. With this insight of the variation of strength and suction at different biopolymer dosages, the study is furthered here to understand the effect of biopolymer on the durability of treated earthen construction material.

3 MATERIALS AND METHODS

3.1 *Materials*

The soil mixture used in the previous study (Muguda et al. 2017) was used herein comprising 20% Kaolin, 70% sharp sand and 10% gravel by mass. This soil mix complies with the requirements for earthen construction materials given in the literature (e.g. Oliver & Mesbah 1987; Houben & Guillaud 1994) and is a combination widely investigated in earthen construction. Atterberg limits and compaction characteristics (using the 2.5kg Proctor test) obtained in accordance with British Standards (BS 1377-2 1990; BS 1337-4 1990) for the unamended soil mixture are given in Table 1. Commercially available guar gum and xanthan gum were chosen as biopolymer stabilisers in this study.

Table 1. Physical properties of the unamended soil mixture in this study

Index property	
Standard compaction tests	
Maximum dry density (kg/m^3)	1870
Optimum moisture content (%)	9.8
Grain size distribution	
Gravel content (%)	10
Sand content (%)	70
Silt content (≤ 63 μm, %)	04
Clay content (≤ 2 μm, %)	16
Atterberg limits	
Plastic limit (%)	36
Liquid limit (%)	18
Plasticity index (%)	18

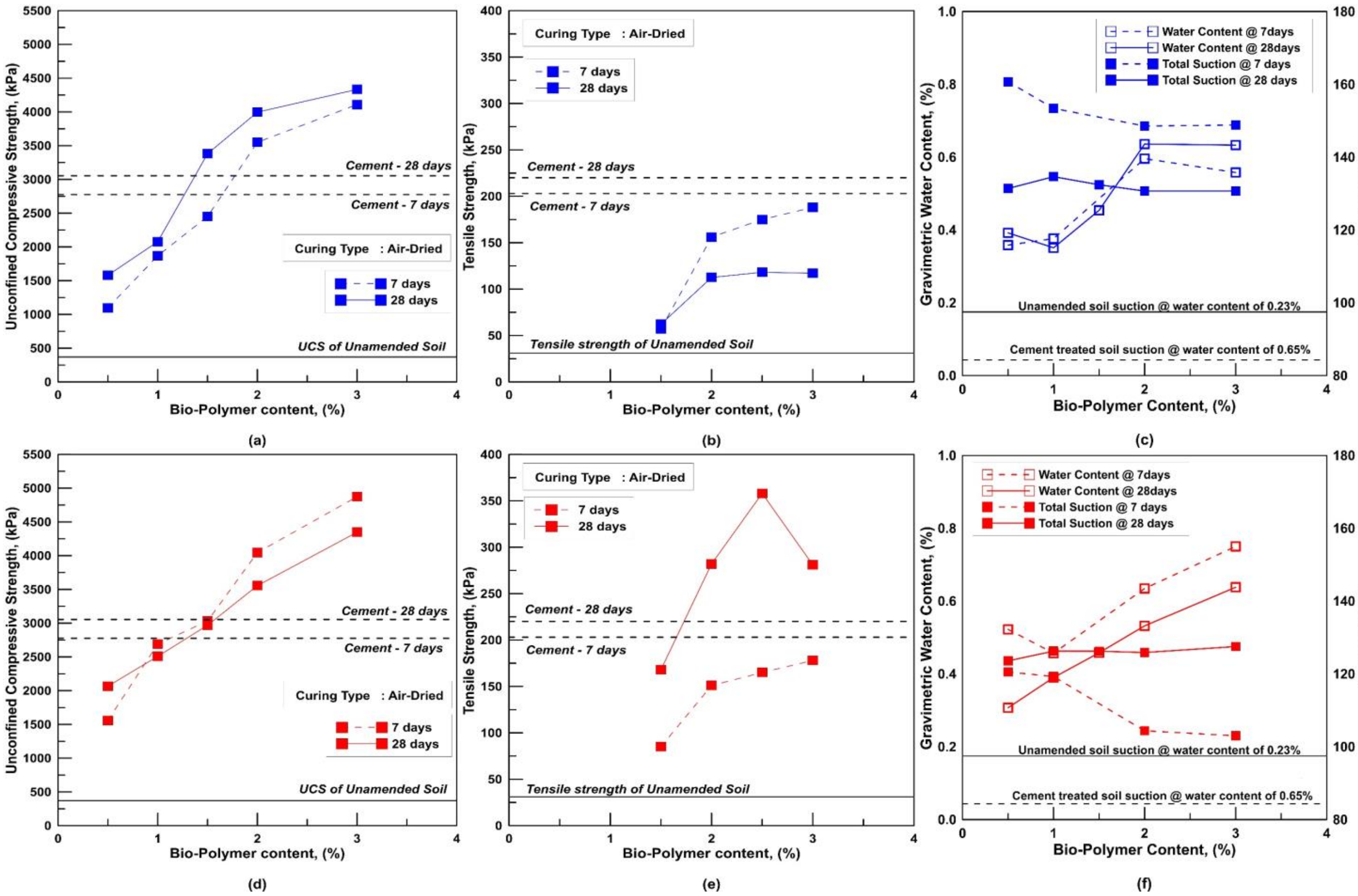

Figure 1. Variation of compressive strength, tensile strength, total suction and water content with different biopolymer content for both the biopolymers. Guar Gum (Fig 1a to 1c) and Xanthan gum (1d to 1f) (As per Muguda et al. 2017)

3.2 *Experimental Programme*

In order to understand the durability properties of the treated biopolymer treated materials, two recognized durability tests, namely the "Geelong" Test (erosion test) as per New Zealand earthen construction (NZS 4298 1998) and the "Immersion" test as per German code (DIN 18945 2013) were chosen for this study.

3.2.1 *Geelong tests*

It can be noted from Fig 1a and 1d, that for both the biopolymers, the compressive strengths of samples treated at 1.5% stabiliser content achieved similar strengths of 8% cement treated samples, indicating about 1.5% stabiliser content is enough to match the performance of 8% cement. Hence, for the Geelong tests, earthen cubes of 150mm stabilised with 1.5% of biopolymer content formed the test samples. All the ingredients were dry mixed initially and later water as added and mixed thoroughly for 10-15 mins. The bulk soil mix was then divided into three equal parts and introduced to the mould one part at a time. Using a vibratory hammer, each layer was compacted to the required density. These steps were repeated for all the three portions. All blocks were compacted to achieve identical initial dry density, porosity and void ratio as that of the unconfined compressive test specimens described in section 2. Once the block was moulded, it was taken out carefully and left to air cure at a relative humidity of 50% and temperature of 21^0C. After 7 and 28 days of curing, the earthen blocks were tested for its resistance against water erosion through the procedure described in the code. The procedure involves dripping 100ml of water from a height of 400mm on to the surface of a prepared earthen block kept at an inclination of 2H:1V. 100ml of water is applied within a time period of 20-60 minutes. After dripping is complete, the surface of the block is wiped using a wire brush to remove the eroded soil particles and the depth of erosion is measured using a Vernier caliper with a depth gauge having a precision of 0.02mm. According to the standard, if the depth of erosion is within 5mm from surface, the earthen construction material is considered to have passed the erosion tests.

3.2.2 *Immersion tests*

As a quick assessment to understand stabilisation effect against immersion, emulating flooding for instance, portion of the remains of unconfined compression specimens for all biopolymer contents studied in Muguda et al. (2017) were immersed completely into water and the time taken for the specimen to completely disintegrate completely was noted. As per the code (DIN 18945 2013), earthen construction material which deteriorates within 45 mins of immersion is considered unsuitable for earthen construction.

3.2.3 *XRCT Imaging*

Ayeldeen et al. (2016), through the use of Scanning Electron Microscopy (SEM) imaging reported the feature noted above, that the hydrogels of biopolymers transform from “rubbery” to “glassy” state with time. However, the mechanical properties of these hydrogels during the transformation is uncertain. In this study the samples were also subjected to X-Ray Computed Tomography (XRCT). Cylindrical samples treated with 2% of biopolymer were scanned at 7 and 28 days respectively. XRCT images were obtained using an XRadia/Zeiss XRM-410 machine based at the Durham University XCT service at 8.5μm resolution which is similar to the study in Beckett et al. (2013) also for earthen construction.

4 RESULTS AND DISCUSSION

4.1 *Geelong tests*

Fig 2a presents the durability test setup, while Figs 2b and 2c show the eroded surface of the earthen block treated with guar gum and xanthan gum respectively at 7 days of ageing. It was noted that the surface exposed to dripping was intact after durability tests for both the blocks treated with guar gum and xanthan gum respectively. Depth of erosion was well within 5mm which satisfies the requirement of the standard. Similar behaviour was observed at 28 days. As a quick visual assessment, against varying atmospheric conditions, the physical appearance of earthen materials was assessed. It was noted that for guar gum treated sample, the sides and edges had worn off, while for the xanthan gum treated sample it remained intact.

4.2 *Immersion tests*

Immersion tests were performed for all stabiliser contents for both the biopolymers. It was noted for the given range of stabiliser content i.e., 0.5-3.0%, all the guar gum treated samples disintegrated within 45 min of immersion, while, for all the xanthan treated samples, the time taken for disintegration was more than 45 min. it was noted that even after 24h, the samples remained intact, but had become considerably soft. The softness of material was determined by poking a pointed spatula into the immersed specimen.

4.3 *XRCT Scanning*

XRCT tomographies were processed into 2-D slices across the diameter of the specimens. Due to the restriction of space here, only one slice for each sample at particular curing period is presented in this paper. Figs 3a and 3b, show the 2-D slice for the sample treated with guar gum at 7 and 28 days respectively, while Figs 3c and 3d are for the xanthan treated specimens.

The brightest regions correspond to the densest material in the specimen such as gravel or coarse sand portions of the soil mix, while the darkest regions correspond to pore spaces which have low or zero density. The main intention of these scans was to capture the transformation of hydrogels from “rubbery” to “glassy” state. However, on examination of the scans it was noted, that for the given biopolymer content, it was not possible for the XRCT system at this resolution to capture hydrogels occurring at macro level of the specimen. Hence, further tests at higher concentrations of the biopolymer are planned to be undertaken. However, it was noted, for both the biopolymers there was slight rearrangement of the soil-particles (highlighted portion in Fig 3). This rearrangement was more evident for guar gum treated samples.

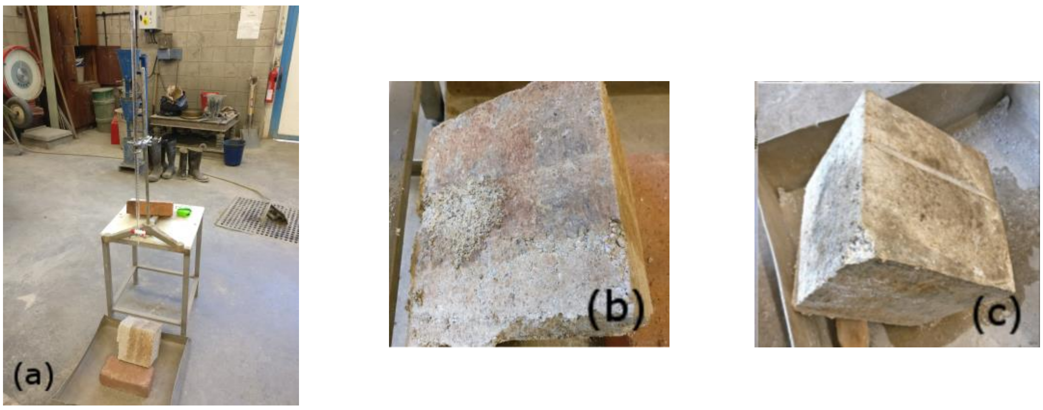

Figure 2. Durability studies. (a) Test Set-up, Test block of (b) Guar Gum & (c) Xanthan gum

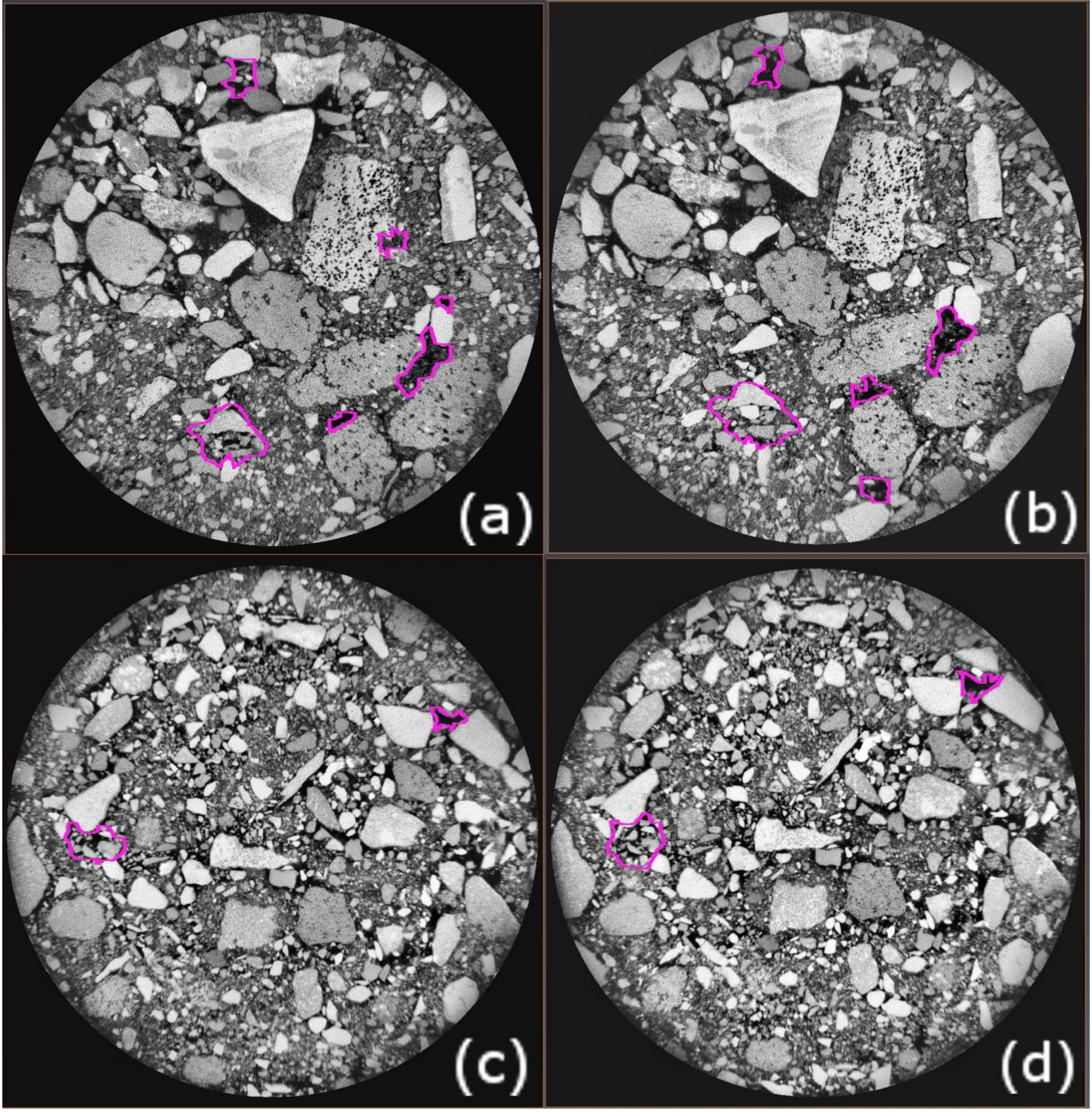

Figure 3. XRCT Scan images for guar gum (a & b) and xanthan gum (c & d) treated specimens after 7 and 28 days respectively.

5 CONCLUSIONS

Based on the background study and the tests undertaken in this study, it can be concluded that the addition of biopolymers has a significant effect on suction and mechanical behaviour of earthen construction materials which can be regarded as manufactured unsaturated soils. The strengths of the biopolymer treated materials appears to be linked to a combination of suction and hydrogel bonding. The durability tests suggest that xanthan gum performs satisfactorily in both erosional and immersion tests, while guar gum performs satisfactorily only in erosional tests. The initial XRCT scans could not capture the hydrogels at both the curing periods. However, it was noted that there was slight rearrangement of soil particles between 7 and 28 days. This rearrangement was more evident in guar gum treated specimens.

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