CHAPTER- 4

APPLICATIONS OF BIOPOLYMERS IN CIVIL ENGINEERING

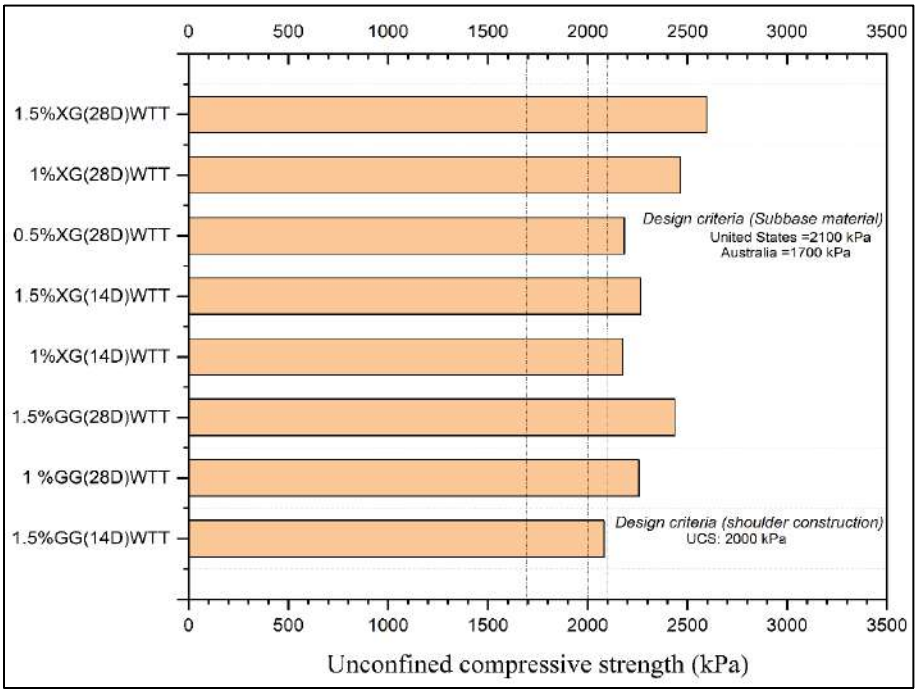
From the experimental results of the current research (presented in chapter 3), it is evident that the bauxite residue and coal mine overburden stabilized with the biopolymers, Xanthan and Guar gums (XG and GG), have satisfactory strength characteristics (Unconfined compressive strength of bauxite residue ≈ 3177 kPa and 2808 kPa at 28 days curing period with 1.5% XG and GG), and satisfactory durability characteristics (Freeze-thaw, Strength loss ≈ 11.6% at 1.5% XG compared to 46.0% (untreated bauxite residue)). Coal mine overburden waste also showed good strength characteristics (Unconfined compressive strength of CMO = 1264 kPa and 966 kPa at 28 days curing period with 1.5% XG and GG). Hence, biopolymers can improve different soil/waste characteristics so that they can be helpful in various geotechnical applications such as:

- Shoulder, Base and Sub-base stabilization
- Increasing Soil Bearing Capacity for Shallow Foundation
- Slope surface stabilization
- Earth stabilization
- Slurry Barrier Trench Excavations

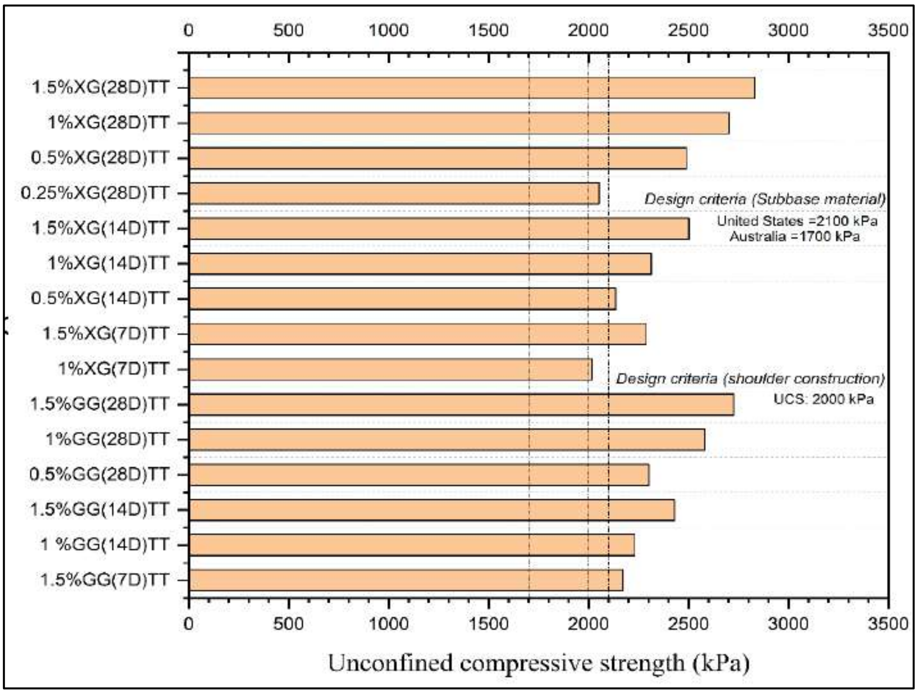
4.1 Application in Civil Engineering

4.1.1 Flexibility of Biopolymer Stabilization for Road Shoulder Construction

Road shoulders are an important element of the highway system, to provide stable surfaces for vehicles and pedestrians, space for emergency stops, a recovery zone for errant vehicles, structural support for the pavement, drainage, improved sight distance and passage for bicyclists. As reported in the literature, the soft shoulders with CBR values of less than 65% (Approximately identical to UCS = 2.0 MPa) demonstrate insufficient in situ performance in terms of surface erosion and bearing failure [97, 98]. Also, for the stabilized subbase material, different design criteria are recommended in the USA [99] and Australia [100]. Figure 4.1 shows all the biopolymer stabilized bauxite residue samples at different concentrations and curing times, with and without thermal treatment, that satisfy the requirement of compressive strength for use as shoulder and subbase in road construction.



(a)



(b)

Figure 4.1. Comparison of UCS of stabilized bauxite residue with strength requirements for shoulder and subbase construction. (a) Without thermal treatment (b) with thermal treatment.

4.1.2 Increasing soil bearing capacity for shallow foundation

Soil bearing capacity is the ability of soil to support a load from the foundation without causing a shear failure or excessive settlement. When the applied load exceeds the bearing capacity of the soil, the footing penetrates the soil either in horizontal or vertical directions so that it could lead to a bearing capacity failure. The bearing capacity of soil is variable for different soil conditions and is dependent on several factors. Past studies have shown that biopolymer stabilization enhances significantly the apparent cohesion in both cohesive (clay) and cohesionless (sand) soils regardless of soil saturation compared to the untreated condition [101-104]. Also, a numerical study on PLAXIS2D has shown the effect of guar and xanthan gums in terms of improved bearing capacity of the soil, attenuating the negative effect of saturation degree, and decreased settlement during and after saturation.

4.1.3 Slope surface stabilization

The potential application of biopolymers stabilization in soil erosion control has been investigated by many researchers [105-108]. A recent study was performed to control the surface erosion in an earth-compacted embankment in the field.

To test the biopolymer application on the field, biopolymer solution and *in situ* soil were pressurized and sprayed using hydraulic and pneumatic pump equipment to form biopolymer layers (thickness 15-20 cm) on embankment slope surfaces. In addition, vegetation seeds were also sprayed on the biopolymer stabilized layer to observe the growth behavior of vegetation in the field. As shown in Figure 4.2, the pilot construction site was divided into three sections for different purposes (section 1: xanthan gum biopolymer stabilization for vegetation growth promotion; section 2: casein biopolymer stabilization for surface erosion control; section 3: Xanthan and starch combined biopolymer stabilization for surface erosion control and weed mitigation).

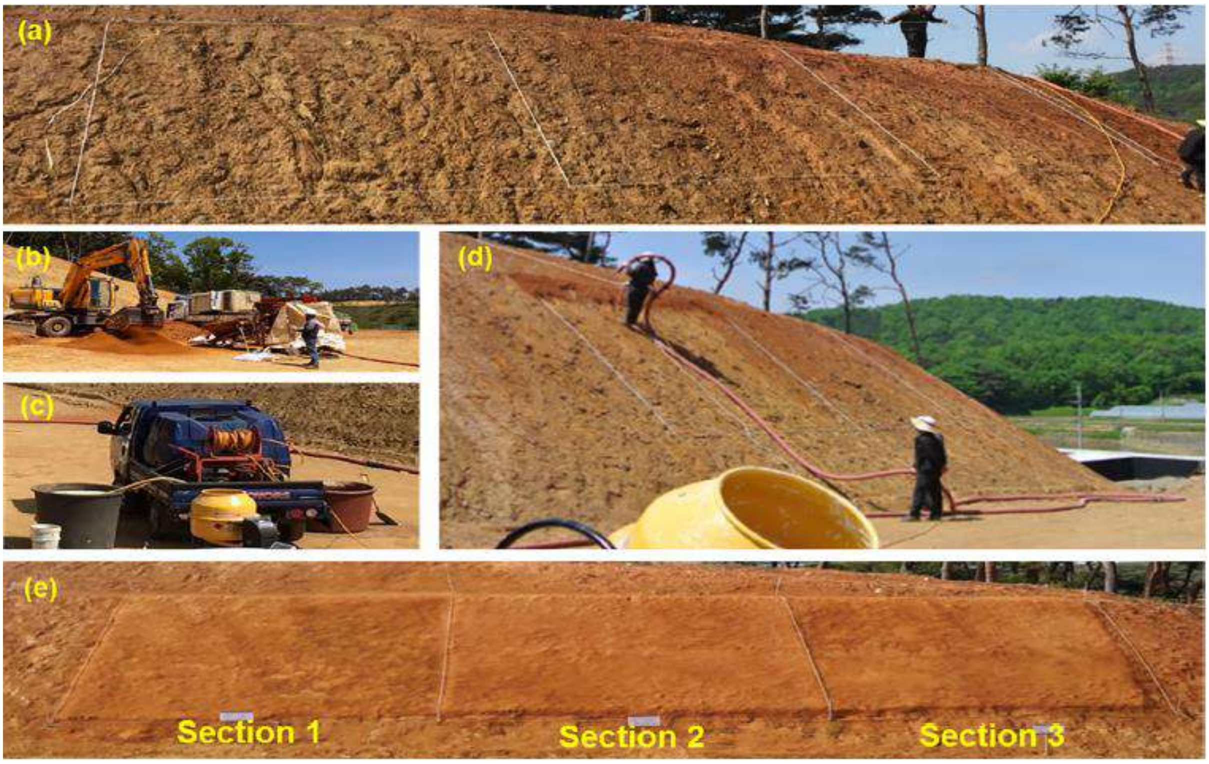


Figure 4.2. Biopolymer stabilization for slope surface protection (Seosan, Korea, May 2016)

In situ implementation was conducted following surface cleaning and flattening the slope surface with a backhoe (Figure 4.2a). *In situ* soil was sieved to remove oversized aggregates and sprayed via pneumatic pressure using a high-pressure air compressor (Figure 4.2b). A biopolymer solution was uniformly prepared using an electric mixer(Figure 4.2c), transported with soil using separate pipes, and sprayed by a dual-channel nozzle at the end (Figure 4.2d). After spraying the soil-biopolymer mixture, seeds were uniformly seeded on the biopolymer stabilized surface. After the completion of slope construction, the second biopolymer layer was sprayed to check the feasibility of multiple biopolymer spraying.

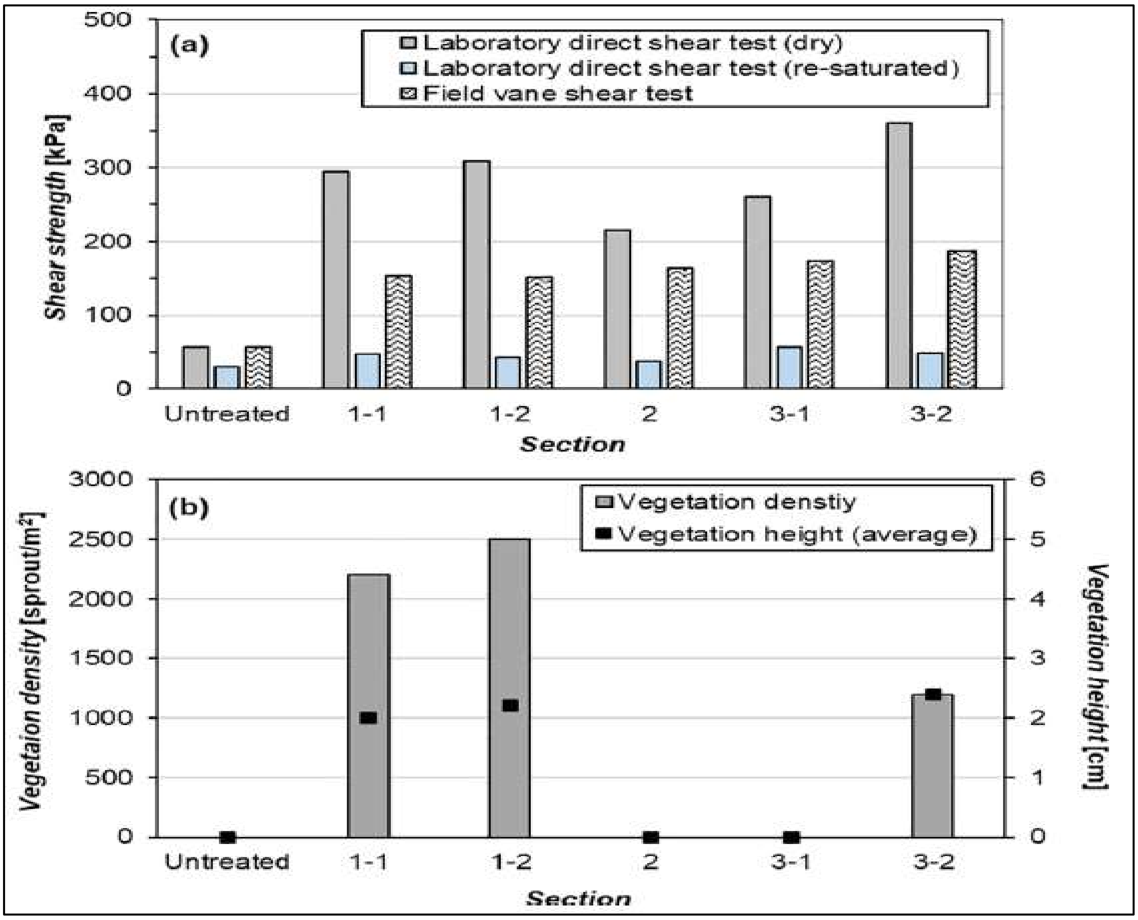


Figure 4.3 Effect of biopolymer stabilization after 100 days on (a) shear strength (b) surface vegetation growth behavior (Seosan, Korea, May 2016).

The *in situ* site was monitored for the next 100 days. Vegetation density was measured via site survey, while shear strength was analyzed via a field vane shear test, and undisturbed samples were collected from the site to perform a laboratory direct shear test. The stabilized sections (1 to 3) showed strength enhancement compared to the untreated condition (Figure 4.3a). Also, a significant increase in vegetation density was observed on biopolymer stabilized sections compared to the others and untreated conditions (Figure 4.3b).

4.1.4 Earth stabilization using biopolymer

The feasibility of biopolymer stabilization on earth stabilization (pavement) was verified on field. A non-paved pedestrian trail (50 m long and 1m wide) was stabilized with biopolymer solution on site (Daejeon, Korea; Figure 4.4a). The on field biopolymer stabilization process was performed by following steps: (1) site clearance (removing surface vegetation, followed by compaction (Figure 4.4b); (2) *in situ* soil, biopolymer and water mixing on site (Figure 4.4c); (3) applying the stabilized mixture on target surface (10 cm thickness) (Figure 4.4d); surface leveling via vibratory compactor (Figure 4.4e); and (5) prepared surface after completion (Figure 4.4f).

Figure 4.4 Overall procedure of earth stabilization using biopolymer solution (Daejeon, Korea; October 2015)

The stabilized pedestrian trail showed effective surface stiffness and high surface erosion resistance. However, this case study also raised questions about the further development of biopolymer specific field equipment and considered the rheological characteristics of biopolymer and the application of biopolymer soil mixture in civil engineering purposes.

4.2 Economic Feasibility of Biopolymer for Soil/Waste Treatment

There is a growing interest in using biopolymers in stabilizing soils due to its mass production and expanded utilization resulting in a significant cost reduction, as was the case with the considerable price reduction of xanthan gum following its commercialization. The cost of xanthan gum in the 1960s was about 30 USD/kg. Simultaneously, it has dropped to 1/4th by 2004 and 1/10th by 2014 (Chang et al., 2016) due to the development of technologies and expanded applications in the field of medical science, cosmetics, food industry, and construction.

In the 1960s, the universal source of biopolymer production was edible biomass, such as maize and sugarcane. Further, in the 1990s, non-edible sources such as agricultural and food waste were employed to produce biopolymer. Niaounakis [110] has reported an alternative source of consumption of CO^2 in the production of various biopolymers. It is also observed that xanthan gum manufacturing consumes about 4.95 kg of CO2 per kg of biopolymer [111, 112]. In contrast, cement manufacturing emits 1.24 tonnes of CO2 per ton of cement as a combined outcome of chemical responses (52%) and the burning of fossil fuel (48%) during the calcination process [113]. The present study shows that 0.5% concentration of xanthan, guar and composite gums treated bauxite residue sample for strength enhancement results in equal or higher strengthening effect than conventional treatment with 10% cement. However, using 0.5% XG for the treatment of bauxite residue (1 ton) is uneconomical compared to cement treatment, and 30% more expensive (xanthan gum: 1000 INR/ton of bauxite residue; guar gum: 1200 INR/ton of bauxite residue; cement: 700 INR/ton of bauxite residue). However, considering global initiatives to reduce greenhouse gas and carbon emission trading (at a rate of 22 USD/ton CO2), the bauxite residue treatment with 10% cement has been estimated to be 2.75 USD (207 INR).

In comparison, 0.5% XG treatment would secure 0.54 USD (40 INR) (Certified Emission reduction) for 1 ton of bauxite residue treatment. Thus, the net cost of treatment with cement is 907 INR (700 + 207 INR), and that with a biopolymer is 960 INR (1000 – 40 INR) for xanthan gum; 1160 INR (1200 – 40 INR) for guar gum. So, economically, the usage of biopolymer treatment is remarkably competitive, being only 5% expensive than cement treatment, but saving a lot on carbon emission. Therefore, the biopolymers have an excellent ability to substitute high carbon-emitting soil/waste treatment materials, particularly when considering the challenges of eco-friendly construction and development. A tentative estimate of the cost of treatment and carbon emission for one ton of waste treatment has been shown in Table 4.1.

Table 4.1 Economic feasibility comparison of biopolymer stabilization with cement treatment

Soil treatment material	Cement	Xanthan gum	Guar gum
Market price of material	7 INR /kg [a]	200 INR/kg [b]	120 INR/kg [b]
Required amount for 1 ton soil treatment	100 kg (10 % to soil 1 ton)	5kg (0.5% to soil 1 ton)	10kg (1% to soil 1 ton)
Cost for 1 ton soil treatment	700 INR	1000 INR	1200 INR
CO_2 emission per 1 kg material production (kg CO_2)	+1.25	-4.97	-4.97
CO_2 emission related to 1 ton soil treatment (kg CO_2)	+125	-24.85	-24.85
CO_2 emission trade related to 1 ton soil treatment [c]	+207 INR	-40 INR	-40 INR
Total cost for 1 ton soil treatment (with carbon trade exchange considerations)	907 INR	960 INR	1160 INR

[a] Depicts average market price of cement in India ,

[b] Depicts average price of xanthan gum (INDIA MART)

[c] EUETS (European Union Emission Trading Scheme) carbon emission trade: 22 USD/ton (1.66 INR/kg) of CO_2, in 2012. (1USD=75.4 INR)