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Development of vegetation concrete technology for slope protection and greening

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ABSTRACT

Slope vegetation clearing for urban development purposes often leaves the slope prone to surface erosion prior to revegetation establishment. This study is in response to the requirement of immediate slope protection and revegetation. As no research in Australia exists on vegetation concrete technology, this paper analyses and presents the results of growing various native Australian grass species on porous concrete under different mix compositions. It aimed to determine the feasibility of an integration of vegetation and concrete for use in slope protection, more specifically, explored the effect of a concrete environment on the following Australian native grass species: Themeda trianda, Chloris truncata and Elymus scaber. To enhance the survival of grasses, calcium aluminate cement (CAC) with a lower pH than ordinary Portland cement was used. Additionally, the influence of various fly ash contents on strength characteristics (compressive strength, tensile strength and elastic modulus) of porous concrete was also examined. The growth characteristics of the vegetation concrete grass species were monitored for 8 weeks during which the average grass height, relative coverage and root development were observed. The experimental results showed that the compressive and tensile strengths of the tested porous concrete were comparable and similar to the currently applied slope protection methods. Furthermore, it was evident that Chloris truncata was better adapted to the concrete environment than the other two tested grass species. However, Elymus scaber thrived with a remarkable coverage at high fly ash content, whereas Themeda trianda preferred a lower fly ash content. The results pave the path for further research into this technology and have significant implications for the application of vegetation concrete technology, especially in an Australian context.

1. Introduction

Infrastructural construction typically leaves bare slopes that are susceptible to soil erosion, water runoff and have potential for shallow landslides. The result of this runoff can have adverse impacts on both the slope and its surroundings [9]. Many approaches to negate these unfavourable effects have been developed as a form of slope protection. Some methods that are used for surface protection include vegetation, hydromulch, geotextiles, wire mesh, soil stabilising agent as well as inorganic methods of slope protection which primarily involve using concrete including shotcrete, precast, concrete canvas and masonry [11]. Although differing in function, durability and cost, they are all similar in the sense that they do not intend to provide substantial resisting forces to the slope as retaining structures and anchoring systems do.

Inorganic methods are typically designed for functional purposes, providing structural stability based on geotechnical investigations [8]. However, inorganic methods have high initial costs due to both production and application of the slope protection system. Furthermore, although exhibiting durable characteristics, these methods still require general maintenance over time and succumb to a design life whereby extensive restoration or total replacement may be necessary, incurring large costs [12]. Besides, the soils within the frame of grid beams are vulnerable to be washed away during heavy rain. One of the fastest and most environmentally friendly techniques to forbid and remedy a runoff on a slope is to vegetate it [6]. Vegetation's aesthetic role as a natural component of the landscape is of irrefutable importance socially and culturally. The positive role of vegetation on slope protection and the effect of vegetation removal on slope stability have both been well documented. However, flowing excess water, such as storm water, melt water or water from other sources over the slope surface may still result in the surface runoff.

On the other hand, native vegetation clearing in Australia is a major threat to its ecology [5]. In addition to disturbing its unique

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biodiversity, the clearing of Australia's native vegetation also impacts on its society's culture, recreation, eco-tourism and aesthetics. So bioengineering has become ever prevalent in the current engineering climate. It seeks to incorporate different fields into a design that produces an optimum balance between differing and potentially conflicting requirements.

It is well known that surface drainage can effectively prevent the slope from runoff [10]. Soil-cement cover is a common method for surface drainage. Nevertheless, growing vegetation on the surface is the main issue that restricts the feasibility of this method. In this regard, porous concrete which also referred to pervious concrete, can be used as an alternative to conventional concrete by encouraging infiltration of stormwater runoff: hence reducing erosion, reducing deviation from natural water flow patterns and enhancing groundwater level recharge.

By combining traditional engineering application with horticultural influence, the development of Vegetation Concrete Technology (VCT) is focused in this paper as a possible slope protection method. VCT integrates vegetation and concrete by laying a porous concrete medium in which water, air, soil and roots can pass freely through its continuous pores. Vegetation is then able to germinate and root itself through the porous concrete frame and into the underlying soil strata. The fundamental intent of this integration is to utilise porous concrete to provide immediate slope protection whilst also facilitating the growth of beneficial surface vegetation. The VCT benefits from higher strength in comparison to the soil and a higher infiltration capacity rather than concrete [15,20]. Consequently, the surface drainage can be increased substantially.

It is noteworthy that VCT uses the mechanical properties of the porous concrete to maintain slope stability whilst acting as a concrete framework for vegetation establishment and growth on mild to moderate slopes. This slope protection method will require initial costs similar to inorganic methods due to concrete production and slope application, however after vegetation establishment the slope will require little maintenance costs as the vegetation develops to naturally protect the slope surface.

In recent years, some limited studies have aimed to progress the field of ecological engineering by combining traditional slope protection methods. These studies shared the same ultimate goal of protecting and aesthetically enhancing slope surfaces by integrating concrete and vegetation. Chen et al. [3] evaluated the impacts of concrete content on seed germination and seedling establishment. They combined the principles of hydromulching with the introduction of concrete by spray technique, and resulted in a vegetation concrete matrix to provide slope stability and protection to ranging slope gradients. It was found that for optimum vegetation growth the matrix should contain 8% concrete content as a stabilising agent. However, appropriate materials with enough moisture and nutrients required by plants are needed to fill the numerous pores of vegetation concrete matrix effectively. Because the plant roots should have capability of growing and extending through the pores to shape an integrated system of concrete and plant matter. Chen et al. [3] stated that a wide range of crucial features should be taken into account in order to apply VCT successfully in construction industry. For instances, a wide variety of plants must be able to grow in normal soil; the pores in concrete should be filled up with vegetation matrix to maintain moisture and nutrients; and enough coverage of plants on surface of VCT should be achieved. Shi and Kong [17] suggested that the VCT should either be prefabricated to efficiently decrease the construction period or be cast onsite. However, one of the problems regarding the production of VCT is the vegetal characterization of this type of concrete. The hydration reaction of ordinary Portland cement (OPC) makes the concrete alkaline with pH amount of up to 12–13. Consequently, hydrated OPC is not favourable to the growth of ground and aquatic plants in concrete. In this regard, Bao et al. [2] reduced the alkalinity of previous concrete by the addition of a self-designed admixture into the cement paste. It was stated that by increasing the admixture content to approximately 3.6%, the compressive strength of pervious concrete was more than 25 MPa and the vegetation managed to grow satisfactorily.

However, the development of vegetation concrete composite is still in its infancy and there is only a small amount of published literature available for direct review. Particularly, research on VCT in an Australian context is currently lacking. Results from investigations into such technology abroad suggested that Australian native grass species (ANGS) could be a suitable candidate for a concrete integration. Accordingly, this paper investigated the growth characteristics (i.e. average grass height, relative coverage and root development) of three ANGS (Themeda trianda, Chloris truncata and Elymus scaber) on pervious concrete. To enhance the survival of grasses, calcium aluminate cement (CAC) with a lower pH than ordinary Portland cement was used. Additionally, the influence of various fly ash contents on strength characteristics (compressive strength, tensile strength and elastic modulus) of porous concrete was also examined. The contributions of this study can provide beneficial knowledge for future researchers on the feasibility of VCT in an Australian context.

2. Experimental program

2.1. Materials

The materials used for the experiment can be divided into two major components: porous concrete and vegetation. As with traditional concrete, porous concrete is a composite material composed of aggregate, cement and additives to achieve desired concrete characteristics. The following materials detail the constituents used for this experimental investigation. Calcium aluminate cement (CAC), having a specific gravity of 3.24 g/cm^3 and a lower pH than OPC, sourced from Kerneos Aluminate Technologies Australia was used as cementitious materials. Fly ash in compliance with AS3582 was used as a supplementary cementing material to reduce the amount of CAC. The typical chemical composition of CAC and FA are shown in Table 1. 20 mm crushed gravel was used as coarse aggregate. No fines (sand) were used in the production of porous concrete. Air-entraining admixture based on Bycol was used as admixture. Three ANGS namely Elymus scaber, Themeda trianda and Chloris truncata were used as grass seeds. The basic properties of selected grass species are given in Table 2. Soil mix consisted of 1 part peat moss, 1 part river sand and 1 part perlite was used to fill the pores of concrete.

2.2. Preparation procedure and test specimens

A total of 4 mixtures were designed. The CAC was replaced by fly ash at 10, 20 and 30% by volume of binder. The ratio of water/binder was kept constant as 0.4 which was determined with

Table 1
Chemical composition of calcium aluminate cement and fly ash.

Constituents (wt%)	Calcium Aluminate Cement	Fly ash
SiO_2	≤ 6	64.2
Al_2O_3	≥ 37	25.5
Fe_2O_3	≤ 18.5	3.92
CaO	≤ 39.8	2.27
MgO		0.69
MnO		0.08
K_2O		1.24
Na_2O		0.52
TiO2		0.97
LOI		0.61