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A Review: Assessment of Stabilization Dust Using Liquid Enzymes

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ABSTRACT

Roads play a significant part of economic development. Due to financial constraints, in many developing countries like Botswana, there are large networks of unpaved roads. The major detriment effect of unpaved or gravel roads is dust emissions. Dust affects the climate change which in turn increases the generation of dust. This has a huge impact on human health which has risen to great concern. The best solution to mitigate dust emission from gravel roads is to seal the gravel roads but this cannot be easily achieved due to financial constraints. Traditionally, road managers have controlled dust by applying calcium chloride or magnesium chloride to the road surface. However, these salts easily leach out of the soil during precipitation events and may not be an option in environmentally sensitive areas. Bio-enzymes have emerged as environmentally friendly soil stabilizers. They are cheap and can easily be available. In this review paper the use of bio-enzymes as stabilizers and a solution to reducing dust will be reviewed, health effects of dust in this exercise to try and see if they can mitigate dust on earth roads that have been constructed using material at site or calcrete. The findings could spread the awareness of effects of dust in Botswana so that the public and private sector can help in supplying the enzymes to reduce health issues affecting the society in Botswana. It will also help decision-makers to make a wise choice of which bio-enzyme to be used effectively.

Keywords: Unpaved roads; dust; bio-enzymes; health effects

INTRODUCTION

Roads have an important role in economic development, increasingly bringing financial and social advantages to local people. While the roads that were traditionally constructed with lime, cement and bitumen serve best, these are hardly affordable in developing countries hence the use of unpaved roads. The unpaved roads referring to unsealed, unsurfaced or gravel roads. The major detriment effect of unpaved or gravel roads is dust emissions which comprises of topographical material that is infused into the environment by vehicle-related exercises from unpaved roads (Ma et al. 2020; Liu & Yoon 2019; Alves et al. 2018; Jones et al. 2013) and road dust has been said as a significant reason for atmospheric particles. Studies stated that road dirt re-suspension is one of the fundamental sources of particulate matter with effects on air quality and climate. Long-term exposure to traffic-generated dust can fairly be expected to contribute the 1.5 to 2 million people, mainly women and kids, yearly in low-income countries, who die upfront from the results (Greening 2011; Schweitzer 2018).

Roads developed with right best materials mixed with appropriate design, construction and keeping stability between overall performance and cost of the roads and at the same time gratifying the environmental guidelines is turning into a challenge to the public and non-public sector as the traditionally used soil stabilizers (lime, cement and bitumen) are expensive and this leads to the use of poorer quality materials, accelerated frequency and the cost of maintenance and greater dirt. The declining availability of nonrenewable resources leads to the use of poorer construction materials, accelerated frequency and the cost of maintenance as well as greater amounts of dust emissions. The large gravel road network in Botswana and Africa is the main leading reason to a significant content of dust particles in the air due to lack of finances in the developing countries. From a study conducted by The African Development Bank's Statistics department (2014), it was estimated that the cost of construction/upgrading of a paved road of length greater than or equal to 100km would cost between USD166 300 and 425 400/lane km (P1 129 177 – P2 888 466) and the cost of maintenance would range between USD56 900 – 72 000/lane km (P386 351 – P488 880). When it involves low-volume traffic and remoteness of the area, it is difficult to pave gravel roads and a costly task that may remain unrealistic and therefore the best solution is unpaved roads (Beaulieu et al. 2013). Thus proving that the value of constructing or maintaining a paved road is relatively high and construction of new roads or maintenance of existing ones could be costly, as such minimizing cost would be ideal. The major detrimental effect brought about by unpaved roads is dust emissions which have aroused concern among international agencies due to health effects of dust on people. Gravel roads have been classified as the major source of dust (Alves et al. 2018).

Due to their large networking in developing countries or use in remote areas, huge amounts of dust produced are even worse and this has a huge impact on local people. The best way to mitigate dust emissions besides using hardly affordable and best solutions like traditional stabilizers (lime, cement and bitumen), spraying water comes as a well-adopted way of suppressing dust. This is being used in mines where temporary roads are constantly used and use of traditional stabilizer method may not be economical because of the need to constantly changing road routes in the mine. In fact, water only has a short period of time to control the dust and require frequent application. In some conditions like in arid and semi-arid areas, the situation gets worse due to increase loss of water from the soil. This leads to the high demand of water supply on which in some developing countries like Botswana where water is scarce, this may not be economical. Lately, bio-enzymes has been introduced as soil stabilizers, especially in highway projects. They are easily soluble in water and are provided in liquid form. By using these enzymes, not only would they save time and costs normally consumed by the mixing of traditional solid stabilizers with soil but are also environmentally friendly. Hence, this makes them a method to consider to mitigate dust economically and effectively. This article then focuses on the review of literature under a few issues being unpaved road dust emissions, effects of dust on health and use of bio-enzymes as stabilizers in the construction industry and how these enzymes can be used to find out if they can reduce dust emissions.

GRAVEL ROADS AND DUST EMISSIONS

Gravel roads are an easy transportation infrastructure to access nearby towns or commercial centers from remote areas in developing countries together with some developed countries. They are usually produced by making use of the soil or material on site or any good material easily available like gravel. The roadbed of the unpaved road is usually compacted and graded. Due to the movement of traffic, huge amounts of dust are generated (Koh & Kim 2019; Etyemezian et al. 2005; Chen et al. 2019; Barnes & Connor 2014; Giunta 2020; Saha & Ksaibatib 2020; 2018; Lim et al. 2015; Aleadelat & Ksaibati 2018; Díaz-Nigenda et al. 2018). The extent of the quantity of dust produced relies upon the fine particle content material in the surfacing material, water content, number of vehicles, and their speed and roadbed capacity according to (Edvardsson 2009; Watson et al. 1996; Gillies et al. 1999; Okok et al. 2019).

Tarimo et al. (2017) point out that gravel roads can provide the intended transportation services economically and satisfactorily if proper construction and practices are used. The growth or increase in number of vehicles over the years demand good and high quality road construction materials to reduce wearing or deterioration. However, affordability of these good quality materials is a struggle in developing countries due to low incomes. Regardless that this kind of road would be of great help to the economy of some developing countries (Liu & Yoon 2019; Amato et al. 2019; Khan & Strand 2018).

Unpaved roads are one of the foremost sources of the particulate matter (PM) acknowledged to negatively affect human fitness due to carcinogenic and toxic elements doubtlessly existing in the micron-sized fractions and control of PM10 and PM2.5 of which are particles with diameter less than 10 μm and less than 2.5 μm, respectively is a concern which is rising among many international agencies (Potgieter-Vermaak et al. 2012; Gillies et al. 1999). In 1975, U.S. Environmental Protection Agency (EPA) came out the first emission factor equation for unpaved roads, and also there are various large-scale or site-specific PM10 estimation models. Though there is a great detriment of dust generation from gravel roads that has a huge impact on human health (Gillies et al. 1999). Indeed many studies have been conducted on air pollution due to road dust posing threat to public health like increase in respiratory and cardiovascular hospitalization and untimely passing due to air particulate matter (Mukaria et al. 2017; Antipova 2020; Ajibade et al. 2020) but less studies have been written on quantifying the effect of dust from these roads (Greening 2011). A few studies within the USA (Ma et al. 2019) show that as much as 50% of PM10 emanations and 19% of PM2.5 outflows are due to street tidy. Moreover, road dust is considered to be the single biggest source of PM10 emanations and 65% of road dust is ascribed to unpaved streets. Nieder et al. (2018) reported some elements like Cr which causes inhaling problems and cancer to both adults and children. Outflows of dust from unpaved roads are assessed based on silt content (g/m^2) or fine particles passing through the seve No. 200.

Unpaved roads are lengthy wind-prone regions, and is often regarded as major causes of dust clouds that affect urban air quality and visibility during the dry season, referring to a natural hazard to human. The ability to show PM10 outflows and ways that could provide an arranging apparatus for residue prevention strategies to focus on source regions. It will also provide a means of assessing the potential effects of well-being on vulnerable populations downwind, such as schools, medical clinics and people in general. Also, the fact that dust produced by traffic on dirt roads can be a significant source of particulate matter directly emanating from urban unpaved street surfaces (Díaz-Nigenda et al. 2018).

The exposure of employees such as coal miners and quarry employees to high concentrations of dust for a long time is clear from its safety impacts. Although road users and residents in developing countries are not usually going to have such high concentrated exposure, constant near-daily exposure for several years is highly likely to present a serious health risk. Some studies suggested that indoor levels could be as high as 70% to 80% of outdoor levels in areas where these smaller particles are present (Wallace 1996). In some countries like Botswana, such figures are also higher because of the larger proportion of unpaved road networks. For all rural road users, especially children, many of whom walk along these roads to and from school every day and who also live in villages served by unpaved roads; dust can pose a significant long-term health risk. Thus, an emergency and economical solution is needed to solve this issue.

EFFECTS ON CLIMATE CHANGE

Climatic changes over a period of time has been said to be caused by dust. The issues with gravel roads are troublesome, the major problem being dust generation leading to health hazard and poor quality of air. One of its most drastic effects is its outcome on the respiratory health of people, particularly of young children (Greening 2011). The generation of dust happens primarily as soil disaggregates due to diminished cohesion (Okok et al. 2017). Recently, introduced enzymes assist in the alignment of clay particles preventing expansion of the clay in the presence of water. The soils achieve higher density thus reducing emissions of dust. Enzyme is able to reduce more stress at the surface and bonding capacity is also improved by adding enzymes (Lin al. 2019).

TREATMENT DUST ON UNPAVED ROADS

Gravel roads dust is often fine enough to enter the lungs and cause severe irritation or damage. Different infectious and non-infectious diseases are due to dust exposure (Keil et al. 2016; Schweitzer et al. 2018; Liu & Yoon 2019:, Díaz-Nigenda et al. 2018) and this tend to have a detrimental effect on children, older people, and have a detrimental people with chronic cardiopulmonary diseases or respiratory conditions like asthma. The long-term exposure of workers such as coal miners and quarry workers to high concentrations of dust is evident from its health impacts. While road users and residents in developing countries are not normally going to have such high concentrated exposure, continuous near-daily exposure over many years is highly likely to pose a significant health hazard. Some studies have also demonstrated that in areas where such fine particles are present, indoor levels may range from 70% to 80% of outdoor levels (Wallace 1996).

Dust has traditionally been regulated by road managers by adding calcium chloride or magnesium chloride to the road surface. These things are relatively low-cost and easy to implement. However, during precipitation events, both of these salts readily leach out of the soil. Depending on the venue, the foundlings show that salts lose their efficiency in about one year (Barnes & Connor 2014). The use of these salts in some areas is not a choice. For example, in rural Alaska, where hunting, fishing, and berry picking make up a good portion of the food supply of residences, because of the effect on their food supply and they do not like salt palliatives. Furthermore, salts may not be a selection in environmentally sensitive zones. In locations where salt is not an option, other means of chemical stabilization of the fine particles are required (Barnes & Connor 2014).

Non-petroleum-based organics such as lignosulfonate and tall oils, synthetic polymers, and electrochemical products are included in these alternate means of dust control. These products' implementations are very site-specific and they all operate with varying success. Our measurement of how well these products perform to manage dust on an unsealed surface has, however, been largely qualitative so far (Barnes & Connor 2014).

Although many materials are sold to remedy unpaved road dust issues, or to stabilize soils, only a few are safe for the environment. Water spraying can be considered as the cheapest and easiest suppressant of dust. It would need frequent application in dry and hot environments Bituminous and some chemical suppressants contain elements or compounds that can negatively affect the environment. Water spraying leads to slippery, adhesion of mud to wheels, and erosion. Alternative approaches to address the issue were put in order to find efficient and environmentally friendly solutions (Magafu & Li 2010; Agarwal & Kaur 2014; Cuccurullo et al. 2019).

The ability to control ways of lowering dust emissions from unpaved roads has not been well described or documented. The so-called traditional stabilizers like lime are rarely available and tend to use huge resources (Agarwal & Kaur 2014). Many studies refer to lime as the best soil stabilizer due to its ability to reduce plasticity and moisture holding capacity of soil which in turn produces high stabilisation but certain reaction that takes place on the lime leads to weak and breaking of bonds between soil particles over time (Agarwal & Kaur 2014; Gillies et al. 1999). From the geotechnical perspective, bio-enzymes have emerged as a new chemical for soil stabilization. Biocatalyst with dust suppressant reduces emissions of PM10 from unpaved public roads. Bio-enzymes are non-toxic, non-corrosive, non-flammable natural liquid enzymes produced from the fermentation of vegetable extracts, improving the soil's engineering qualities, facilitating higher soil compaction densities and increasing stability as described by their manufacturing companies or makers (Agarwal & Kaur 2014; Gillies et al. 1999).

Manufacturers of bio-enzymes claim their products are effective, environmentally friendly (non-toxic), cost efficient and effective to use. Besides that, they enhance compressive power, decrease compaction effort, and increase density while also decreasing permeability. It has also been said by some studies that these enzymes are not only degradable but also reduces carbon footprint (Taha et al. 2013 & Khan et al. 2015). However, the studies up to this point recommended that these claims need to be verified by independent laboratory testing before these bio-enzymes are applied in the field. The use of enzymes as stabilisers has not experienced any scientific progress and is currently performed using methodological criteria based on past experience. Dust suppressant application rates depend on traffic, climate, road location, mineralogy, and particle size distribution of granular material. Thus, treatment performance varies widely according to these parameters (Edvardsson, 2009).

James J, Pandian (2016) states that in comparison to the application of conventional stabilizers such as lime, cement or fly ash, chemical stabilization using non-traditional additives has been described as an effective solution for these problems. This is due mainly to the environmental and economic feasibility of current stabilizers, which can result in high greenhouse gas emissions and unsustainable costs in their applications. Soil stabilisation based on enzymes is a form of non-traditional chemical stabilization that has been used successfully in road construction over the past 30 years. Despite its use over the last three decades, there has been no universal standard or tool that practitioners can use to assess the performance of stabilized unbound paving with enzyme additives. The study claims that the enzyme stabilization showed substantial improvements in road safety, as evidenced by test results based on site soil before and after stabilization. Some studies have applied some enzymes to certain types of soil but no change was seen whereas some have given a positive testimony (Khan et al. 2015).

BIO-ENZYMES

There are various dust suppressants available that can be used to mitigate dust production from roads but they are mostly not environmentally friendly. Recently, bio-enzymes have been introduced as the most economical and environmentally friendly soil stabilizers. These are non-flammable, non-toxic, non-corrosive liquid enzyme, manufactured from fermentation of vegetable extracts. They are sold in the commercial markets in high concentrated liquid form which require dilution before application (Khan et al. 2015).

The chemical composition of these bio-enzymes is never really revealed due to proprietary by the manufacturers and many studies have shown that the effectiveness and properties of these enzymes are not clearly known (Taha et al. 2013). Clays in general have an overall negative charge when there is the same number of positive and negative charges from the surrounding of the clay become attracted to the surfaces of the clay and are also held at the edges of the clay (Firoozi et al. 2017). As shown in Figure 1, it leads to a reaction between clay and organic cations without the enzymes becoming part of the end product but just catalyzes the reaction (Agarwal P, K. 2014; Ravi et al. 2009; Lim et al. 2015). This then leads to binding of clay particles making them agglomerates. This thereby reduces pore space, swelling and shrinkage, optimum moisture content and increases the stability of the soil and gaining of strength of the soil.

The soil cannot easily be re-suspended by the wind effect or vehicle movement. Enzyme catalyse the reactions between clay and organic cations, and accelerate the process of cationic exchange to reduce the thickness of the adsorbed layer. Chemicals are mixed with soil for other types of chemical stabilisation, which is difficult to mix thoroughly, but bio-enzyme is simple to use as it can be mixed with water at optimum moisture content and then sprayed over the soil and compacted. Luckily, liquid enzymes are available that can be used to agglomerate fine particles that make them larger so that they cannot become airborne. In an attempt to hopefully meet the sustainability objective and also hopefully attempt to reduce the cost of road construction, the use of liquid enzymes is explored in this research. Bio-enzymes for soil stabilisation have recently been introduced, especially in highway projects.

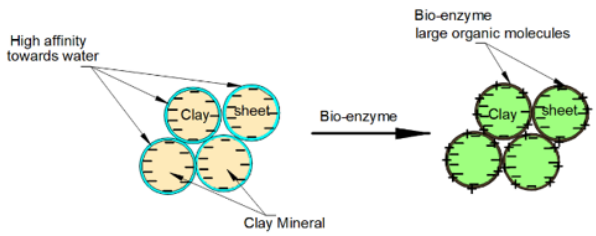

FIGURE 1. Enzymatic mechanism of soil stabilization (Khan et al. 2019)

Lim et al. (2015) suggests the proportion of soil stabilisers needs to be developed rather than based on a 'trial mix' design or 'experience' design. Some progressive firms have developed guidelines to recommend the proportion of stabilisers to be used depending on subgrade properties and road use. So as to attain good results after application of enzymes.

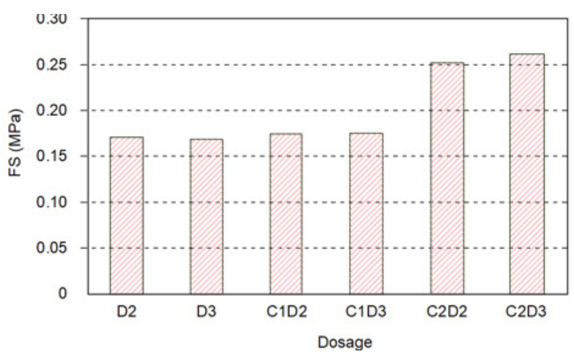

FIGURE 2. Flexural strength of enzymatic stabilized soil (Khan et al. 2019).

From Figure 2, the application of enzymes shows strength gain in terms of flexure test. Significant improvement in the strength with the period of curing is clearly visible for bio-enzyme. The above stated improvement may be attributed to the encapsulation of clay mineral by the large organic molecules that reduced its affinity towards water. Aforementioned mechanism also leads to reduction in inter-particle space, void ratio, moisture holding capacity, plasticity, swelling, and shrinkage making them some of the prime factors leading to strength gain (Agarwal & Kaur 2014).

Khan et al. (2015) found that the enzymes did not produce any comprehensible improvement in Atterberg's limits, compaction, and unconfined compression tests. This might be as a result of shortage of clay content to allow for ion exchange in order to attain cementation, flocculation thereby reducing plasticity and hence improving soil properties. Water was used as a control i.e., soil sample with only water were tested for their original properties and then they were compared to the properties of soil samples treated with bio-enzymes. Their founding is shown in Figure 3. The bio-enzymes used include EZ-1X, Earthzyme and Permazyme which are abbreviated as E-I, E-II and E-III, respectively.

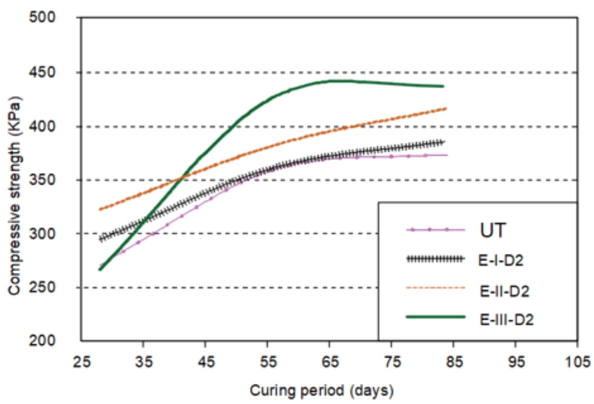

FIGURE 3 Variations of UCS for untreated and treated soil (Khan et al. 2015).

CONCLUSION

This review paper discussed the assessment of additional bio-enzymes to improve soil and reduce dust in roller roads and the following major conclusions are drawn:

1. From the reviews, it can be concluded that reduction of dust should be a priority and the use of the bio-enzymes makes it an easy goal if the enzymes are effective. As traditionally used stabilisers are either expensive or unaffordable like lime. These stabilizers have greenhouse houses hence bio-enzymes are product though they might be applied frequently over the unpaved roads. Furthermore, these enzymes act as stabilizers and can reduce the need of new construction material and can also act as a carbon footprint.

2. Dust has a great effect on climate change which increases more dust generation. Dry and hot climate conditions produce more dust in the atmosphere due to free soil particles with little to no moisture content. These are the conditions as such as in African countries like Botswana.

3. It has been seen that diseases such asthma became worse due to dust content in the air. Dust mostly affects children and elderly people in the society. This is because of the content in these soil particles like chemical components.

4. Stabilisation occurs when there is deduction in plasticity and pore space.

For effective results, clay content of the surfacing material needs to be considered as most researches regard any fine particle as good for enzymes to work on which is not necessarily true. Not all fine particles are clay and have charge on them. The content of clay must also be limited to a certain range to avoid too much of it and too little to attain good results. It is also advisable to first make a laboratory test on the enzymes before application on field.

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DECLARATION OF COMPETING INTEREST

None

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