SUITABILITY OF β-KERATIN FROM CHICKEN FEATHERS AS SURFACE SEALANT FOR DUST CONTROL ON GRAVEL ROADS

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature…………………………………………… Date………………………..…

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This thesis has been submitted for examination with our approval as the University Supervisors

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DEDICATION

I dedicate this work to my Parents, Mr. Justus Ndege and Mrs. Susan Ndege, my wife Mrs. Judy Kariuki, my son Bradye Flavio, my daughters Talia Flavia, Faila Portia, my brothers and sisters for overwhelmingly supporting and encouraging me during my studies.

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ACRONYMS AND ABBREVIATIONS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Material Testing
CBR	California Bearing Ratio
CFF	Chicken Feathers Fibres
CMC	Carboxymethyl cellulose
CPS	Conservation Practice Standard
HPLTC	High Performance Thin Layer Chromatography
IC	Indigenous Chicken
Ifs	Intermediate Filaments
JICA	Japan International Cooperation Agency
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KeNHA	Kenya National Highways Authority
KeRRA	Kenya Rural Roads Authority
KRB	Kenya Roads Board
KURA	Kenya Urban Roads Authority

KWS	Kenya Wildlife Service
LL	Liquid Limit
LS	Linear Shrinkage
MC30	Medium Curing Cutback
MDD	Maximum Dry Density
MOE	Flexural Strength
MOR	Flexural Modulus
MTs	Mine Tailings or Mill Tailings
PI	Plasticity Index
PL	Plastic Limit
SMARTEC	Sustainable Materials Research and Technology Centre
SPR	Special Purpose Road
U	Unclassified Roads
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System of gravel
UV- ViS	Ultraviolet Visible Spectrometer
VPD	Vehicle Per Day
WBS	Work Breakdown Structures

W/C	Water-Cement

ABSTRACT

Dust from unpaved roads has adverse effects like health and costly routine maintenance of re-grading and re-gravelling of unpaved roads for smooth flow of traffic. This study focused on suitability of β-keratin (from chicken feathers) as surface sealant for dust control on gravel roads. It involved evaluating the mechanical, chemical, and physical properties of β-keratin, gravel properties when mixed with β-keratin and cost implications of using β-keratin gravel. In previous studies, cement-feather mix for concrete works containing 5% to 10% fiber or ground feather (with β-keratin) at water-cement ratio (W/C) of 0.60 showed good workability, allowing formation of a paste that coated all feather fibers or particles with cement. β-keratin is a hygroscopic product, extracted from chicken feather fibers by analysis of amino acids. The chemical properties were determined by distillation of residue using high performance thin layer chromatography (HPTLC) method. The Physical properties (absorbance and wavelength) were determined using Ultraviolet Visible Spectrometer (UV-ViS) method. For test of its mechanical properties, using an emulsifier carboxymethyl cellulose (CMC) to enhance the tests; the viscosity test was conducted as per ASTM D2170 and AASHTO T201 standards, the penetration test was conducted as per ASTM D5 and AASHTO T49 standards. Finally, the penetration test was conducted as per ASTM D113 and AASHTO T51 standards. For comparisons of gravel properties containing β-keratin from chicken feathers as an alternative to MC30 sealants for dust control in gravel roads, california bearing ratio (CBR), optimum moisture content (OMC) and maximum dry density (MDD), and finally atterberg limits were carried out on β-keratin mixed with gravel at 0, 1.5, 2.0, 2.5 and 3.0% by dry weight of gravel respectively. Also, cost analysis for producing β-keratin from chicken feathers and its comparisons with MC30 sealants in gravel roads was done. The absorbance and wavelength of β-keratin solution of 1:10 (1 ml proportion of β-keratin to 10 ml proportion of distilled water) concentration gave results of 0.4295 and 275.4 nm respectively. β-keratin is a protein polymer made up of amino acids as building blocks, a hydrocarbon with a chemical formula $C_{28}H_{48}N_2O_{32}S_4$ which melts and burns easily under fire. 1 litre of β-keratin mixed with CMC (55 and 65 g/liter) yielded acceptable results of between 30-60 Kg/s.m viscosity at 60^0c as per ASTM D2170 and AASHTO T201. Optimum percentage mix of β-keratin in gravel mixture was found to be 2.0% giving a CBR value of 57% which was acceptable as per BS 1377-9:1990, had the least swell (0.3%) at MDD of 1850 kg/m^3 (above 1500 kg/m^3), and the OMC corresponding was taken as 15.8% all acceptable as per BS 1377: 2-1990. The cost of extraction of pure 1 litre of β-keratin was found to be kshs.172.40, cheaper than MC30 currently (Kshs. 239- Kshs. 283) depending on the Kenyan region. Also, it was established that when one litre of pure β-keratin is dosed with 55 and 65g of CMC the results meet range of specification, and this was the recommended dosage rate. Also, 10% dilution with water for use as surface sealant on gravel roads was recommended for better results as per the tests results, but more field tests and numerical analysis on the results achieved was recommended.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Dust is dirt or bits of earthen material or particulate matter, usually kicked up by tires from vehicles become airborne, blowing any way the wind carries, most of which comes from unpaved roads. As dust from roads is correlated with vehicle speed, traffic can be slowed by employing road dips, curves, or more infrequent grading schedules. Application of gravel and other dust suppressants to unpaved roads have also been shown to be effective (Edvardsson, 2009), with magnesium chloride application reducing fugitive dust up to fourfold, compared to untreated roads although these often encourage high- speed travel (Sanders et al. 2015). Gravel roads with annual average daily traffic (AADT) of 100 vehicles per day (vpd) and with travelling speed of 75 km/h, up to 25 tonnes of gravel wearing layer aggregate can be lost annually per km (Jones, 1984). It results in a thickness reduction of wearing layer approximately 4 mm for a road of 7 m in width (Edvardsson, 2009). Besides, dust causes allergies and accumulates in the human respiratory tract (Edvardsson, 2009).

Spraying a gravel road with water will undoubtedly keep the dust down as long as the road stays wet. However, on dry hot summer days, keeping the road wet enough to maintain dust control would be a full-time endeavor. A sprinkler system would need to be used that would waste hundreds of gallons of water and would therefore not be a practical solution. Spraying roads with oil is a much more workable proposition. Oil remains active for much longer periods of time, quite possibly for an entire summer. The huge drawback is the environmental ramifications of spraying petroleum-based oil products into the environment. Rain runoff can pollute ponds and destroy plants growing next to the road, and because of these environmental concerns, many communities around United States have banned oil spraying on roads (USDA, 2016).

Close to three decades, Kenya’s road network has been in poor order creating a road infrastructure gap. Most of Kenya’s road infrastructure is in urgent need of maintenance, rehabilitation, upgrade and new construction so as to reduce the infrastructure gap in terms of quantity and quality. The road agencies responsible for various road classes are Kenya National Highway Authority (KeNHA), Kenya Rural Roads Authority (KeRRA), Kenya Urban Roads Authority (KURA) and Kenya Wildlife Service (KWS). Paved and unpaved roads constitute of 11,197 and 149,689 kilometers respectively hence unpaved roads constituting 93% of the entire road network in Kenya (Ong’uti, 2015). According to studies conducted on rate of dust emission from unpaved roads in South Africa, a road of 500,000 km length produces approximately 300,000,000 tonnes of dust annually (Veelen & Visservol, 2007). Hence based on this study, unpaved road network in Kenya with 149,689 km (Ong’uti, 2015) can produce up to 90,000,000 tonnes of dust annually.

Industrial wastes like molasses can be utilized on unpaved roads in order to alleviate poverty through provision of standard unpaved roads which will ensure smooth operation of vehicles and reduce dust pollution. According to Amunga et al., (2017), molasses when used to stabilize lateritic soils can help save on costs incurred on unpaved road maintenance as the molasses binds the soil particles stronger than if the soils were used alone, hence reducing the pollution effects of dust emissions. According to Walker and Everett (1987), road dust from unpaved roads (dirt roads) is a major source of airborne particulates; the loss of those fines accelerates the deterioration of roads. As a result, road dust emissions are a major concern of the users and managers of dirt roads.

According to Ndoke (2005), the road dust problem has generated a lot of interest of late. Traffic on unpaved roads has been reported to produce about 35% of atmospheric pollution worldwide. Unpaved roads comprise the major part of most road networks amounting to 81% of all roads in a major survey carried out by the World Bank in 1997. The percentage of unpaved roads in Africa was put at 90% and about 70% in Asia and the Middle East. They provide vital links between people in the hinterlands, agricultural produce and people and markets in urban settings. During the dry season the dust from these roads can constitute a health hazard to the populace living close to them. The dust generated from these roads equally reduces visibility and vehicle efficiency during the hot dry season. This study aims at investigating the application of a cheap and readily available product to act as dust suppressant to minimize dust emission in gravel as compared to the normal dust suppressant methods like bitumen-based seal such as a surface dressing, Cape seal or Otta seal. Treatment with bitumen emulsion alone is less effective and is also prone to surface damage if the compaction water or gravel contains certain salts. In Kenya, poultry farming of indigenous chicken (IC) is a very common practice and it results to about six million kg of waste feathers annually when the birds are processed in commercial dressing plants. Chicken feathers contain both hygroscopic (~60%) and hydrophilic amino acid sequences in form of β-keratin protein (Menandro, 2010). Due to its high hygroscopic nature (attract water vapor from the atmosphere), it can be deemed suitable for use as dust control for unpaved roads.

The current research study entailed carrying out tests on physical, chemical, and mechanical properties of β-keratin found in chicken feathers to find its suitability for use as road sealant on gravel roads. The use of chicken feathers in production of β-keratin can bring great impact on reducing the negative effects, on the environment, created by feathers waste disposal.

1.2 Problem Statement

Majority of roads in Kenya are unpaved posing major environmental and health effects to citizens from different parts of the country. It is evident that most people in arid and semi-arid regions in Kenya are greatly affected by dust either from the construction road site diversions, graveled or earth roads that produce high quantities tonnes of dust during dry spell causing dusting in households, clothes, domestic water and greatly causes respiratory ailments, (Gottschalk, 1994). Dust on unpaved roads poses major threats to road users classified into three namely safety hazard, nuisance, and loss of road materials. Also, the current methods of road carpeting used in Kenya utilize bitumen products, concrete products that are expensive to build and maintain.

The most common sealant as prime coat material used on Kenyan roads in MC30 bitumen, which is a petroleum product, and currently the cost of petroleum products are globally increasing hence making it more expensive to pave all the roads using MC30 bitumen.

Environmental degradation is a major concern in Kenya. Environment protection plays a vital role in underpinning the development of the nation. The achievement of Vision 2030 depends on how the Kenyan government and the public maintain a pollution-free environment which is a major sustainable development goal in the country. Also, for the current government to achieve the five core pillars namely: Agriculture; Micro, Small and Medium Enterprise (MSME) Economy; Housing and Settlement; Healthcare; Digital Superhighway and Creative Economy, a good road network is a key factor. Hence, through improvement of the unpaved road network through dust control will assist in realization of the five core pillars of development.

1.3 Objectives

1.3.1 Main objective

The main objective of this study is to investigate the suitability of β-keratin found in chicken feathers in controlling dust on gravel roads.

1.3.2 Specific Objectives

1. To analyze mechanical, chemical and physical properties of β-keratin as surface sealant for dust control on gravel roads.
2. To determine the mechanical properties of gravel treated with β-keratin from chicken feathers.
3. To evaluate the cost implications of using β-keratin from chicken feathers as an alternative to MC30 sealants.

1.4 Research Questions

The study was guided by the following research questions?

1. What are the chemical, physical, and mechanical properties of β-keratin obtained from chicken feathers for use as surface sealant for dust control on gravel roads?
2. What are the mechanical properties of gravel treated with β-keratin from chicken feathers?
3. What are the benefits of using β-keratin from chicken feathers as an alternative to MC30 sealants used on roads?

1.5 Justification of the Study

The main theme of the research was to investigate suitability of β-keratin in reduction of dust emission from gravel roads as a cheaper alternative product from chicken feathers. By using β-keratin as sealant for dust control in Kenyan unpaved roads was to be possible as it has higher resilience to activities of proteolytic enzymes making it water insoluble but highly hygroscopic. It was believed that if β-keratin was to prove to be a good product for reducing dust on gravel roads, it would be used to reduce the use of MC30 bitumen which is mostly used and is expensive to obtain since it can only be imported for use in Kenya. Also, reduction in dust from the gravel roads by use of β-keratin product from chicken feathers would lead to proper reduction of air pollution by dust; hence, achievement of current governments big five core pillars as it will impact on health and proper road network.

1.6 Scope and Limitations

1.6.1 Scope

The raw materials for β-keratin are chicken feathers obtained from local chicken vendors in Juja and gravel was obtained from Juja area in Kiambu County. Tests were carried out on β-keratin and MC30 as sealants for comparisons in determining their suitability when placed in the class of road surface prime coat. All laboratory tests were conducted at Jomo Kenyatta University of Agriculture and Technology.

1.6.2 Limitations

1. Tests on unpaved road containing the β-keratin as road sealant were not done due to the high costs of road construction and the time involved.
2. Only MC30 sealants were used for comparison purposes but not all the sealants in the market currently. However, it is the most used sealant on Kenyan roads at the moment.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter aims at reviewing past studies in line of the research title whereby the main sections of the chapter are dust control on unpaved roads, stabilization of gravel wearing course services, the road infrastructure in Kenya, indigenous chicken farming in Kenya, environmental impact of chicken feathers, chicken feathers fiber as source of keratin, and the properties of keratin. The chapter also includes a conceptual framework and a summary section.

2.2 The Road Infrastructure in Kenya

The Central Bureau of Statistics, 2003, revealed that the classification of the Kenya road network was finalized in 1970 to fall under either of the following classes. These include (i) class A international trunk roads. They link the centers of international importance and crossing international boundaries or terminating at international airports. (ii) Class B national trunk roads. They link nationally important centers. (iii) Class C primary roads. They link locally important centers and higher-class roads. (iv) Class D secondary roads. They link locally important centers and to higher class roads. (v) Class E minor roads. Any link to a minor center. (vi) Class F special purpose roads. They include parks, township, agriculture, fish and strategic roads. Special purpose roads include government access, settlement, rural access, sugar, tea and wheat roads (Central Bureau of Statics, 2003). The roads coverage is as shown in Table 2.1.

2.3 Dust Control on Unpaved Roads

Traffic on unpaved roads has been reported to produce about 35% of atmospheric pollution worldwide. Of this 28% is from dust while 7% is from exhaust fumes. Dust on unpaved roads creates a number of problems, all of which can be placed into three groups: (i) nuisance, (ii) safety hazard, and (iii) loss of road materials. The nuisance and safety hazard are causes for many complaints about dusty roads. The loss of road materials, in the form of dust, represents a significant economic loss (Everett et al., 1987).

Table 2.1: Kenya's Road Networks (km)

Agency	Road class	Paved	Unpaved	Total	Percentage of unpaved roads (%)
KeNHA	A	2,772	816	3,588	22.74
	B	1,482	1,156	2,638	43.82
	C	2,529	4,932	7,461	66.10
	Total	**6,783**	**6,904**	**13,687**	**50.44**
KeRRA	D	1,069	9,092	10,161	89.48
	E	461	24,448	24,909	98.15
	SPR	46	9,817	9,863	99.53
	U	692	84,442	85,134	99.19
	Total	**2,286**	**127,799**	**130,067**	**98.26**
KURA	B	7		7	0.00
	C	164	2	166	1.20
	D	169	367	536	68.47
	E	116	919	1,035	88.79
	SPR	64	552	616	89.61
	U	1,620	8,569	10,189	84.10
	Total	**2,140**	**10,409**	**12,549**	**82.95**
KWS	C		230	230	100.00
	D		24	24	100.00
	E		704	704	100.00
	SPR		7	7	100.00
	U	6	3,612	3,618	99.83
	Total	**6**	**4,577**	**4,583**	**99.87**
	Total classified	8879	53,066	61,945	85.67
	Total unclassified	2318	96,923	98,941	97.96
	Total network	**11197**	**149,689**	**160,886**	**93.04**

Source: Ong'uti, (2015)

According to natural resources conservation service (Conservation Practice Standard Code, 2010) on dust control on unpaved roads and surfaces, the palliative (dust control product) includes one of the following: - (i) Water (ii) Water absorbing suppressant (hygroscopic palliative) (iii) Adhesive (iv) Petroleum emulsion (v) Polymer emulsion (vi) Clay additive and (vii) Bituminous (petroleum-based road oil). MC30 is a petroleum product used to waterproof the base layer of a road pavement by binding the soil particles together. This reduces dust production from gravel layer resistant and also reduces permeability until the bituminous surfacing layer is laid on it. Hygroscopic palliatives (those that control dust by absorbing water from the air) should not be used in arid and semi-arid environments. This is because they contain calcium chloride and magnesium chloride which should not be used in locations where the daily summertime relative humidity averages are below 30% like the arid and semi-arid areas. Since they control dust by absorbing water from the air, their usage is limited to locations with humidity averages above 30%.

Dust influences workers' health and therefore some methods have been used to decrease dust concentration in work fields. Aspiration of fine dust particles (<10 µm) that stay in the air for a long time increases risk of disease. Fine dust particles generated by gravel roads can easily move with airflow in the nostrils as airborne dust. On the other hand, to decrease the amount of dust generation, sprinkling water can be used on unpaved roads which is cheaper than dust collectors. However, sprinkling water cannot perfectly prevent dust from becoming air borne. Therefore, removal of air-borne dust is necessary. According to study by Hirokazu et al., (2017) on water particles generated by ultrasonic atomization, the temperature of fine water particles is controlled by changing the temperature of irradiated water. The study examined dust suppression using water particles generated by ultrasonic atomization at low temperature (10 °C). Additionally, the effect of the amount of water vapor (absolute humidity) and water particles generated by ultrasonic atomization on the amount of dust dispersion was investigated using experimental data at different temperatures, 10, 20, and 30 °C. It was concluded that the method was not suitable for controlling dust in long stretches of gravel roads.

There are over 500,000 km of unsealed roads in South Africa. Service roads belonging to rail authorities and electricity and telecommunication providers, and forestry roads are not included in this total. Unacceptable levels of dust, poor riding quality and impassability in wet weather are experienced on much of this road network. It is estimated that approximately three million tonnes of dust are generated on South Africa's unsealed road network every year. It is assumed that two thirds of this dust resettle on the road and that one million tonnes of material are permanently lost from South African unsealed roads. Not only does this lead to reduced quality of life and an increased safety hazard, but it also results in accelerated gravel loss and more rapid deterioration of the surface area of the unpaved road. Lost paving material will more frequently need to be replaced and grader maintenance applied (Veelen and Visservol, 2007).

Depending on the situation of the pavement, treating an unpaved road with an appropriate additive generally limits the fines loss. Fines are the "glue" that holds the larger aggregates of an unpaved road together to form the surface layer. Keeping fines in the road leads to: - (i) reduced dust levels (ii) improved safety and driver experience (iii) improved air and water quality by reducing particulate matter and sediment runoff (iv) improved quality of life of nearby residents (v) extended intervals between gravel replacement needs (vi) reduced maintenance costs through extended intervals between grader blading needs; and (vii) reduced public complaints. For example, most chemical treatments rely on mechanical and/or chemical reactions with the soil to be effective. Roads constructed with geologically young glacially deposited material performed differently from roads constructed with highly weathered basalt materials with high clay contents (Mwaipungu and Allopi, 2014). Hence, different road management approaches and different chemical treatment programs ought to be followed. A wide variety of generic and vendor-specific chemical treatments are available to road practitioners. According to Unpaved Road Dust Management, 2013, before a chemical treatment is selected, a balanced judgment on its effectiveness, availability, cost, and safety should be evaluated for efficient and effective road dust management solutions.

2.4 Sustainability of Chicken Feathers as a β-Keratin Source

Most of the Kenyan population resides in the rural areas and is characterized by low income and food insecurity leading to high levels of poverty. Poultry production and in particular indigenous chicken (IC) production play a significant role in the economic and social life of these resource-poor households, contributing to cheap source of animal proteins and cash income. According to Mold, (2006), indigenous chicken (IC) population has increased by more than 75% as shown in Tables 2.2 and 2.3 and their egg and meat products by more than 34% and 79%, respectively between 1984 and 2004. This increase is attributed to an increase in the human population and hence a corresponding demand for chicken products as shown by more than 100% increase in egg and meat production from commercial layers and broilers, Magothe et al., (2012). Comparing with another country, for instance Philippine poultry industry produces approximately 40 million chickens of broilers every year (Menandro, 2010). These broiler chickens produce roughly six million kg of feathers waste every year from birds processing in commercial processing plants.

Table 2.2: Indigenous Chicken (IC) Population Distribution in Kenya

Province	Commercial layers	Commercial broilers	Indigenous chickens	Others	Total	Percentage of IC over other breeds (%)
Nyanza	230,000	99,000	5,683,000	47,000	6,059,000	93.79
Rift Valley	437,000	258,000	5,623,000	128,000	6,446,000	87.23
Eastern	165,000	113,000	3,865,000	23,000	4,166,000	92.77
Western	113000	18,000	2,644,000	236,000	3,011,000	87.81
Central	1,085,000	1,437,000	1,967,000	49,000	4,538,000	43.35
Coast	230,000	637,000	1,947,000	94,000	2,908,000	66.95
North Eastern	300	200	165,000	0	165,500	99.70
Nairobi	188,000	1,607,000	141,000	10,000	1,946,000	7.25
Total	**2,448,300**	**4,169,200**	**22,035,000**	**587,000**	**29,239,500**	**75.36**

Source: Mold, (2006)

Table 2.3: Indigenous Chicken (IC) Population, Eggs and Meat and Distribution in Kenya

Year	Population (million)	Eggs (million)	Meat (metric tons)
1984	11.56	406.58	6.011.20
1994	17.49	459.06	9,094.00
2004	20.77	545.20	10,800.00

Source: Mold, (2006)

In a different research, Mold, (2015) also found out that indigenous chicken was highest constituting 35 million in total, as shown in Figure 2.1.

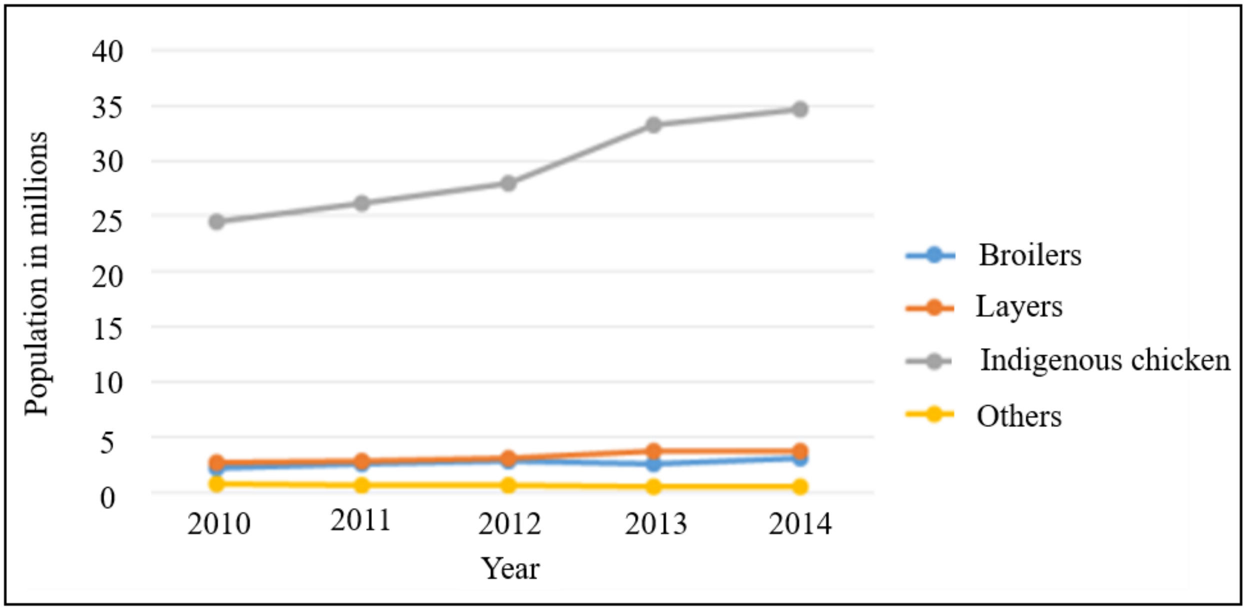

Figure 2.1: Chicken Production Rate in Kenya from 2010 - 2014

Source: Mold, (2015)

Chicken generated about six million kilograms of waste feathers annually when the birds are processed in commercial dressing plants in the year 2000. This value was set to increase since the consumption of poultry meat in Kenya was predicted to increase from 54.8 thousand metric tonnes in 2000 to 164.6 in 2030, and from 6 to 30.5 thousand metric tonnes in Nairobi (Robinson et al., 2011). Traditional disposal strategies of chicken feather are expensive and difficult. They are often burned in incineration plants, buried in landfills or recycled into low quality animal feeds. However, these disposal methods are restricted or generate greenhouse gases that pose danger to the environment. A cement-feather mix for concrete works containing 5% to 10% fiber or ground feather at water-cement ratio (W/C) of 0.60 showed good workability, allowing formation of a paste that coated all feather fibers or particles with cement. However, workability of the mix decreased significantly at 15% to 20% fiber or ground feather content due to the tendency of short fibers to form clumps and cling to one another, a problem also noted by Menandro, (2010). Apparently, the superplasticizers had no or little effect on improving mix workability at these higher levels of feather content.

2.5 Stabilization of Gravel Wearing Course Surface

Trailers while transporting cane exert a lot of pressure on the unpaved roads due to increased loads. Jan (2012) published a patent and records that the wearing course for gravel roads should have a hard and even surface and yet be elastic to withstand traffic and weather, in order not to generate dust and to manage the ground frost in the winter. He further recorded that the wearing course should comprise additives of starch, kaolin, lime, cement, vegetable substances, minerals or chlorides.

Various methods have been used to stabilize gravel for wearing course surfaces. Amunga et al., (2017) carried out research on stabilization techniques of rural roads. They attempted to bring together soil road stabilization technologies for the extremes of dry and wet weather conditions. The methods notably mentioned for stabilizing gravel wearing course surface included: - (a) Chlorides- which facilitate compaction and promote soil stabilization. The products are very effective if used, simple to use but expensive to obtain. (b) Resins (Lignosulfonates) - they constitute lignin sulfonate which is a by-product of pulp milling industry. They draw moisture from the air to keep the road surface moist but are not readily available. (c) Electrolyte emulsions- They contain chemicals that affect the electro- chemical bonding characteristics of soils and replace water molecules within the soil structure. The treated soil loses its affinity for water. (d) Molasses- used to stabilize Lateritic Soil for unpaved roads but limited to sugar belt regions; hence, inadequate for national use. (e) Mill tailings (MTs)- The use of natural and renewable biopolymers, xanthan gum and guar gum, to stabilize MTs for dust control showed that both compounds were effective in enhancing the moisture retention capacity, improving the dust resistance, and increasing the surface strength of MTs beyond that of water wetting. This is mainly because the biopolymers form coatings on MT particles and create bonding between them. The results also demonstrate that the flat-ended cylindrical penetrometer is a promising technique for characterizing the dust resistance of MTs (Rui et al., 2015). (f) Colorado State University Dustometer and its associated dust measurement protocol- it was found that all chemical suppressants decrease dust emissions, and that magnesium chloride ($MgCl_2$) was the most effective dust suppressant under the prevailing weather conditions. It was also found that the native soil road surface type performed better than the new gravel road surface type and that emissions were related to speed, Sanders et al., (2015). (g) Palm kernel shells- They reduce the impact of dust on dust-sensitive vegetation, vehicular action, respiratory problems, complaints from public road users and sedimentation in water bodies. Immediate application of palm kernel shells reduced the dust produced from the road at some speeds to zero. The rate of preservation of materials was between 75 and 100% (Ndoke, 2005). In Kenya, palms are only found in coastal regions therefore the method can't be sustainable as a result of raw material adequacy aspect.

2.6 Chicken Feather Fibers as Source of Keratin

Keratin is one of the most abundant proteins found in the body of mammals, birds and reptiles. It is a structural component of wool, nails, horn and feathers and provides strength to the body (Sharma, & Gupta, 2016). Keratin is contained in chicken feathers, which are waste products of the poultry industry. Billions of kg of waste feathers are generated each year by poultry processing plants, creating a serious solid waste problem (Menandro, 2010). According to Srivastava et al. (2017), a total of 5-7 % weight of mature chicken comprises of feathers. Feathers are composed of beta keratin which is an insoluble protein and has a stable rigid structure because of several cross-linking disulfide bonds (central structural element which stabilizes the mature proteins' 3D structure) involving cysteine (sulfur-containing amino acid that is propanoic acid with an amino group at position 2 and a sulfanyl group at position 3). Keratin is also very rich in amino acids like Leucine and Serine (Srivastava et al. 2017). Sithole B., (2016) indicated that chicken feathers contain about 91% keratin, 1% lipids and 8% water. This was like a study by Sharma et al. (2016) whereby the chicken feathers composition was found to contain 90% keratin. Keratins are cysteine rich proteins associated with intermediate filaments (IFs) which are cytoskeleton elements with diameter of 8-10 nm (Sharma et al., 2016). It is mainly found in two forms α and β-keratin. α-keratins are abundantly found in soft tissues such as sheep wool, skin and hair. These are rich in cysteine and contain fewer amounts of hydroxyproline and proline amino acids. However, β-keratins are present in hard tissue protein of bird feathers quill, fish scales, nails and others Sharma et al. (2016).

Chemically, keratins are highly stable and insoluble in most of organic solvents. The presence of cysteine in ample amounts makes keratin susceptible for hydrolytic and oxidation reactions. Today huge volumes of keratin by-products are disposed in terms of waste posing potential threat to the environment Sharma et al. (2016). If, instead, they are used in reduction of dust in unpaved roads, their negative effects on the environment will be greatly reduced.

2.7 Biological Constitution of Keratin

Keratins are materials that are insoluble and highly stable, when put in organic solvents. Keratin biomass are obtained from living organisms or after their deaths, they can be obtained from their body parts. The major source of β-keratin in livestock includes sheepskins, goatskins, buffalo hides and cattle hides. Also, skin and its attachments like hair, nails, feathers, hooves, wool, stratum conium and scales contain highest amounts of keratin ranging from 15 to 18% nitrogen, 3.20% mineral elements, 1.27% fat and 2-5% Sulphur and about 90% proteins (Sharma et al. 2016).

Keratin provides flexibility, durability and strength, and proper functionality to hair through different properties (Sharma et al. 2016). The need of wool, birds, chicken, reptiles and fish, in textile and food industries is inevitable but there should be proper waste products disposal for clean environment. The increased use of these products to cater for human needs leads to generation increased waste loads and hence this leads to increased accumulation of various wastes in the ecosystem. The increased use and high amounts of poultry by people has led to higher environmental problems ranging from regional to the global scales rates (Sharma et al. 2016).

Keratin proteins from feathers are uniform and small in size, with molecular weights of about 10 kDa which is equals to 10,000 g (Sharma et al. 2016). Proteins from feather keratin have hydrogen bonds, forces of hydrophobic and interactions of covalent like disulfide bonds (Sharma & Gupta, 2016). They constitute hydrophobic residues, cystine, β-sheet conformations and (Sharma, & Gupta, 2016). Active functional groups being present, like amino ions ($-NH_2$), backbone of peptide, carboxylic acid ions (-COOH) and disulfides (-S-S), makes them chemically reactive in favorable reactive conditions. Under controlled reduction, disulfides bonds are broken down into free groups of thiol (-SH) with combination of $-NH_2$ and other categories in keratin which activates the surface to be positively charged. Hence, during protonation, the protein from keratin acquires positive charged surface and changes to pseudocationic biopolymer. This can be produced to various forms, like films, gels, nano/micro-particles and beads. When modification is done, it gets various applications in the fields of food sciences, green chemistry, cosmetic industries and pharmaceuticals. Various methods have been developed for extracting keratin like reductive and oxidative chemical processes. The technologies have been applied initially on animal's hoofs and horns, human hairs and chicken feathers. Various researchers have used the method of Shindai for keratin extraction from feathers of poultry (Sharma et al. 2016).

Keratin proteins comprise of various amino acids but largely comprise of lysine, cystine, serine and proline (Menandro, 2010). The amino acids usually cross-link one another through forming hydrogen and disulfide bonds resulting to fibers which are strong, lightweight and tough having good acoustic and thermal properties (Menandro, 2010).

The specific properties of keratin have attracted interest in researching on the use of chicken feathers waste for a wide range of applications from microchips to reinforcement in plastics (Menandro, 2010). Unlikely, because of the low volume needs of the products, the products usually constitute of a blend between chicken feather and cement to increase their dimensional stability and hygroscopic effects like thickness swelling and water absorption so as to conform with American society for testing materials (ASTM D1037- 1995) with various modifications.

Upon the keratin from the feathers being subjected to various modifications, they can successfully be used as dust suppressants to trap the dust by presence of water and forming coating s on the road surface.

2.8 Carboxymethyl Cellulose (CMC) Emulsifier

In research by Benslimane et al. (2018), on petroleum industry, where drilling muds are of particular importance, bentonite / polymer blends are often used as drilling fluids. Polymers such as carboxymethyl cellulose (CMC) are used for stabilizing and plastering the clay suspension, increasing the viscosity, controlling the mud losses, and maintaining adequate flow properties at high salinity, pressure and temperature. According to Jun-Feng Su, (2015), CMC contains a hydrophobic polysaccharide backbone and many hydrophilic carboxyl groups, and hence shows amphiphilic characteristics (chemical compound possessing both hydrophilic (water-loving, polar) and lipophilic (fat-loving) properties). Also, owing to its non-toxicity, biocompatibility, biodegradability, hydrophilicity, and good film-forming ability, CMC has been used in several edible film formulations. In addition, the current research proved that CMC had viscosity addition effect; thereby it can increase the viscosity of a solution. The sample product is shown in Figure 2.2.

2.9 Summary of Literature Review and Research Gap

According to Ong'uti, (2015), the total unpaved roads coverage in Kenya is 93%. Mwaipungu R. and Allopi D., (2014), presents the various effects of unpaved roads have on the environment and people.

Figure 2.2: Carboxymethyl Cellulose (CMC) Emulsifier

Unpaved roads contribute to 35% of the world's atmospheric pollution, whereby exhaust fumes contribute 7% whereas dust contributes 28%. Amunga et al. (2017) research on stabilization techniques of rural roads attempted to bring together soil road stabilization technologies for the extremes of dry and wet conditions.

According to Menandro, 2010, a total of 5-7 % weight of mature chicken comprises of feathers, and this goes to waste. Feathers are composed of beta keratin which is an insoluble protein and has a stable rigid structure because of several cross-linking disulfide bonds involving cysteine. Keratin has water absorption capacity by hygroscopic protein which makes it a good material for use as dust depressant.

Bitumen, being a petroleum product, is affected by the increasing cost of oil in the world, and has impacts on the environment, and changes in the property of materials due to changing weather conditions (Epps et al. 2014). These problems can be reduced by carrying out more research on cheaper, environmentally friendly, and readily available by-product of chicken feathers, for instance keratin. From literature review, several dust control methods such as bitumen-based seals (surface dressing, Cape seal or Otta seal) have been discussed but there is very little information on use of keratin as sealant for dust control on gravel roads has ever been discussed.

Therefore, the current study intended to investigate how keratin from chicken feathers can positively contribute to reduction of dust on gravel roads and as a measure to reduce negative impact into our environment. Use of chicken feathers for production of keratin as gravel roads surface sealant can also reduce global warming effects of other road sealants by having reduced emission of greenhouse gases to the environment. This research project focused on ensuring a cleaner environment by putting into use waste materials from the poultry industry. The keratin obtained from chicken feathers was used as a sealant to control dust in gravel roads to partly replace bituminous material. This therefore means that the results for this research can be used as an alternative product to bitumen and other imported materials that are used as dust suppressant and as primers currently in Kenyan roads.

2.10 Conceptual Framework

Table 2.4 shows conceptual framework of the research showing the various flow of variables then the resulting end product.

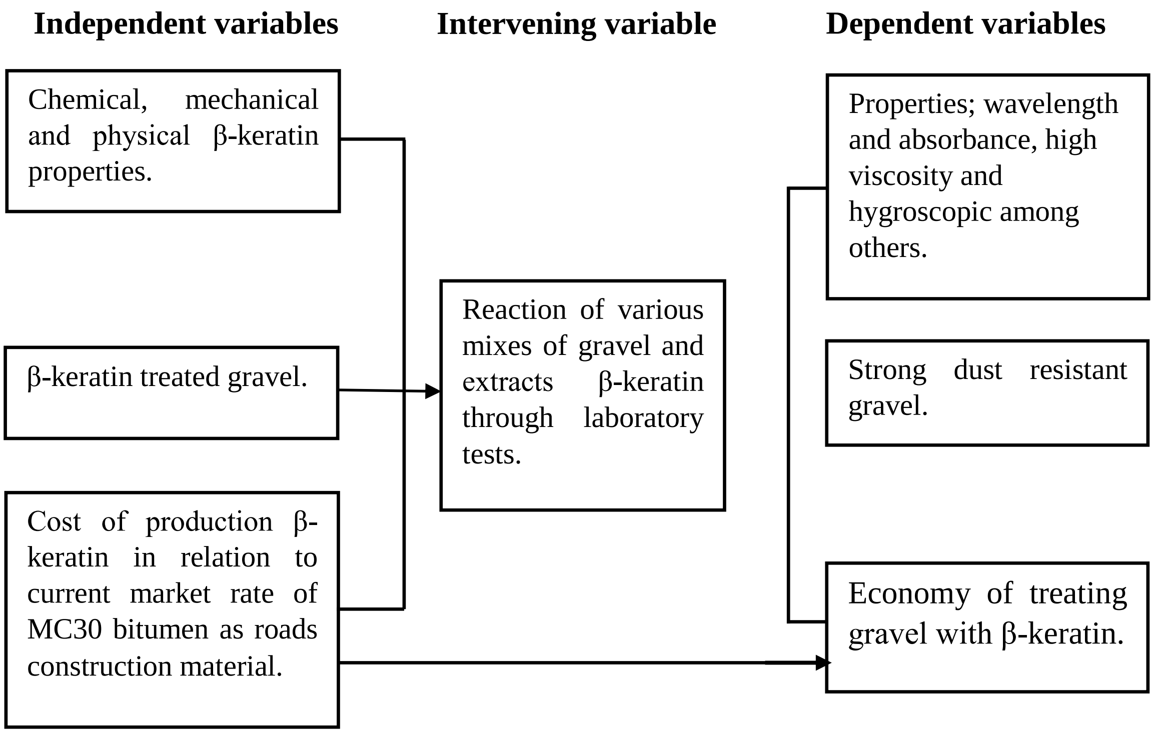

Figure 2.3: Research Conceptual Framework

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

The following section describes the methodology that the researcher used to achieve the study goals and answer research questions. The study was aimed at investigating the effect of β-keratin found in chicken feathers in controlling dust on gravel roads by determining its chemical, mechanical, and physical properties.

3.2 Materials

The main study materials used during different laboratory tests were chicken feathers from processing plant (Ruiru chicken centre) in Ruiru and neat gravel from Kiambu County in Kenya. The choice of source of materials was necessitated by proximity to the University.

3.3 Research Design

The following study used an experimental design approach to measure properties of β-keratin in chicken feathers and its effects when used as road sealant for gravel roads. According to Creswell, (2013), experimental research designs are essential in investigating causal relationships. The design was the most effective in answering the study questions and meet the study goals. The study investigated the various properties of gravel with β-keratin produced by chicken feathers and compare these properties with those of sealant materials used on gravel roads to control dust.

3.4 Mechanical, Chemical and Physical Properties of Gravel Containing β-Keratin

3.4.1 Experimental Set Up

Chicken feather samples were collected and soaked in water for 24 hours to loosen all the dirt. The untreated chicken feather fibers (CFF) were washed with 5% solution of soap, then rinsing followed. The CFF, once washed, were then dried at moderate conditions of heat. The washed CFF was sterilized then dipped in polar solvent and water at room with ph. levels adjusted to 8. They were then rinsed with distilled water and dried in air. This is a procedure adopted by Buket et al. (2015) and sequentially listed below.

(a) Pre-Treatment of the Feathers

As discussed in chapter 3.4.1, the cleaning and sterilization was done initially to ensure the CFF was clean from any dirt. The feathers were then dried under sunlight. The dried feathers were blended and kept carefully in a sealed plastic bag.

(b) Dissolving of Chicken Feathers

Two litres of 0.5M sodium sulfide solution was prepared in two litre conical flask. 50 g of the blended chicken feathers were weighed and added to the sodium sulfide solution for disinfection. The solution was heated to a temperature of 30^{o}C, ph was maintained for about 10-13 and the solution was continuously stirred for 6 hours. The solution was then filtered and centrifuged at 10,000 revolutions per minute (rpm) for 5 minutes. The supernatant liquid was carefully collected then filtered using filter paper to make it particle free.

(c) Preparation of Ammonium Sulfate Solution

700 g of ammonium sulfate was dissolved in one litre of deionized water. The solution was stirred until all the ammonium sulfate particles were dissolved. The solution was then filtered to make it particle free.

(d) Protein Precipitation

After collecting the feather filtrate solution, it was then placed in a beaker then stirred. Ammonium sulfate solution was added slowly drop wise to enable the dissolving of CFF into liquid form. The ratio of feather filtrate solution and ammonium sulfate solution added should be 1:1. The solution was then centrifuged at 10,000 rpm for 5 minutes. The solid particles were carefully collected while the remaining liquid was collected separately, then steps 2 and 3 were repeated with it.

(e) Protein Purification

The solid particles collected were added into 100 ml deionized water and stirred (washing). The solution was centrifuged at 10,000 rpm for 5 minutes and the solids were gathered carefully (β-keratin solids). The collected solid particles were dissolved in 100 ml of 2M sodium hydroxide solution to stabilize the β-keratin in liquid form. The solution was then centrifuged again at 10,000 rpm for 5 minutes and all the liquids was collected carefully and stored (β-keratin solution) while the solids were discarded. The precipitating, washing and dissolving steps were repeated 3 times.

(f) Biuret Test

1% copper sulphate solution and 1% potassium hydroxide solution were prepared. The 5 ml of the solution collected was mixed with potassium hydroxide solution with 1:1 ratio. Three drops of copper sulphate solution were added to the mixture solution. This was to enable the β-keratin to be visible during the absorbance and wavelength test. Changes in the solution were observed and recorded. The solution was analyzed under Ultraviolet Visible Spectrometer (UV-ViS) to obtain its absorbance and wavelength.

For the chemical analysis of β-keratin solution, the method adopted to carry out properties analysis was High Performance Thin Layer Chromatography (HPTLC) as proposed by Buket et al., (2015).

3.4.2 Data Collection and Analysis

A test sample was placed first inside a calibrated viscometer and placed inside viscosity bath set at a constant temperature of 40°C. The time taken by a fixed volume of liquid to flow under gravity through the capillary of the viscometer was measured for the sample in the bath. Viscosity can be defined as the ratio of shear stress applied to the rate of shear strain. It is measured in kg/s.m. The dynamic viscosity can also be calculated in terms of kinematic viscosity in units m^2/s or mm^2/s. 1 mm^2/s = 1 cSt (Centistoke). The kinematic viscosity of the sample was measured using the particular time and a calibration constant of the viscometer. The acceptable viscosity should be between 30-60 kg/s.m as per ASTM D2170. To increase the viscosity of β-keratin, an emulsifier, carboxymethylcellulose (CMC) gradually dozed in intervals of 10 from zero g/l into 1 litre β-keratin sample. X-grams of CMC was added in one litre of β-keratin, it was stirred until it achieved homogenous. After different trials, the quantity of the emulsifier, which gave better results, was 1 litre β-keratin + CMC (55 g/litre). The proportion was increased further to 1 litre β-keratin + CMC (65 g/litre). The other various parameters, their acceptable ranges and corresponding standards are as shown in Table 3.1.

Table 3.1: Various Tests on Curing Cutback: MC30 and β-Keratin from Chicken Feathers

Test on residue from distillation			
Property unit	**Unit**	**Specification**	**Test method**
Viscosity at 60˚c	kg/s.m	30-60	ASTM D2170 AASHTO T201
Penetration at 25 ˚c	100 g/5s	70/140	ASTMD5 AASHTO T49
Ductility at 25 ˚c	Cm	Over 100	ASTMD113 AASHTO T51
Solubility in trichloroethylene	%	99	ASTMD2042 AASHTO T44

3.5 Determination of Properties of Gravel Treated with β-Keratin

3.5.1 Experimental Set Up

The California Bearing Ratio test, CBR test, was carried out in the laboratory in accordance to according to BS 1377-9:1990.

The proctor test (soil compaction test) was carried out in accordance to BS 1377-4:1990 to determine the mass per cubic meter of dry soil once it is compacted over some moisture contents, giving rise to the maximum dry density occurring at optimum moisture content.

The Atterberg parameters tested in accordance to according to BS 1377-9:1990 included plastic limit (PL), liquid limit (LL), Plastic Index (PI) and Linear Shrinkage (LS).

The gravelling material (neat gravel) was obtained from a road construction site within Kiambu County in Kenya. The site involved gravelling of a murram roads within coffee estates, by the County government. The tests carried out were compaction (proctor) test, California bearing ratio test and Atterberg limits tests and the procedures are discussed below. In order to achieve this objective, gravel sample was stabilized by β-keratin extract in the following percentages by weight of sample, whereby the mixes were obtained based on the proctor mix test results. The mixes were: sample A- (0%) Neat sample, sample B- 1.5% β-keratin, sample C- 2.0% β-keratin, sample D- 2.5% β-keratin and sample E- 3.0% β-keratin.

3.5.2 Data Collection and Analysis

In order to determine the properties of the gravel treated with β-keratin at various proportions explained above, the following data collection on the following tests was done: -

(a) Compaction (Proctor) Test of β-Keratin Gravel

The test gave results on the compaction characteristics of the soil under different moisture contents. The dry density of the soil was used to determine the degree of compaction. At optimum water content, the dry density was taken as maximum.

(b) California Bearing Ratio Test of β-Keratin Gravel

The test gave results on the soil's load penetration resistance. The force and penetration relationship when cylindrical plunger was used to penetrate soil at a standard rate, gave the CBR value. The prove ring factor for 2.5 mm was 13.24 and for 5.0 mm was 19.96. The CBR (%) was calculated using Equation 3.1, whereby PRDR means prove ring dial reading and PRF means prove ring factor.

$$CBR\ (\%) = \frac{PRDR \times 100}{PRF} \qquad \text{Eq. 3.1}$$

Where:

PRDR	prove ring dial reading
PRF	prove ring factor
CBR (%)	percentage of California bearing ratio

(c) Atterberg Limits Tests of β-Keratin Gravel

Plastic limit is the minimum moisture content that changes a soil from solid (dry state) to plastic (moldable state). The air-dried soil was sieved on 0.425 mm sieve to obtain about 300 g and taken 20 g of the material for test. 20 g was placed on a glass plate and mixed thoroughly with distilled water using spatula. A ball was molded between the figures and then rolled it between the palms of hands until slight cracks appear on the surface. A thread of about 6mm was molded between the finger and the thumb. It was rolled between tips of the fingers and the plate until it cracked. The broken pieces were collected into two containers and determined the moisture content. The average moisture content was the plastic limit. Liquid limit is the moisture content that changes soil from plastic state to liquid state. It was determined in laboratory as the moisture content that allows the cone to penetrate 20 mm in a soil sample in 5 seconds. The same sample of plastic limit test was used for this test. Plastic index is the range in moisture content at which soils remained plastic (moldable condition). It was determined arithmetically as the difference of the liquid limit and plastic limit.

Linear shrinkage is the decrease in the length of a wet soil after drying. It simulates the volumetric changes that occur when wet soil dries. This was done by cleaning the mold, measuring its length, and applying a thin film of grease to the inside walls. About 150 g of the soil paste at liquid limit was taken, filled fully in the mold and tapped it on a hard surface to remove air pockets. It was leveled to remove surplus soil around it. It was allowed to dry in the air for 24 hours and then dried in an oven. Finally, it was allowed to cool and measured its length. The linear shrinkage was calculated as a percentage change of the original length after drying given by Eq. 3.2 where; LS is linear shrinkage; L_0 is initial length, L is dry length while ΔL is change in length after shrinkage.

$$LS\ (\%) = \frac{(L_0 - L) \times 100}{L_0};\ LS = \frac{\Delta L \times 100}{L_0} \qquad \text{Eq. (3.2)}$$

Where;

L_o	initial length
LS	linear shrinkage
L	dry length
ΔL	change in length after shrinkage

3.6 Cost Comparisons of Gravel Properties Containing MC30 and β-Keratin from Chicken Feathers

The various costs incurred on materials for making β-keratin from chicken feathers and using it to make sealant for dust control was evaluated as per the current market rates.

Also, the prices of MC30 were evaluated as per the guidelines provided by the Kenya Roads Board (KRB) with support of Japan International Cooperation Agency (JICA). The prices variations in the past are as shown in Table A5 in the appendix.

For the purpose of comparing market prices of MC30 with the cost of production of β-keratin, previous and current market rates based on the Cost Estimation Manuals were considered for the evaluation. This involved 2019 and 2022-2023 fiscal year manuals where the prices increased from the range of (Kshs. 202-219) to (Kshs. 239-283) per litre as per KRB, 2019 and 2022-2023 respectively. It was indeed evident that the bituminous material prices were quite volatile and kept on fluctuating from time to time due to the ever-increasing prices of petroleum products globally.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the research findings of the properties of β-keratin. Also, when gravel is mixed with β-keratin, the results are also presented and finally the cost effect of using β-keratin in gravel is also discussed.

4.2 Determination of Physical, Chemical, and Mechanical Properties of β-Keratin

4.2.1 Determination of Physical Properties of β-Keratin

The mixes were carried out and the subsequent results are as shown in Table A1 in appendix and the recorded results shown in Table 4.1.

Table 4.1: Physical Properties; Absorbance (No Units) and Wavelength (nm)) of β-Keratin Solution

Mix	Mix ratio (β-keratin: water)	Results (Absorbance, wavelength (nm))	Remarks
c	1:10	(0.4295, 275.4)	Machine read

N.B: The 1:10 mix ratio represents 1 ml proportion of β-keratin to 10 ml proportion of distilled water.

Mixes a, b, d, e from Table A1 in appendix failed to give any results in terms of absorbance and wavelength as they were either too concentrated or too diluted. Sample mix c gave wavelength and absorbance in the spectrum as 275.4 nm and 0.4295 respectively. Absorbance is dimensionless.

From the results above, the acceptable concentration of β-keratin which gave reflective light wavelength was 1:10. As per the spectrometer equipment used, the rays had wavelength of 275.4 nm corresponding to absorbance of 0.4295. Too much concentration did not give readable results as the light rays could not go through. On contrary, too diluted solution could not give readable results as the rays could not detect the solution particles. Detectable results indicated the right or optimum concentration of the mixture. The addition of water, making β-keratin less concentrated, increased viscosity, enabled by the water molecules penetrating the amorphous matrix and plasticizing it. In the concentrated specimens, the effect of the mineral phase becomes stronger, Yu et al., (2017) hence making it difficult to get results.

4.2.2 Determination of Chemical Properties of β-Keratin

For the chemical analysis of β-keratin solution, the results are as demonstrated in Table 4.2, showing the monomers present in β keratin.

Table 4.2: Chemical Properties of β-Keratin Solution

Protein 11.9%	Leucine-8.3%	Glyrine 13.5%

From the chemical analysis results, the indication was that β-keratin was a protein polymer made up of amino acids as building blocks. It is a hydrocarbon with a chemical formula $C_{28}H_{48}N_2O_{32}S_4$. When this polymer is subjected to flames it melts and burn easily, similar characteristics gotten by Mao et al., (2007) whereby the β-keratin was described as an hydrocarbon which has a low thermal conductivity of just 0.19 $Wm^{-1}K^{-1}$. However, when arranged into low-density wool, the combined thermal conductivity reduced to 0.03 $Wm^{-1}K^{-1}$. The properties of the hydrocarbon are: -

Solubility- when dissolved in 5% sodium hydroxide solution both in hot or cold state, it dissolved as seen in its preparation, during dissolving of solid β-keratin to store it in liquid form.

Hygroscopic nature- The hydrocarbon attracted water vapor from the atmosphere and got damaged.

The hygroscopic and solubility of β-keratin in nature expressed similar results as the stuy conducted by Yu et al., (2017), because it can dissolve in water and when in natural state, it behaves like salt, by trapping water vapor from the atmosphere. The chemical results showed that β-keratin as a hydrocarbon contains similar compounds with most bitumen as they are composed of mainly 82-88% carbon, 8-11% hydrogen, 0-6% Sulphur, 0-1.5% oxygen, and 0-1% nitrogen (ASTM D2170). This means that they can be classified as belonging to the same family of hydrocarbons which are mostly used for production of most road surface sealants.

4.2.3 Determination of Mechanical Properties of β-Keratin

The various tests conducted on β- keratin to ascertain its properties for use as surface sealant as dust control were viscosity, penetration, and ductility tests. Due to repetitiveness of different mixes, more tests were conducted for determination of viscosity. MC30 Standard tests were used for reference. The results are tabulated in Table 4.3.

Table 4.3: Tests on β-Keratin from Chicken Feathers

Property unit	Unit	Specification	Neat β-keratin	Test method
Viscosity at 60˚c	kg/s.m	30-60	8	ASTM D2170 AASHTO T201
Penetration at 25 ˚c	100g/5s	70/140	0	ASTM D5 AASHTO T49
Ductility at 25 ˚c	Cm	Over 100	0	ASTM D113 AASHTO T51

From these results, it was noted that after various tests run, only the viscosity test gave out results, but it did not meet the required standard limits (low viscosity of 8 against a standard range of 30-60 CTS. The β-keratin viscosity was 8 kg/s.m. This might have been due to weak covalent bonds between the molecules of the β-keratin. If the product is used for sealing gravel roads, low viscosity emulsions are likely to run off the road, hence this prompted an addition of an emulsifier. For 55 g of carboxymethylcellulose (CMC) added in one litre of β-keratin, the results read 32 kg/m^2 which resulted in bare minimum standard when 65 g of CMC was added in one litre of β-keratin, the results read 38 kg/m^2.

The emulsifier, CMC, strengthens the covalent bonds between the molecules, hence strengthening the solution at the heating time, thus the viscosity rising to 32 and 38 kg/m^2 (Table 4.4) which are within the acceptable limits, hence the product can be used as a surface sealant for gravel roads. This high viscosity of β-keratin was discussed by Fudge et al., (2003) as being caused by the high tensile strains of the covalent bonds linking different molecules of the hydrocarbon, β-keratin, reaching as high as 2 MPa.

Table 4.4: Tests on β-Keratin from Chicken Feathers Using with Carboxymethylcellulose (CMC)

Property unit	**Unit**	**Specification**	**Neat β-keratin**	**1 litre β-keratin + CMC (55 g/litre)**	**1 litre β-keratin + CMC (65 g/litre)**	**Test method**
Viscosity at 60˚c	kg/s.m	30-60	8	32	38	ASTM D2170 AASHTO T201

4.3 Properties of Gravel Containing β-Keratin from Chicken Feathers

In order to achieve this objective, several tests were conducted, and the results were obtained and compared with the various standard requirements as per the test. These tests included california bearing ratio, optimum moisture content and atterberg limits.

4.3.1 California Bearing Ratio (CBR) Test of β-Keratin Gravel

The results shown in Table A2 in appendix were recorded at penetration of 2.5 mm and 5.0 mm and the higher value obtained was reported as the CBR of the material. The British Standards (BS 1377-9:1990) specifies CBR value at 2.5 mm and require the test to be re-run if the value at 5.0 mm is greater than one at 2.5 mm. The CBR (%) was calculated using Equation 3.0. The variation of CBR values for the various β-keratin proportions in gravel sample are shown in Figure 4.1.

From the Table A2 in appendix, results on 2.5 mm penetrations gave the highest CBR values which were considered as required by BS 1377-9:1990. From the test results, the optimum percentage mix of β-keratin in gravel mixture was found to be 2.0% giving a CBR value of 57% which conformed with Unified Soil Classification System (USCS) of gravel soils which range from 20%-60%.

In Figure 4.1, increase in β-keratin in gravel increases the load bearing capacity. This behavior is the same as the effect of water on the bearing ratio of gravels. At 2% β-keratin gave the strongest gravel mix. Any extra amount added resulted in increasing the saturation of the gravel, in addition to the water content of the soil. This results in strength reduction of the soil hence reduction of the CBR past 2%.

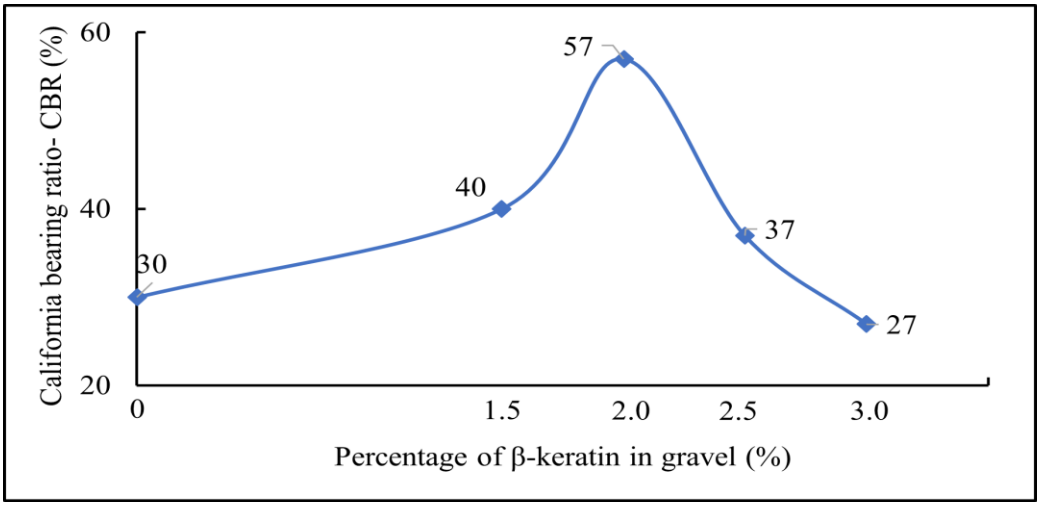

Figure 4.1: CBR Results for β-Keratin Gravel

These results can be compared with the use of a hydrocarbon, polypropylene, (Pitti et al. 2018), whose 1% mix in a highly cohesive soil, clay, resulted in an increase in CBR by 50% while 2% β-keratin gave a 90% increase in CBR in the current study. Similarly, tire shreds, a hydrocarbon byproduct, at 2% by weight of soil, gave an improvement of 21%

CBR, (Nilesh et al., 2019). Hence, the impact of 2% β-keratin in gravel on CBR improvement can be considered as acceptable.

4.3.2 Optimum Moisture Content and Maximum Dry Density of Gravel with β-Keratin

To predict the specific gravity and moisture content of β-keratin gravel in terms of optimum moisture content (OMC) and maximum dry density (MDD) in accordance to BS 1377: 2- 1990, compaction proctor test was carried out using the samples variations A, B, C, D and E and the raw results are as shown in Table A3 in the appendix and plotted in Figure 4.2. It was found that upon increase in β-keratin extract from 0%, 1.5%, 2%, 2.5% and 3% the dry density increased as shown in Figure 4.2.

To establish the relationship between maximum dry density and optimum moisture content, the peak values for the dry density and moisture content for each test sample of 0%, 1.5%, 2%, 2.5% and 3% β-keratin gravel and the results are as shown in Figure 4.3.

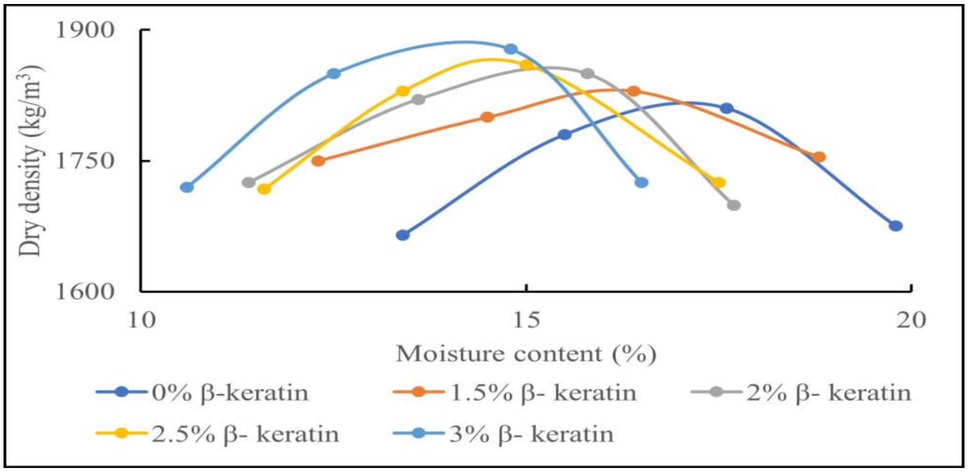

Figure 4.2: Compaction Proctor Test Results for β-Keratin Gravel

The results in Figure 4.3 shows that, as the level of β-keratin in gravel was increasing, the OMC was decreasing while the MDD was increasing.

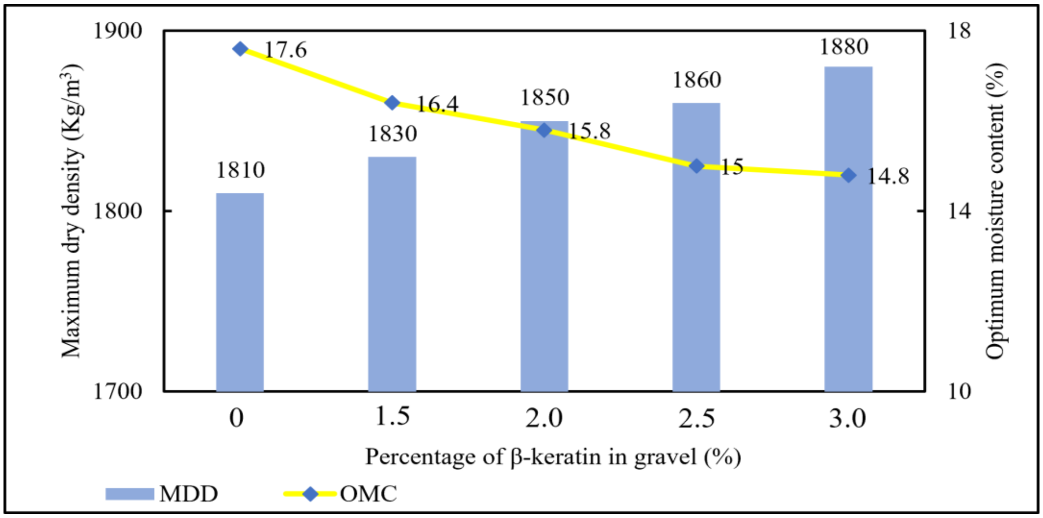

Figure 4.3: MDD and OMC Relationship of β-Keratin Gravel

The optimum β-keratin mix in CBR results was found to be 2%, and the same was confirmed in the MDD and OMC relationship. The OMC and MDD are inversely proportional. This is because, when the amount of liquid in soil is reduced, the voids are becoming less occupied, void ratio increases. This increases the dry weight of the soil that occupies small volume and subsequent higher maximum dry density. The intersection of the OMC and MDD can be taken as the optimum CBR proportion. This inverse proportional behavior of MDD and OMC was supported by Salimnezhad et al. (2021), in studies on bioremediation of crude oil using bacterial powder on behavior of highly plastic clayey soils.

Further, to clarify the above results, the soil swell variations during the compaction proctor test was done and the results are as shown in Figure 4.4.

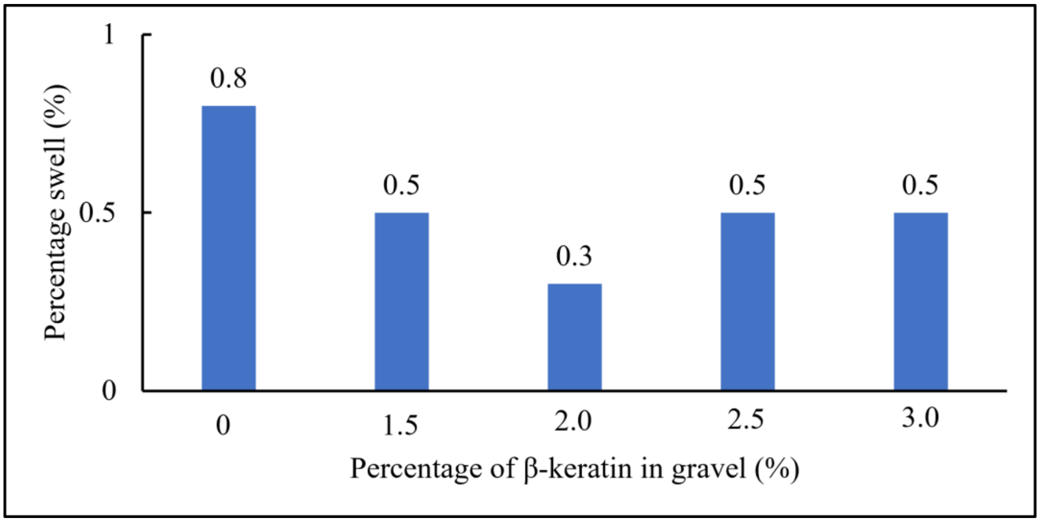

Figure 4.4: Percentage Swell Results for β-Keratin Gravel

From Figure 4.3 and Figure 4.4, the optimum results were given by the sample of gravel containing 2.0% β- keratin. This was also confirmed by the CBR results in Figure 4.1. According to BS 1377: 2-1990, the lower the OMC and higher the MDD (above 1500 kg/m^3) the better the sample.

4.3.3 Atterberg Limits of β-Keratin Gravel as per ASTM D 4318-00

The Atterberg limits (PL, LL, PI and LS) tests were conducted according to ASTM D4318-00 and the results are as shown in Table A4 in appendix. From the test results shown in Figure 4.5, an increase in the percent β-keratin proportion in gravel sample leads to a decrease in the LS and also lowers the PI. According to ASTM D4318-00, from 0% to 2.5% β- keratin proportion in gravel, the soil behaved as medium plastic (7-17% PI) while for 3.0% it behaved slightly plastic (< 7% PI). Similar test results by Noori et al., (2017); on different soil mixes with and without kerosene or gasoil (hydrocarbon products) showed related behavior in PI reduction as the kerosene and gasoil proportions increased.

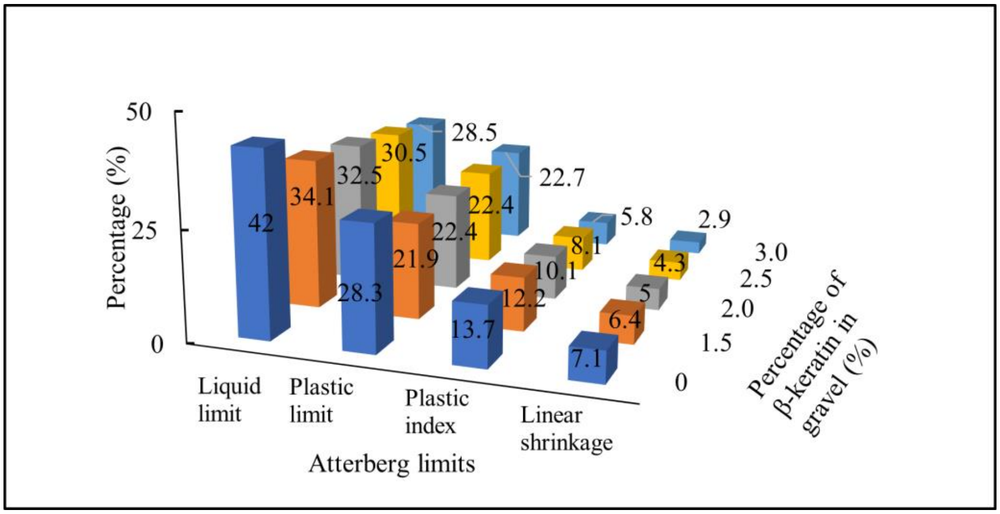

Figure 4.5: Atterberg Limits Results for β-Keratin Gravel

The decrease in LS and lowering of plasticity with increase in β-keratin can be attributed to the strengthening of the soil by the covalent bonds in β-keratin. Since the β-keratin has some residual viscosity, as seen in the viscosity test results, this has the effect of pulling the soil mass together hence reducing its flowability (plasticity) and voluminous change (linear shrinkage). Since sample with 2.0% β-keratin had the least swell of 0.3% and had acceptable optimum MDD of 1850 kg/m^3 as per BS 1377: 2- 1990 (greater than 1500 kg/m^3), the OMC corresponding was taken as 15.8%, the sample was taken as the acceptable β-keratin proportion, 2.0%.

4.4 Cost Implications of Using β-Keratin from Chicken Feathers as an Alternative to MC30

The quantities of materials used for making three liters of β-keratin extract used for the research study and their respective costs are given in Table 4.5. From the results, it was found that the average cost of production of 1 litre of pure β-keratin extract for use as road sealant for gravel road is Kshs. 1723.50. As a road sealant, the pure β-keratin was found to work well when mixed with water in the ratio of 1:10, hence the cost per litre becomes Kshs. 172.40. Currently, in Kenya, the cost of MC30 bitumen ranges between Kshs. 239 and Kshs. 283 per litre depending on the region in Kenya, therefore β-keratin proves cheaper alternative material as compared to MC30. Since this is a new product, more research and use of admixtures/ additives can further reduce the cost per litre while solving the waste management problem of greenhouse gases emitted by chicken feathers disposal to the environment. Also, it was established that when one litre of pure β-keratin was dosed with 55 and 65 g of CMC emulsifier, the results conform with various test requirements as discussed in sub-section 4.2.2. When used as a road sealant for gravel roads, there will be less demand to import MC30 bitumen as this new product will act as an alternative material to the existing sealants in the market currently.

Table 4.5: Quantities and Cost of Making 3 Liters of β-Keratin Extract

Raw material	**Unit cost (Kshs. /g)**	**Quantity for producing three liters of keratin (g)**	**Cost of raw materials consumed (Kshs.)**
Chicken feathers	0.5	399	199.5
Sodium sulfide	3.6	390	1404
Ammonium sulfate	2.4	1200	2880
Sodium Hydroxide	1.6	180	288
CMC	6.6	60	396
Total Cost (Kshs.)			**5167.5**

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the research conducted, tests conducted, and results gathered, the following conclusions based on the research findings were made: -

a) The wavelength and absorbance of β-keratin solution of 1:10 (1 ml proportion of β-keratin to 10 ml proportion of distilled water) concentration gave results of 275.4 nm and 0.4295 respectively. One litre of β-keratin mixed with CMC (55 and 65 g/liter) yielded acceptable results of between 30-60 kg/s.m viscosity at 60^0c as per ASTM D2170 and AASHTO T201.

b) Gravel mixed with 2.0% β-keratin gave CBR value of 57% which was acceptable as per BS 1377-9:1990. It had the least swell of 0.3% and had acceptable optimum MDD of 1850 kg/m^3 as per BS 1377: 2- 1990 and the OMC corresponding was taken as 15.8%. The sample was taken as the optimum mixed sample.

c) The cost of preparing 1 litre of β-keratin (in ratio of 1:10 with water), was kshs.172.40 which was cheaper compared to the market rate of MC30 ranging between Kshs. 239 and Kshs. 283 per litre respectively.

5.2 Recommendations from the Study

a) β-keratin from chicken feathers should be treated with an emulsifier, CMC at the rate of 55-65g of CMC per 1 litre of β-keratin. From the tests conducted, this proportion gave acceptable results.

b) β-keratin from chicken feathers can be used as surface sealant for gravel roads at proportion of 2% by weight of gravel. This yields acceptable results as per the tests conducted.

5.3 Recommendations for Further Research

a. In situ performance of β-keratin gravel for comparison of the laboratory work studied.
b. Modelling the performance of β-keratin gravel and numerically validate the results.
c. Study on surface morphology of β-keratin and chicken feathers.

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61826fff6cc60.pdf&ved=2ahUKEwj2_p7Lma-GAxVRm68BHRGEAIoQFnoECB0QAQ&usg=AOvVaw2D3fueFHLbgj2r7QdzDWks

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APPENDICES

Appendix I: β-Keratin Properties, California Bearing Ratio, Standard Proctor, Atterberg Results and Cost Tables

Table A1: Physical Properties; Absorbance (no units) and Wavelength (nm)) of β-Keratin

Mix	Mix ratio (β-keratin: water)	Results (Absorbance, wavelength (nm))	Remarks
a	1:1	Nil	Sample too concentrated for machine to read
b	1:5	Nil	Sample concentrated for machine to read
c	1:10	(0.4295, 275.4)	Machine read
d	1:20	Nil	Sample too diluted for machine to read
e	1:100	Nil	Sample too diluted for machine to read
f	1:1000	Nil	Sample too diluted for machine to read

Table A2: CBR test Results of β-Keratin Gravel as per (BS 1377-9:1990)

Samples	Measured	Test runs for various sample penetrations				
		Run 1 (2.5 mm from top)	Run 2 (2.5 mm from bottom)	Run 3 (5.0 mm from top)	Run 4 (5.0 mm from bottom)	CBR (%)
Sample A (Neat-0%)	PRDR	3.99	3.84	5.39	5.19	
	CBR (%)	30	29	27	26	30
Sample B (1.5%)	PRDR	5.30	5.03	6.99	6.59	
	CBR (%)	40	38	35	33	40

Sample C (2.0%)	PRDR	7.36	7.55	9.71	9.58	
	CBR (%)	56	57	49	48	57
Sample D (2.5%)	PRDR	4.90	4.37	6.90	6.79	
	CBR (%)	37	33	35	34	37
Sample E (3.0%)	PRDR	3.60	3.44	5.07	4.79	
	CBR (%)	27	26	25	24	27

PRDR- Prove ring dial reading (no units); CBR- California Bearing Ratio (%)

Table A3: Standard Proctor Test results of β-keratin gravel as per (BS 1377-4:1990)

Measured parameters	**Samples**				
	Sample A (Neat-0%)	**Sample B (1.5%)**	**Sample C (2.0%)**	**Sample D (2.5%)**	**Sample E (3.0%)**
MDD (kg/m^3)	1810	1830	1850	1860	1880
OMC (%)	17.6	16.4	15.8	15.0	14.5
Percentage swell (%)	0.8	0.5	0.3	0.5	0.5

MDD- Maximum Dry Density (kg/m^3); OMC- Optimum Moisture Content (%)

Table A4: Atterberg Limits Test Results of β-Keratin Gravel as per (BS 1377-9:1990)

Measured parameters	**Samples**				
	Sample A (Neat-0%)	**Sample B (1.5%)**	**Sample C (2.0%)**	**Sample D (2.5%)**	**Sample E (3.0%)**
Liquid limit (%)	42	34.1	32.5	30.5	28.5
Plastic limit (%)	28.3	21.9	22.4	22.4	22.7
Plastic index (%)	13.7	12.2	10.1	8.1	5.8

Linear shrinkage (%)	7.1	6.4	5.0	4.3	2.9

Table A5: MC30 cost estimates as per Kenya Roads Board, (2019 and 2022-2023)

No.	Region	Unit price (Kshs. per litre) 2019	Unit price (Kshs. per litre) 2022-2023
1	Nairobi and Central	202	242
2	Coast		274.6
3	Nyanza and Western		246.8
4	South Eastern	219	272
5	North Rift		279
6	Lower Eastern		247
7	Upper Eastern		239
8	North Eastern		283

Appendx II: Chicken Feathers Preparation and β-Keratin (Photos)

1.Cleaned chicken feathers

2. Loading chicken feathers to grinding machine

3.Grinding of chicken feathers

4. Chicken fibers

5. Cleaned chicken feathers

6. Weighing of chicken feathers

7.Stirring taking place

8. Stirring Continues

9.Separating solids from liquid by sieving

10. Feather Filtrate

11. β-keratin after extraction (solids form)

12. β-keratin after purification

(liquid form)

Appendix III: Determination of Chemical and Physical Properties of β-Keratin (Photos)

13. β-keratin was subjected to litmus test

14. Litmus paper immersed in the β-keratin sample

15. β-keratin turns litmus paper Blue-Basic

16. β-keratin being heated to get residue

17. Carboxymethylcellulose (CMC)emulsifier

18. Adding to β-keratin with CMC (emulsifier) to improve viscosity

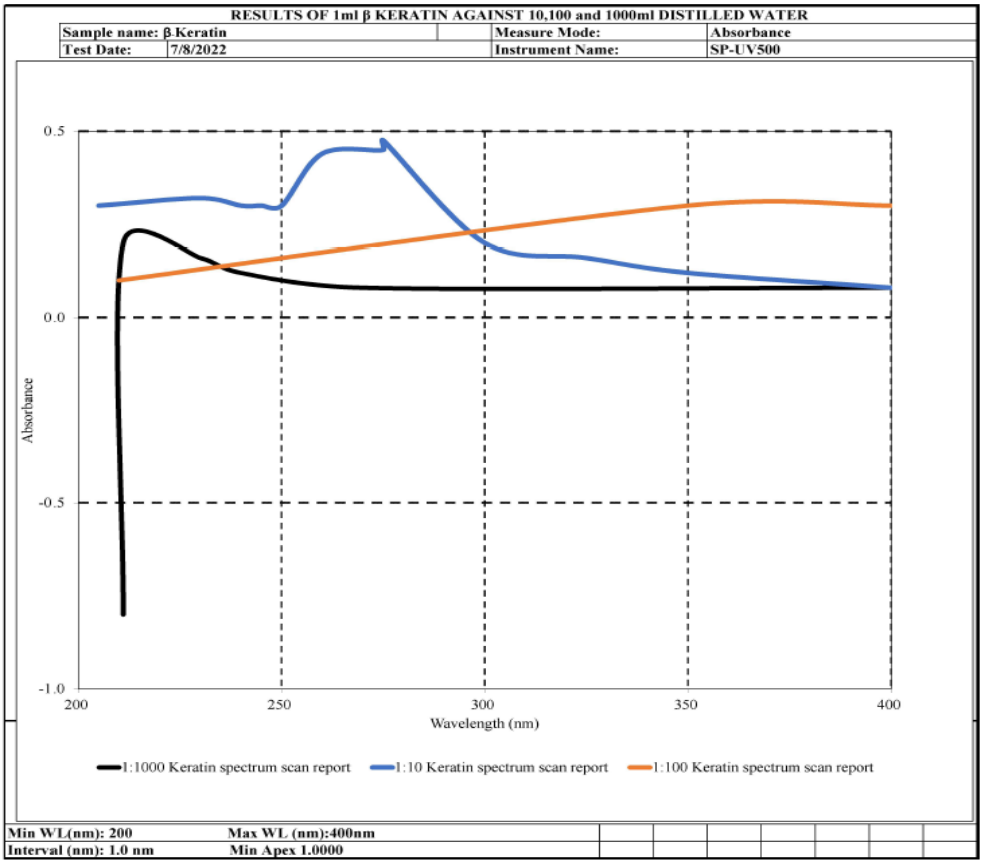
19. β-keratin turns litmus paper Blue-Basic

20. β-keratin being heated to get residue

Appendix IV: California Bearing Ratio, Standard Proctor Test and Atterberg Limits of β-Keratin Gravel (Photos)


TP
11/11/22
18/11/22
MULTISPEED
STOP

Appendix V: Physical Properties (Absorbance and Wavelength) of β-Keratin



RESULTS OF 1ml β KERATIN AGAINST 10,100 and 1000ml DISTILLED WATER

Sample name: β-Keratin		**Measure Mode:**	**Absorbance**
Test Date:	**7/8/2022**	**Instrument Name:**	**SP-UV500**

Min WL(nm): 200 **Max WL (nm):400nm**

Interval (nm): 1.0 nm **Min Apex 1.0000**

Appendix VI: California Bearing Ratio Results of β-keratin Gravel

STUDY ON STABILIZATION OF SOIL USING ß-KERATIN EXTRACT

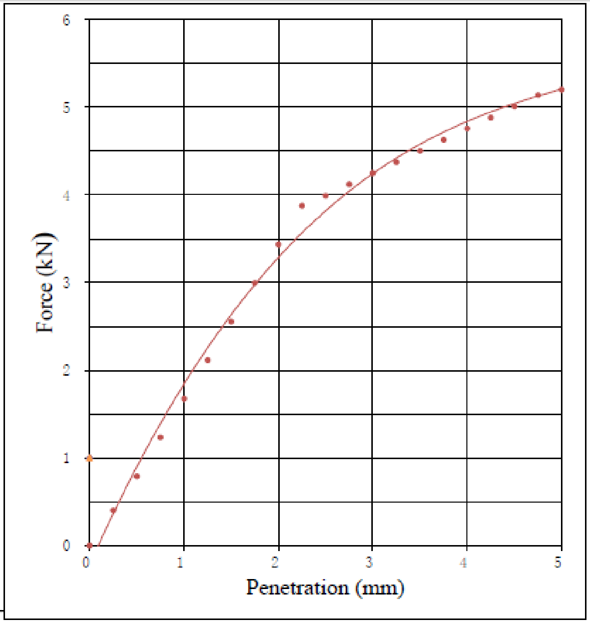
CBR PENETRATION TEST

Description: NEAT GRAVEL
Date moulded: 11.04.2022
Date of soaking: 11.11.2022
Date of Testing/penetration: 18/11/2022
Period Soaked: 4 days

ß-KERATIN 0%

	Specimen1
Tamper(kg):	4.5
Layer(no):	3

Pen(mm)	Force(KN)
0.00	0
0.25	0.4
0.50	0.79
0.75	1.2
1.00	1.7
1.25	2.1
1.50	2.6
1.75	3.0
2.00	3.4
2.25	3.9
2.50	4.0
2.75	4.1
3.00	4.2
3.25	4.4
3.50	4.5
3.75	4.6
4.00	4.8
4.25	4.9
4.50	5.0
4.75	5.1
5.00	5.2
5.25	5.3
5.50	5.4



SPECIMEN No.	1
DRY DENSITY	1810
Prov ring fact 2.5mm	13
Prov ring fact 5mm	20
Percentage Swell	0.8%

CBR at 2.5mm	**30**
CBR at 5.0mm	**27**
CBR selected	**30**

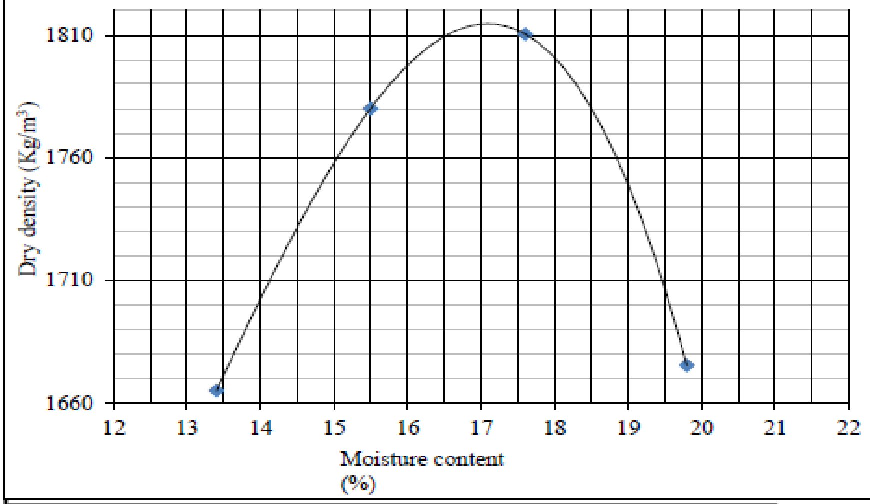
NAME: **PIUS NDEGE** **DATE:** **22-11-2022** **SIGN:**

STUDY ON GRAVEL STABILIZATION USING ß-KERATIN

Maximum Dry Density&Optimum Moisture Test

Material:	NEAT GRAVEL	Date of testing:
Standard:	**BS 1377-4:1990**	18/11/2022

Test No.		1	2	3	4
Water Added	%	8	10	12	15
Weight of mould + sample	g	5158	5326	5399	5277
Weight of mould	g	3270	3270	3270	3270
Weight of sample	g	1888	2056	2129	2007
Bulk density	kg/m3	1888	2056	2129	2007
Moisture content		13.4	15.5	17.6	19.8
Dry density	Kg/m^3	1665	1780	1810	1675



MDD: 1815 Kg/m^3

OMC: 17.0 %

NAME: **PIUS NDEGE**

DATE: **22-11-2022**

SIGN:

STUDY ON STABILIZATION OF SOIL USING ß-KERATIN EXTRACT

CBR PENETRATION TEST

Description: NEAT GRAVEL

Date moulded: 04.11.2022

Date of soaking: 11.11.2022

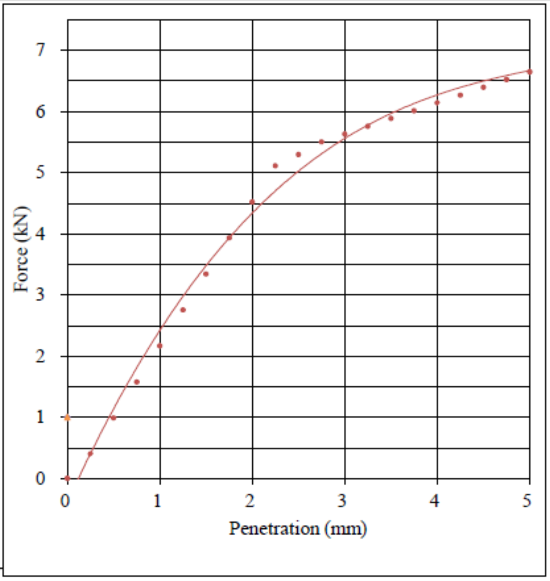
ß-KERATIN 1.5%

Date of Testing/penetration: 18.11.2022

Period Soaked: 4 days

	Specimen1
Tamper(kg):	4.5
Layer(no):	3

Pen(mm)	Force(KN)
0.00	0
0.25	0.4
0.50	0.99
0.75	1.58
1.00	2.17
1.25	2.76
1.50	3.34
1.75	3.93
2.00	4.52
2.25	5.11
2.50	5.3
2.75	5.5
3.00	5.6
3.25	5.8
3.50	5.9
3.75	6.0
4.00	6.1
4.25	6.3
4.50	6.4
4.75	6.5
5.00	6.7
5.25	6.8
5.50	7.0



SPECIMEN No.	1
DRY DENSITY	1830
Prov ring fact 2.5mm	13.2
Prov ring fact 5mm	19.96
Percentage Swell	0.50%

CBR at 2.5mm	**40**
CBR at 5.0mm	**35**
CBR selected	**40**

NAME: **PIUS NDEGE**

DATE: **22-11-2022**

SIGN:

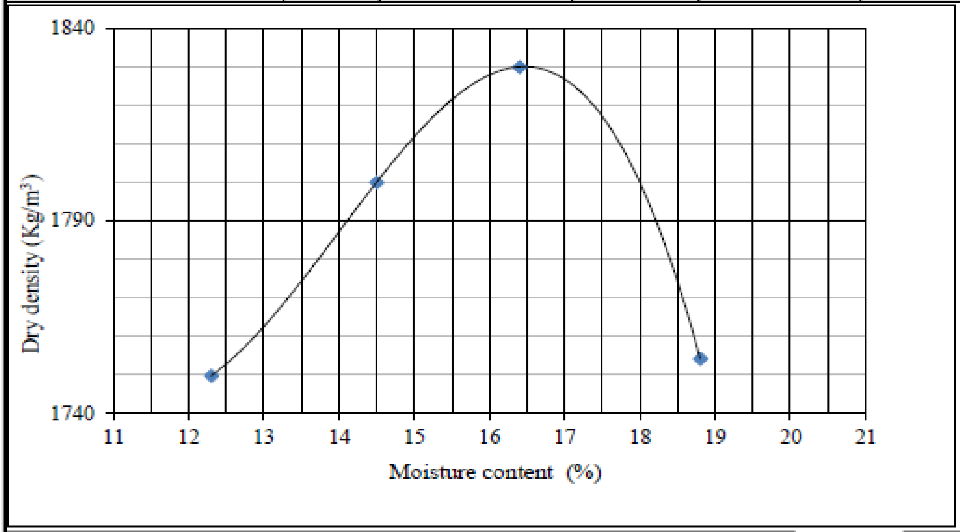
STUDY ON GRAVEL STABILIZATION USING ß-KERATIN

Maximum Dry Density&Optimum Moisture Test

Material: NEAT GRAVEL+ 1.5 % ß-KERATIN Date of testing:

Standard: **BS 1377-4:1990** 18/11/2022

Test No.		1	2	3	4
Water Added	%	8	10	12	14
Weight of mould + sample	g	5349	5445	5514	5468
Weight of mould	g	3384	3384	3384	3384
Weight of sample	g	1965	2061	2130	2084
Bulk density	kg/m3	1965	2061	2130	2084
Moisture content		12.3	14.5	16.4	18.8
Dry density	Kg/m^3	1750	1800	1830	1754



MDD: 1830 Kg/m^3 OMC: 16.5 %

NAME: **PIUS NDEGE** **DATE:** **22-11-2022**

SIGN:

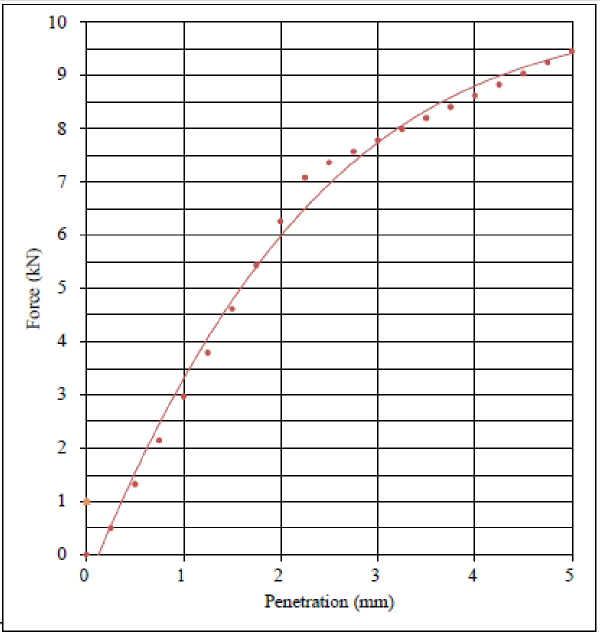
STUDY ON STABILIZATION OF SOIL USING ß-KERATIN EXTRACT

CBR PENETRATION TEST

Description:	NEAT GRAVEL		
Date moulded:	11/04/2022		
Date of soaking:	11/11/2022	**ß-KERATIN**	**2%**
Date of Testing/penetration:	18/11/2022		
Period Soaked:	4 days		

	Specimen1
Tamper(kg):	4.5
Layer(no):	3

Pen(mm)	Force(KN)
0.00	0
0.25	0.5
0.50	1.32
0.75	2.14
1.00	2.97
1.25	3.79
1.50	4.61
1.75	5.43
2.00	6.26
2.25	7.08
2.50	7.4
2.75	7.6
3.00	7.8
3.25	8.0
3.50	8.2
3.75	8.4
4.00	8.6
4.25	8.8
4.50	9.0
4.75	9.2
5.00	9.4
5.25	9.7
5.50	9.7



SPECIMEN No.	1
DRY DENSITY	1850
Prov ring fact 2.5mm	13.2
Prov ring fact 5mm	19.96
Percentage Swell	0.30%

CBR at 2.5mm	**56**
CBR at 5.0mm	**49**
CBR selected	**56**

NAME: **PIUS NDEGE** **DATE:** **22-11-2022** **SIGN:**

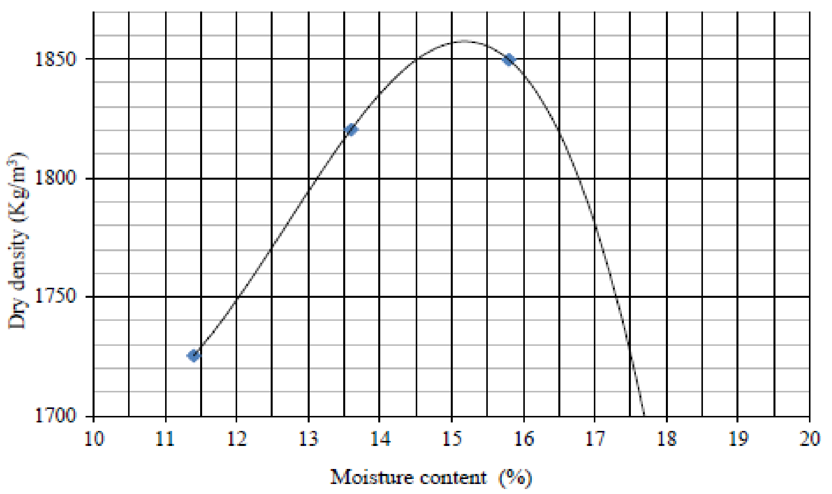
STUDY ON GRAVEL STABILIZATION USING ß-KERATIN

Maximum Dry Density&Optimum Moisture Test

Material: NEAT GRAVEL+2% ß- KERATIN Date of testing:

Standard: **BS 1377-4:1990** 18/11/2022

Test No.		1	2	3	4
Water Added	%	8	10	12	15
Weight of mould + sample	g	5306	5452	5526	5384
Weight of mould	g	3384	3384	3384	3384
Weight of sample	g	1922	2068	2142	2000
Bulk density	kg/m3	1922	2068	2142	2000
Moisture content		11.4	13.6	15.8	17.7
Dry density	Kg/m^3	1725	1820	1850	1699



MDD: 1855 Kg/m^3 OMC: 15.2 %

NAME: **PIUS NDEGE** **DATE:** **22-11-2022**

SIGN:

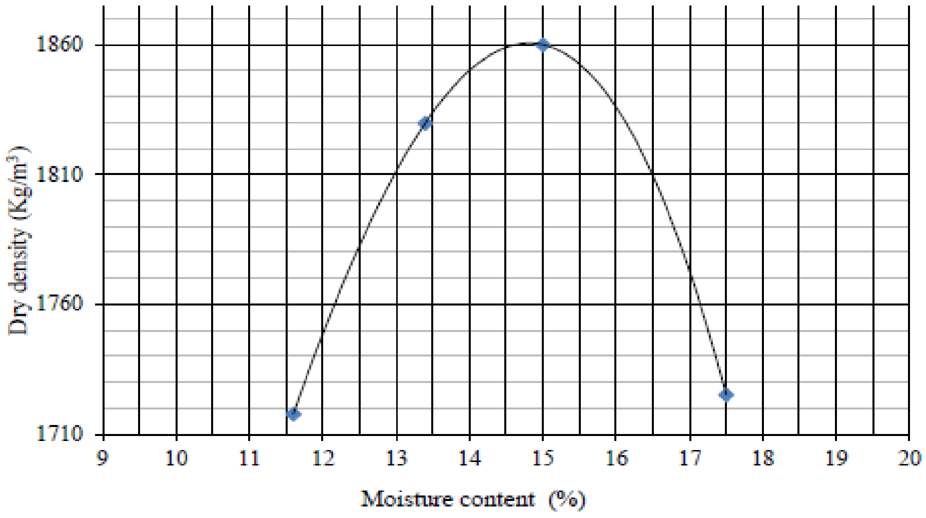
STUDY ON GRAVEL STABILIZATION USING ß-KERATIN

Maximum Dry Density&Optimum Moisture Test

Material: NEAT GRAVEL+2.5% ß-KERATIN Date of testing:

Standard: **BS 1377-4:1990** 18/11/2022

Test No.		1	2	3	4
Water Added	%	8	10	12	14
Weight of mould + sample	g	5301	5459	5523	5411
Weight of mould	g	3384	3384	3384	3384
Weight of sample	g	1917	2075	2139	2027
Bulk density	kg/m3	1917	2075	2139	2027
Moisture content		11.6	13.4	15	17.5
Dry density	Kg/m^3	1718	1830	1860	1725



MDD: 1860 Kg/m^3 OMC: 15.0 %

NAME: **PIUS NDEGE** **DATE:** **22-11-2022**

SIGN:

STUDY ON STABILIZATION OF SOIL USING ß-KERATIN EXTRACT

CBR PENETRATION TEST

Description: NEAT GRAVEL

Date moulded: 11/04/2022

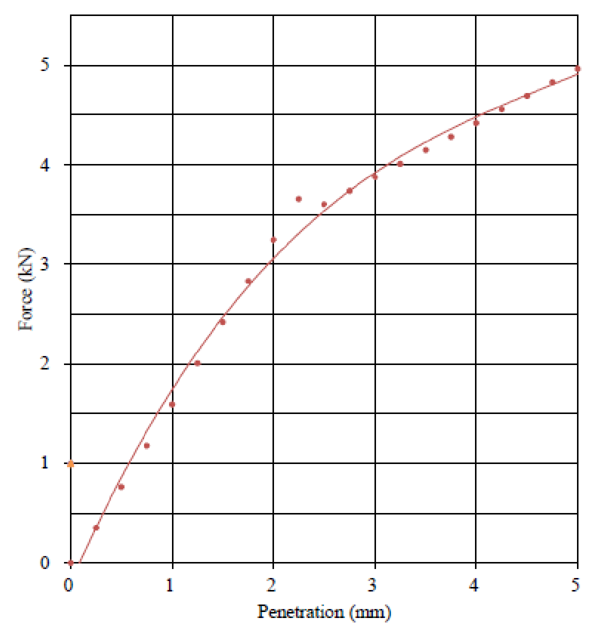
Date of soaking: 11/11/2022 **ß-KERATIN** **3%**

Date of Testing/penetration: 18/11/2022

Period Soaked: 4 days

	Specimen1
Tamper(kg):	4.5
Layer(no):	3

Pen(mm)	Force(KN)
0.00	0.0
0.25	0.4
0.50	0.8
0.75	1.2
1.00	1.6
1.25	2.0
1.50	2.4
1.75	2.8
2.00	3.2
2.25	3.7
2.50	3.6
2.75	3.7
3.00	3.9
3.25	4.0
3.50	4.1
3.75	4.3
4.00	4.4
4.25	4.6
4.50	4.7
4.75	4.8
5.00	5.0
5.25	5.1
5.50	5.1



SPECIMEN No.	1
DRY DENSITY	1810
Prov ring fact 2.5mm	13
Prov ring fact 5mm	20
CBR selected	13

CBR at 2.5mm	**27**
CBR at 5.0mm	**25**
CBR selected	**27**

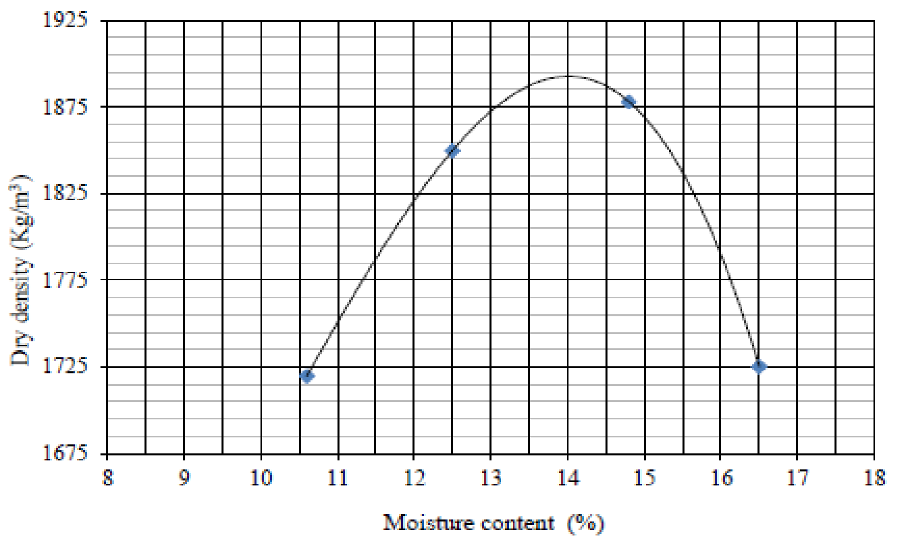
NAME: **PIUS NDEGE** **DATE:** **22-11-2022** **SIGN:**

STUDY ON GRAVEL STABILIZATION USING ß-KERATIN

Maximum Dry Density&Optimum Moisture Test

Material:	NEAT GRAVEL+3% ß-KERATIN	Date of testing:
Standard:	**BS 1377-4:1990**	18/11/2022

Test No.		1	2	3	4
Water Added	%	8	10	12	15
Weight of mould + sample	g	5286	5465	5540	5394
Weight of mould	g	3384	3384	3384	3384
Weight of sample	g	1902	2081	2156	2010
Bulk density	kg/m3	1902	2081	2156	2010
Moisture content		10.6	12.5	14.8	16.5
Dry density	Kg/m^3	1720	1850	1878	1725



MDD: 1890 Kg/m^3

OMC: 14.0 %

NAME: **PIUS NDEGE**

DATE: **22-11-2022**

SIGN:

Appendix VII: Atterberg Limits Results of 0, 1.5, 2.0, 2.5 and 3.0% β-Keratin in Gravel

Gravel mixed with 0% β-keratin.

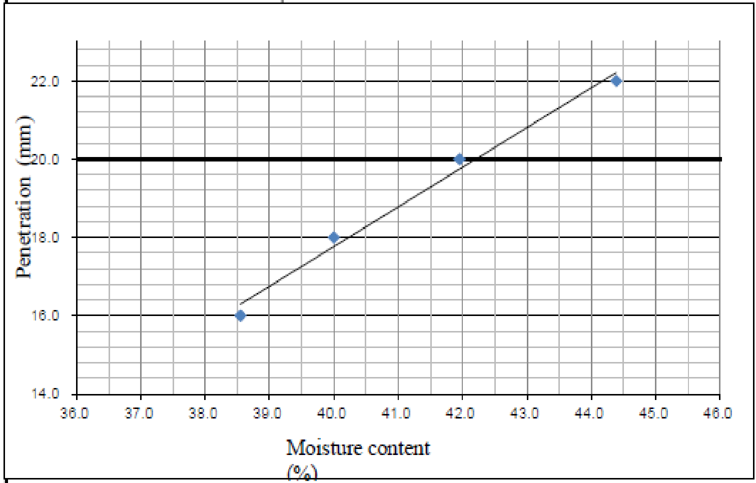
STUDY ON GRAVEL STABILIZATION USING ß-KERATIN

Liquid and Plastic Limits

Material: **NEAT GRAVEL**

Specimen length **10mm** **ß-keratin used** **0%**

	LIQUID LIMIT				**PLASTIC LIMIT**		
Test No.	1	2	3	4	1	2	Average
Average penetration	16.0	18.0	20.0	22.0			
Mass of wet soil+container,g	60.00	51.50	46.50	46.6	22.70	21.8	
Mass of dry soil+container,g	49.4	41.9	37.9	37.9	20.5	19.7	
Mass of container,g	21.9	17.9	17.4	18.3	12.6	12.4	
Mass of moisture,g	10.60	9.6	8.60	8.7	2.2	2.1	
Mass of dry soil,g	27.5	24	20.5	19.6	7.90	7.3	
Moisture content(w),%	38.5	40.0	42.0	44.4	27.8	28.8	



LIQUID LIMIT

LL= 42.0%

PLASTIC LIMIT

PL= 28.0%

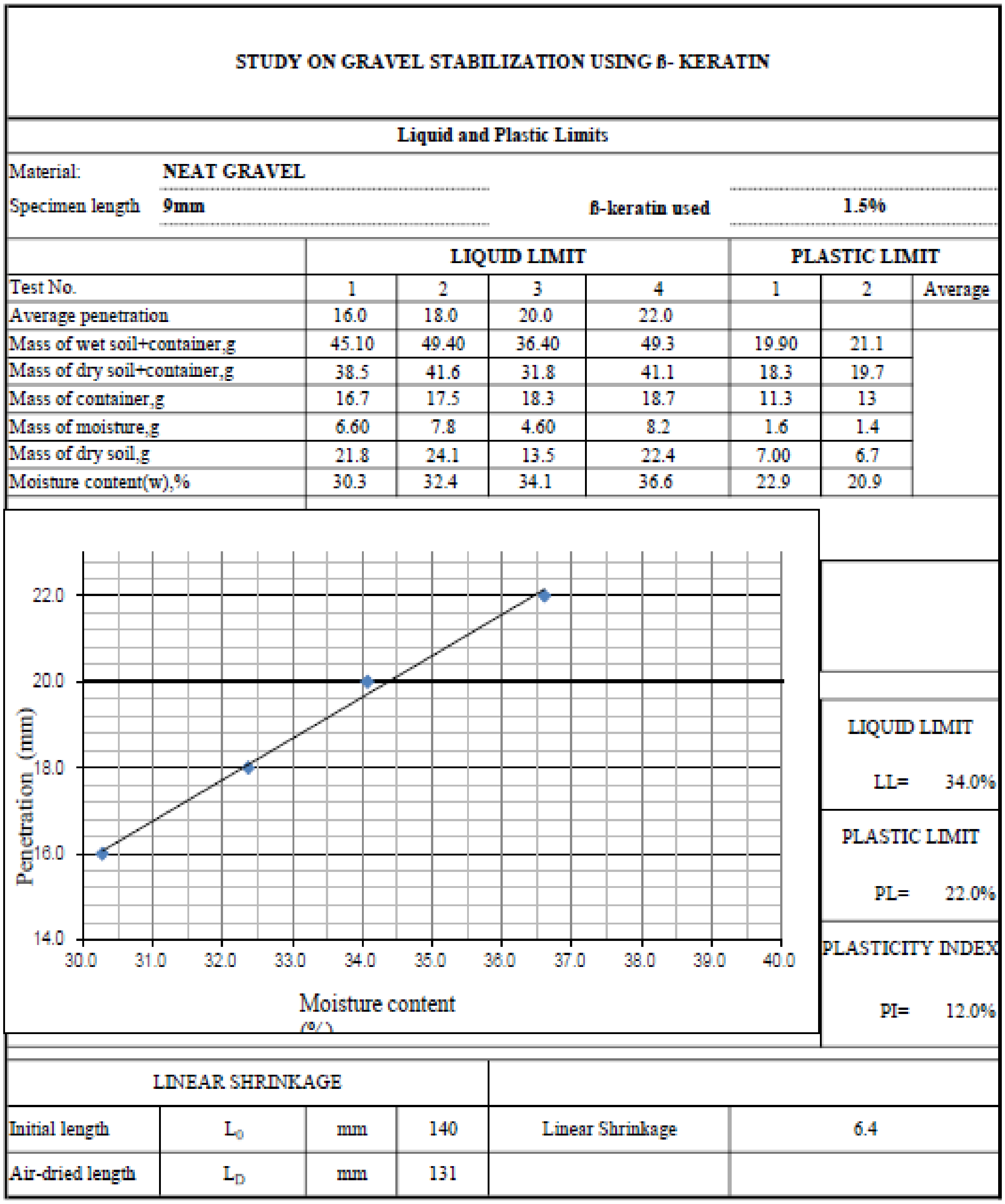
PLASTICITY INDEX

PI= 14.0%

LINEAR SHRINKAGE					
Initial length	L_0	mm	140	Linear Shrinkage	7.1
Air-dried length	L_D	mm	130		

NAME: **PIUS NDEGE** **DATE:** **22-11-2022** **SIGN:**

Gravel mixed with 1.5% β-keratin.



STUDY ON GRAVEL STABILIZATION USING β- KERATIN

Liquid and Plastic Limits

Material: **NEAT GRAVEL**

Specimen length **9mm** **β-keratin used** **1.5%**

	LIQUID LIMIT				PLASTIC LIMIT		
Test No.	1	2	3	4	1	2	Average
Average penetration	16.0	18.0	20.0	22.0			
Mass of wet soil+container,g	45.10	49.40	36.40	49.3	19.90	21.1	
Mass of dry soil+container,g	38.5	41.6	31.8	41.1	18.3	19.7	
Mass of container,g	16.7	17.5	18.3	18.7	11.3	13	
Mass of moisture,g	6.60	7.8	4.60	8.2	1.6	1.4	
Mass of dry soil,g	21.8	24.1	13.5	22.4	7.00	6.7	
Moisture content(w),%	30.3	32.4	34.1	36.6	22.9	20.9	

LIQUID LIMIT

LL= 34.0%

PLASTIC LIMIT

PL= 22.0%

PLASTICITY INDEX

PI= 12.0%

LINEAR SHRINKAGE					
Initial length	L_0	mm	140	Linear Shrinkage	6.4
Air-dried length	L_D	mm	131		

NAME: **PIUS NDEGE** **DATE:** **22-11-2022** **SIGN:**

Gravel mixed with 2.0% β-keratin.

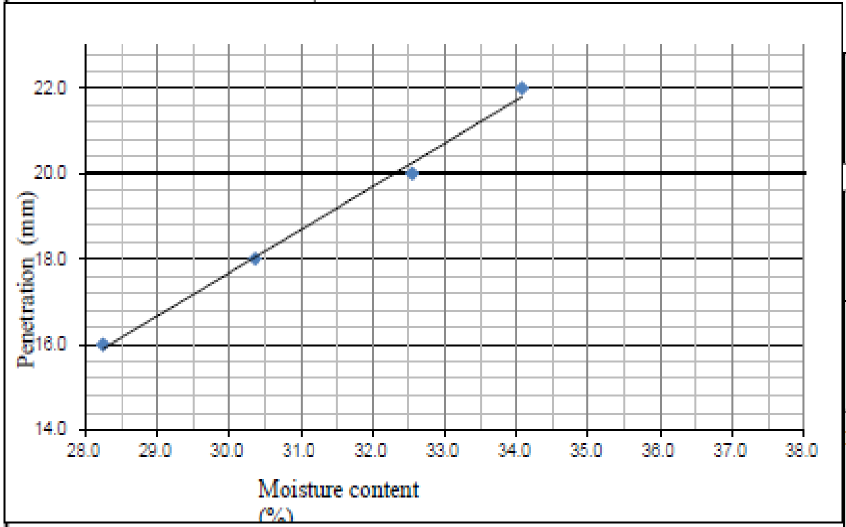
STUDY ON GRAVEL STABILIZATION USING β KERATIN

Liquid and Plastic Limits

Material: **NEAT GRAVEL**

Specimen length **7mm** **β-keratin used** **2%**

	LIQUID LIMIT				PLASTIC LIMIT		
Test No.	1	2	3	4	1	2	Average
Average penetration	16.0	18.0	20.0	22.0			
Mass of wet soil+container,g	52.80	48.40	34.30	30.2	19.40	18.5	
Mass of dry soil+container,g	45.4	41.6	28.8	25.6	18	17.3	
Mass of container,g	19.2	19.2	11.9	12.1	11.9	11.8	
Mass of moisture,g	7.40	6.8	5.50	4.6	1.40	1.2	
Mass of dry soil,g	26.2	22.4	16.9	13.5	6.10	5.5	
Moisture content(w),%	28.2	30.4	32.5	34.1	23.0	21.8	



LIQUID LIMIT

LL= 32.0%

PLASTIC LIMIT

PL= 22.0%

PLASTICITY INDEX

PI= 10.0%

LINEAR SHRINKAGE				EXPANSIVE SOILS	
Initial length	L_0	mm	140	Linear Shrinkage	5.0
Air-dried length	L_D	mm	133		

NAME: **PIUS NDEGE** **DATE:** **22-11-2022** **SIGN:**

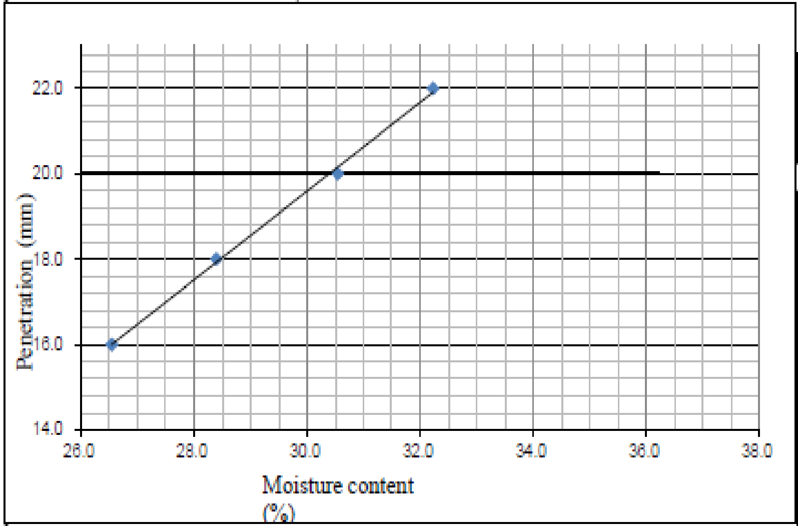
Gravel mixed with 2.5% β-keratin.

STUDY ON GRAVEL STABILIZATION USING ß-KERATIN

Liquid and Plastic Limits

Material:	**NEAT GRAVEL**		
Specimen length	**6mm**	**ß-keratin used**	**2.5%**

	LIQUID LIMIT				PLASTIC LIMIT		
Test No.	1	2	3	4	1	2	Average
Average penetration	16.0	18.0	20.0	22.0			
Mass of wet soil+container,g	40.60	40.90	44.70	47.1	17.60	18.6	
Mass of dry soil+container,g	36.3	36.3	38.5	40.3	16.7	17.5	
Mass of container,g	22.1	20.1	18.2	19.2	13.2	12.1	
Mass of moisture,g	4.30	4.6	6.20	6.8	0.90	1.1	
Mass of dry soil,g	16.2	16.2	20.3	21.1	3.50	5.4	
Moisture content(w),%	26.5	28.4	30.5	32.2	25.7	20.4	



LIQUID LIMIT

LL= 30.0%

PLASTIC LIMIT

PL= 23.0%

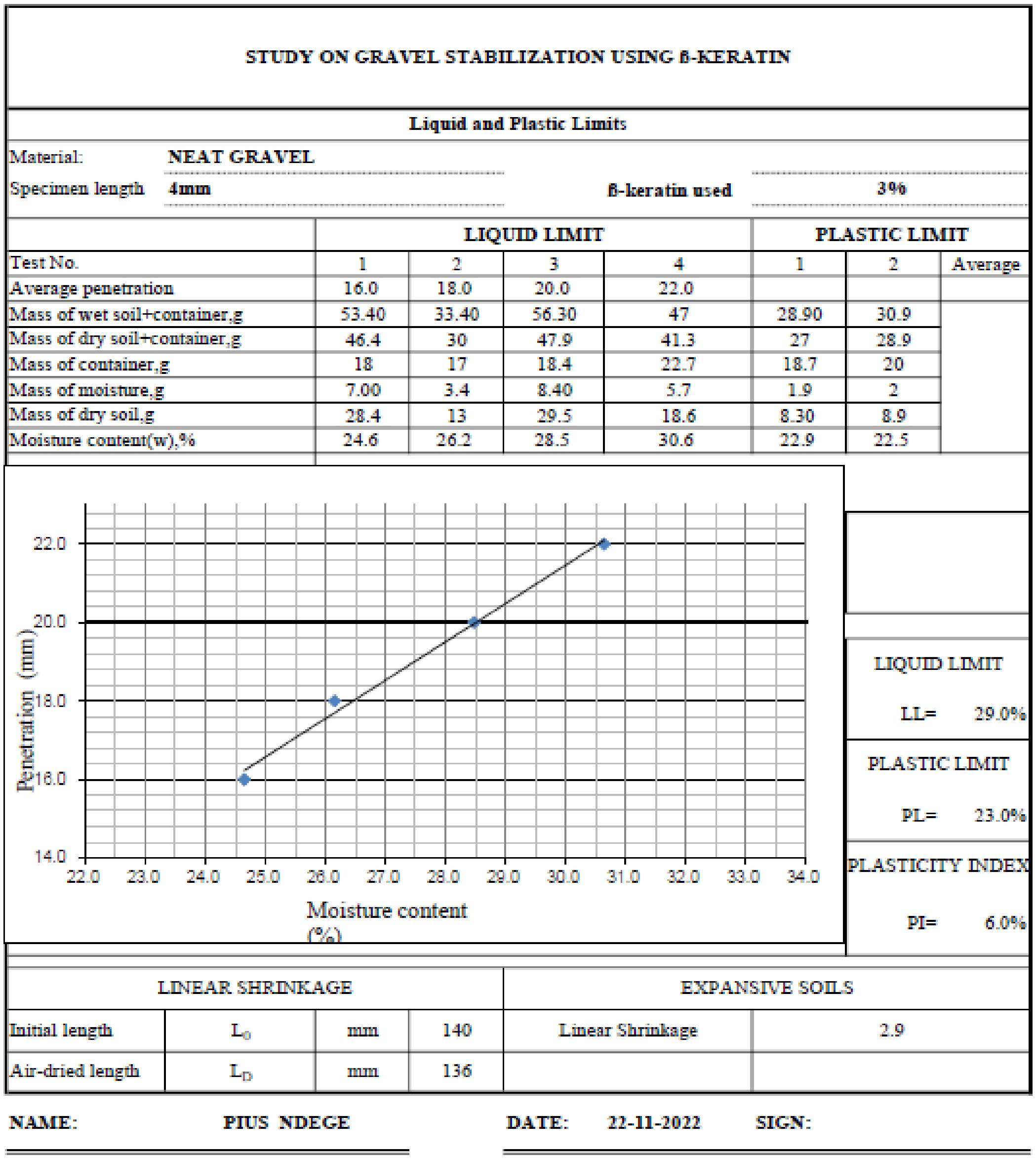
PLASTICITY INDEX

PI= 7.0%

LINEAR SHRINKAGE				EXPANSIVE SOILS	
Initial length	L_0	mm	140	Linear Shrinkage	4.3
Air-dried length	L_D	mm	134		

NAME: **PIUS NDEGE** **DATE:** **22-11-2022** **SIGN:**

Gravel mixed with 3.0% β-keratin.



STUDY ON GRAVEL STABILIZATION USING ß-KERATIN

Liquid and Plastic Limits

Material:	**NEAT GRAVEL**		
Specimen length	**4mm**	**ß-keratin used**	**3%**

	LIQUID LIMIT				**PLASTIC LIMIT**		
Test No.	1	2	3	4	1	2	Average
Average penetration	16.0	18.0	20.0	22.0			
Mass of wet soil+container,g	53.40	33.40	56.30	47	28.90	30.9	
Mass of dry soil+container,g	46.4	30	47.9	41.3	27	28.9	
Mass of container,g	18	17	18.4	22.7	18.7	20	
Mass of moisture,g	7.00	3.4	8.40	5.7	1.9	2	
Mass of dry soil,g	28.4	13	29.5	18.6	8.30	8.9	
Moisture content(w),%	24.6	26.2	28.5	30.6	22.9	22.5	

LIQUID LIMIT

LL= 29.0%

PLASTIC LIMIT

PL= 23.0%

PLASTICITY INDEX

PI= 6.0%

LINEAR SHRINKAGE				EXPANSIVE SOILS	
Initial length	L_o	mm	140	Linear Shrinkage	2.9
Air-dried length	L_D	mm	136		

NAME: **PIUS NDEGE** **DATE:** **22-11-2022** **SIGN:**