An Experimental Study on the Properties of β-Keratin as Dust Suppressant for Gravel Roads

Pius K. Ndege
Sustainable Materials Research & Technology Centre, Jomo Kenyatta University of Agriculture and Technology, Kenya
ndegepius3@gmail.com (corresponding author)

Charles K. Kabubo
Sustainable Materials Research & Technology Centre, Jomo Kenyatta University of Agriculture and Technology, Kenya
kabcha@jkuat.ac.ke

Brian M. Mutua
Department of Civil, Construction and Environmental Engineering, Jomo Kenyatta University of Agriculture and Technology, Kenya
bmutua@jkuat.ac.ke

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ABSTRACT

This study aimed to investigate the suitability of β-keratin, produced from chicken feathers, as a surface sealant to suppress dust on gravel roads, in terms of mechanical, chemical, and physical properties. This study used High-Performance Thin Layer Chromatography (HPTLC) chemical tests, Ultraviolet-Visible Spectrometer (UV-ViS) physical tests, and the standard testing procedures of the American Society for Material Testing (ASTM) and American Association of Highway and Transportation Officials (AASHTO) for mechanical tests. For testing its mechanical properties, β -keratin was mixed with gravel at 0, 1.5, 2.0, 2.5, and 3.0% proportions of dry weight. The wavelength and absorbance of a β-keratin water solution (1:10) were 275.4nm and 0.4295 respectively. β -keratin is a hydrocarbon with the chemical formula $C_{28}H_{48}N_2O_{32}S_4$ and easily melts and burns under fire. 1 liter of Keratin mixed with the carboxymethyl cellulose (CMC) emulsifier at 55 and 65g/liter yielded acceptable results between 30-60kg/m·s viscosity at 60°C according to ASTM D2170 and AASHTO T201. The optimal percentage mix of β-keratin in the gravel mixture was found to be 2.0%, providing a CBR value of 57%, least swell of 0.3%, MDD of 1850kg/m^3, and OMC of 15.8%, all acceptable according to BS 1377:2-1990. For better dust suppressant results, 1 liter of pure β-keratin should be mixed with 55-65g of CMC.

Keywords-β-keratin; gravel; dust suppressant; high-performance thin layer chromatography (HPTLC)

I. INTRODUCTION

Spraying a gravel road with water will undoubtedly keep the dust down as long as the road remains wet. However, on dry hot summer days, keeping the road wet enough to maintain dust control would be a full-time endeavor due to increased temperatures, speeding vehicles, and wind. Speed management should be central and put refocused attention on road and vehicle design and the failure of the related protective features to which fatalities are likely to happen [1-2]. As rain runoff can pollute ponds and harm plants growing near the road, many communities in the U.S. have banned oil spraying [3]. For almost three decades, Kenya's road network has been in poor condition, demonstrating a road infrastructure gap. Paved and unpaved roads constitute 17,652 and 229,105 km respectively; therefore, unpaved roads constitute 93% of the entire road network in Kenya [4]. According to [5], molasse, when used to stabilize lateritic soils, can help save costs incurred in the maintenance of unpaved roads, as it bonds the soil particles stronger.

Road dust from unpaved roads is a major source of airborne particles; the loss of these fine aggregates accelerates the deterioration of the roads and becomes a major contributor to air pollution [6-7]. The problem of road dust has attracted great interest in recent years [8], as traffic on unpaved roads has been reported to produce approximately 35% of atmospheric pollution worldwide. This has become a major concern for users and managers of unpaved (gravel) roads due to significant economic losses [9]. In Kenya, a major part of the population relies on poultry production. This results in about six million kilograms of waste feathers annually when the birds are processed in commercial dressing plants. Therefore, proper disposal or recycling of the waste is key to averting environmental degradation. Chicken feathers contain hygroscopic (~60%) and hydrophilic aminoacid sequences [10]. This study investigated the physical, chemical, and mechanical properties of β-keratin found in chicken feathers to find its effect on controlling dust on gravel roads and reducing the disposal of chicken feather waste and its consequent negative effects on the environment.

II. MATERIALS AND METHODS

A. Materials

Chicken feathers were collected from poultry processing plants in Ruiru, Kiambu County, Kenya. Chemical solutions such as sodium sulfide, ammonium sulfate, sodium hydroxide, and copper sulfate were procured in the Laboratory Chemical Supplies in Nairobi, Kenya. The graveling material (neat gravel) was obtained from a road construction site within Kiambu County in Kenya. The experiments were carried out at Jomo Kenyatta University of Agriculture and Technology, Engineering Materials Laboratory, and Materials Department Laboratory at the Ministry of Roads, Nairobi, Kenya.

B. Methods

The preparation methods used were the same as in [11] for the mechanical characterization and preparation of chicken feather/PLA composites. The chicken feather samples were washed with a 5% solution of soap, dried at moderate conditions of heat, the barbs were removed from quills, and finally, the short fibers were obtained. Short fibers were crushed to almost powder (cotton wool size), then dipped in 0.5 M sodium sulfide solution, and stirred for 6 hours. The solution was then filtered and centrifuged at 10,000 rpm for 5 min. The residual liquid was carefully collected and then filtered using filter paper to make it particle free. Ammonium sulfate solution was added slowly dropwise to the residual liquid, and the solution was centrifuged at 10,000 rpm for 5 min. Solid particles (β-keratin solids) were carefully collected while the remaining liquid was collected separately, and then the centrifuging process was repeated. The solid particles collected were added into 100 cm^3 deionized water and stirred (washing). The solution was centrifuged at 10,000 rpm for 5 min and the solids were gathered carefully. The collected solid particles were dissolved in 100 cm^3 of 2 M sodium hydroxide solution. The solution was then centrifuged again at 10,000 rpm for 5 min and all the liquids (β-keratin solution) were collected carefully and stored, as shown in Figure 1 (a), while the solids were discarded.

A quantity of 5 cm^3 of the collected solution was mixed with potassium hydroxide solution in a 1:1 ratio. Three drops of copper sulfate solution were added to the mixture solution. The changes in the solution were observed and recorded. The solution was analyzed using an Ultraviolet-Visible Spectrometer (UV-ViS) to obtain its absorbance and wavelength. For the chemical analysis of the β-keratin solution, High-Performance Thin Layer Chromatography (HPTLC) was used. The viscosity test was conducted according to ASTM D2170 and AASHTO T201 standards on a neat β-keratin solution to assess its mechanical properties. To increase the viscosity of β-keratin, an emulsifier carboxymethylcellulose (CMC) was used to improve the mechanical properties of the neat β-keratin solution to acceptable ranges according to the reference standards [12]. It was gradually dozed in intervals of 10 from 0 g/l into 1 lt of the β-keratin sample and stirred until achieving a homogenous solution.

To verify the performance of β-keratin gravel, one liter of pure β-keratin was dosed with CMC and added to the neat gravel at 0, 1.5, 2.0, 2.5, and 3.0% of dry weight. Then, the following tests were conducted, according to the respective standards: California Bearing Ratio (CBR) test of β-keratin gravel (BS 1377-9:1990), as shown in Figure 1(b), compaction proctor test (BS 1377:2-1990) to determine the Optimum Moisture Content (OMC), and then the Maximum Dry Density (MDD) of β-keratin gravel and its Atterberg limits according to ASTM D 4318-00.

(a) (b)

Fig. 1. Sample preparation and testing: (a) β -keratin extracted sample, (b) CBR test setup.

III. RESULTS AND DISCUSSION

UV-ViS was used to examine the physical properties of 1:1, 1:5, 1:10, 1:20, 1:200, and 1:1000 solutions of neat β-keratin in water. Only the 1:10 solution was able to provide detectable wavelength and absorbance results of 275.4 nm and 0.4295, respectively, as the other solutions were either too thick (concentrated), or too light (diluted) for the UV rays to pass or deflect them. Chemical analysis of the β-keratin using HPTLC showed that it was a protein polymer made up of amino acids as building blocks. It was a hydrocarbon with the chemical formula $C_{28}H_{48}N_2O_{32}S_4$, and when subjected to fire, it easily melts and burns. The viscosity of β-keratin was 1 mm^2/s, which is lower than the required limits of 30-50CTS according to ASTM D2170 and AASHTO T201. When 55 g of CMC were added to 1 lt of β-keratin, the viscosity increased to 32 kg/m·s. A further increase in CMC content to 65 g resulted in increased viscosity of 38 kg/m·s. Hence, CMC had a positive impact on the viscosity of the β-keratin solution.

CBR results for gravel containing β-keratin were obtained at penetrations of 2.5 and 5 mm, and the higher value obtained was reported as the CBR of the material. BS 1377-9: 1990 specifies a CBR value of 2.5 mm and requires the test to be re-run if the value at 5.0 mm is greater than the one at 2.5 mm. In this case, there were no re-run tests, as all CBR values at 5mm penetration were less than at 2.5 mm. Figure 2 shows the variation of CBR for the various β-keratin proportions in gravel samples. The test results showed that the optimum percentage mix of β-keratin in gravel mixture was 2.0%, providing a CBR value of 57% which is within the acceptable range of BS 1377-9:1990 and greater than 30% of neat gravel roads.

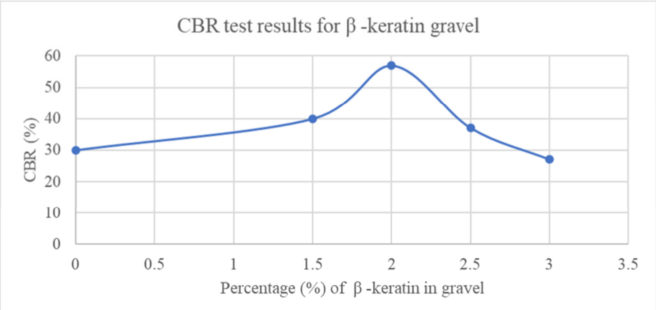

Fig. 2. CBR results for β-keratin gravel.

Pure β-keratin was gradually added to neat gravel at 0, 1.5, 2.0, 2.5, and 3.0% of dry weight. The proctor compaction test was carried out to study the specific gravity, moisture content, OMC, and MDD of β-keratin gravel. Figure 3 shows the performance of neat gravel samples containing different β-keratin proportions. The increase of β-keratin's proportion in neat gravel, increased MDD (1810, 1830, 1850, 1860, and 1880 kg/m^3) but reduced OMC (17.6, 16.4, 15.8, 15.0, and 14.5%).

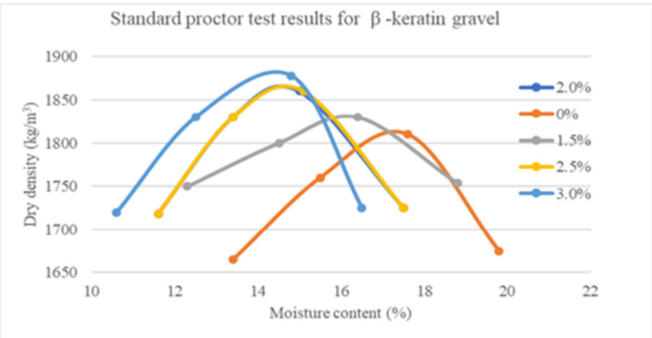

Fig. 3. CBR results for β -keratin gravel.

According to BS 1377:2-1990, the lower the OMC and the higher the MDD (above 1500 kg/m^3), the better the sample. Table I shows the swell variation of the samples with an increase in β-keratin proportion.

TABLE I. ATTERBERG LIMITS OF B -KERATIN GRAVEL

	Samples				
	Sample A (Neat-0%)	Sample B (1.5%)	Sample C (2.0%)	Sample D (2.5%)	Sample E (3.0%)
Swell (%)	0.8	0.5	0.3	0.5	0.5

Since the sample with 2.0% β-keratin had the least swell and the optimal MDD, the corresponding OMC was taken as 15.8%, and the sample was considered the best. Atterberg limit tests (plastic limit-PL, liquid limit-LL, plastic index-PI, and linear shrinkage-LS) were carried out according to ASTM D 4318-00, and the results are shown in Table II.

TABLE II. ATTERBERG LIMITS OF B-KERATIN GRAVEL

Measured parameter	Samples				
	Sample A (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

These results show that an increase in the percentage of β-keratin proportion in gravel leads to a decrease in linear shrinkage and lowers the Plastic Index (PI).

IV. CONCLUSIONS AND RECOMMENDATIONS

This study investigated the use of β-keratin from chicken feathers as a new dust suppressant, to reduce the effects of dust on unpaved roads. The results showed that the wavelength (nm) and absorbance determined using UV-ViS on a β-keratin solution of 1:10 (1 cm^3 β-keratin to 10 cm^3 distilled water) concentration were 275.4 nm and 0.4295, respectively. The chemical tests showed that β-keratin was a protein polymer made up of amino acids as building blocks, having a chemical formula $C_{28}H_{48}N_2O_{32}S_4$. When this polymer is subjected to fire, it easily melts and burns. For the mechanical properties, 1 lt of β-keratin mixed with CMC (55 and 65 g/l) yielded acceptable results of 30-60 kg/m·s viscosity at 60 °C following the ASTM D2170 and AASHTO T201 standards. Finally, using 2.0% β-keratin in gravel provided optimal CBR results of 57%, optimal MDD of 1850 kg/m^3, an OMC of 15.8%, and the least swell of 0.3%, which were within the acceptable limits of BS 1377-9:1990.

The experimental results and analysis indicate that β-keratin from chicken feathers can be used as a surface sealant for gravel roads at a proportion of 2% by weight. The CMC emulsifier should be dozed to the β-keratin at the rate of 55-65 g per 1 lt of β-keratin to get better results. Further studies could examine the in situ performance of β-keratin gravel by conducting numerical analysis and modeling to compare it with the laboratory results.

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