Evaluation of polymers for stabilization pavements soils

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Abstract

New commercial polymers (ROCAMIX, TECOFIX, and EPS PM50-PM70) for the pavement soils stabilization were tested. Soil stabilizer can enhance the soil properties, which can improve ecological environmental problems such as soil erosion and slope instability. This study investigates the water-related physical and mechanical properties of soil stabilization using a polymer soil stabilizer solution synthesized from ROCAMIX, TECOFIX, and EPS PM50-PM70 polymers. The water properties test, mechanical and physical properties test were carried out in the laboratory. Also, the effect of ROCAMIX, TECOFIX, and EPS PM50-PM70 polymers was verified by field tests. The results revealed that ROCAMIX, TECOFIX, and EPS PM50-PM70 polymers can enhance the water-retaining property, strength property of soil, all of which increase with the increase of polymer concentration. In addition, field tests proved that ROCAMIX, TECOFIX, and EPS PM50-PM70 polymers were good effects on soil engineering. These results could be applied as a reference for ROCAMIX, TECOFIX, and EPS PM50-PM70 polymers-improved soil engineering.
Keys words: Polymer ARTS (PM50 and PM70), Polymer ROCAMIX, Polymer TECOFIX, Soil-polymers interaction, Soil lateritic, Soil clay, Soil red sand, mechanical and water properties

I. Introduction

Soil stabilization consists of transforming, fundamentally and sustainably improving the physical characteristics of soils. Soil stabilization is necessary when these characteristics do not fulfill the required conditions (1). Stabilization is carried out physically (increase in density by compacting) or chemically (establishment of chemical bonds between soil particles and additives) (2). Traditional chemical stabilizers are lime, cement, etc… (2) (3) . Nowadays polymers are added to soils in order to further stabilize them. Their soil stabilization mechanism is little studied (3) (4). Several natural and synthetic polymers are marketed for soil stabilization, but the composition of these polymers is typically not accessible for commercial reasons. Nevertheless, it is known that polymers containing hydrocarbon chains act as a binder of soil matrix particles, reducing dust, and stabilizing the system as well. GO et al demonstrated that lignosulfonates can be an effective stabilizer (5). Sinha et al have suggested that lignites may be more effective in stabilizing granulated soils (6) .

Vedenskaya et al. (7) used copolymers to consolidate sands, silts, and clays. The copolymers used were guanidine acrylate (GA), methylene bisacrylamide (MBAM), and ethylene dimethacrylamid (EDMA). The additive formula consisted of a 24:1 ratio of vinyl monomer to diene. The combination of GA and EDMA performed best in sands and loams followed by GA combined with MBAM. They reported an increase in unconfined compressive (UC) of strength 2.452–2.942 kpa for a 5 percent additive mixture in sand.

In developing countries, most roads are made of bitumen (cement, lime, etc.) and soil. Mali is no exception. The main problems of the soils of these roads do not result from excessive loading of the base soil, but rather from swelling, cracking, the emanation of harmful dust, etc… (8).

Our work consists in evaluating some soils taken as samples by three (3) polymeric products from three different companies which are: (Advanced Road and Technologies Solution) ARTS LLC (Expansive PolyStyrene (EPS) PM 50 White liquid and EPS PM 70 Black liquid) and ROCAMIX (Octadecyl Trimethyl Ammonium Chloride 50% (OTAC 50%) in order to determine the mechanical and physical properties, water-retaining property, compression test, ATTERBERG Limits of pavement soils in the laboratory.

To do this, a particle size analysis of the soils is first carried out in the laboratory in order to classify the soils, with and without products. Then, the plasticity, the liquidity and the plasticity index of the soils with and without products were determined by the ATTERBERG limits.

Finally, the density, the bearing capacity, the puncture resistance and the applied loads were determined by the uniaxial or simple compression method of the soils treated with and without the products.

II. Materials and methods

1. Materials

1.1 Polymers ARTS, LLC EPS PM 50 and EPS PM 70

Expansive PolyStyrene (EPS) PM 50 and PM 70 (https://basemasticusa.com/index.php/faq) or (https://basemasticusa.com/) are modified polymer emulsions and polyvinyl copolymers exceptional grip and acetate binding properties. The **EPS-PM 70** was further modified to obtain a highly elastic binder to seal the surface of the road, with or without coating and allow the circulation of heavy weights and dust free.

White **EPS-PM50-PM70** are colorless and preserve the natural color of the road while the black **EPS-PM50-PM70** are given an appearance similar to asphalt pavement with considerable difference in terms of design and cost with respect to the construction of road made of soil cement or bitumen. The data physical and chemical properties of PM 50 and PM 70 were gived by the society. The data results are shown in table 1 and 2

Table1: The data physical and chemical properties of PM50

Boilling point	Freezing point	Vapor pressure	Vapor density	Water solubility	pH@5%	Specifis gravity @60°F	Appearance	Odor	Storage
> 212 °F	<32°F(<0°C)	As water	As water	100% complete	7.1±0.5	1.06±0.01	Milky- white and black	Bland odor	4°C

Table 2: The data physical and chemical properties of PM70

Vapor pressure	Vapor density	Water solubility	pH@10%	Specifis gravity @ 60°F	Appearance	Odor	Storage
As water	As water	100% complete	4.0-7.0	1.04-0.01	Opaque black liquid	Bland odor	4°C

Vinyl Acetate Polymer (9)

Vinyl acetate polymer, which was synthesized in the laboratory, is a white emulsion (Figure 1). The active ingredient of vinyl acetate polymer is latex particles, which contain a large number of polymer chains. There is a mass of hydrophilic carboxyl groups (-COOH) and hydroxyl groups (- OH) in the polymer chain. The basic physical and chemical properties of vinyl acetate polymer were measured in the laboratory. The measured results are shown in Table 3.

Fig.1: Vinyl Acetate Polymer

Table 3: The basic of physical and chemical properties of vinyl acetate polymer

pH	Viscosité(MPa.s)	Relative density (Gs)	Solid content	Water absorption(%)	Gel rate (%)
6-7	400-3000	1.05-1.07	41-45	34-38	1.48-1.53

The basic synthetic material of vinyl acetate polymer is vinyl acetate. Other functional modifier monomer and auxiliary materials are also added in the synthesis formulation. According to the functional requirements of the polymer, several protective colloids, emulsifiers, buffers, stabilizers, plasticizers and anti-ultraviolet materials are added to improve the function of the polymer.

- **Modified Mechanism of Vinyl Acetate Polymer**

Vinyl acetate polymer is a kind of polymer emulsion with strong water resistance. It exhibits negative electricity due to the adsorption of a large amount of anions. When the polymer is in contact with soil particles, it is adsorbed onto the surface of the soil due to electrostatic attraction (Figure 2a). With the diffusion and volatilization of water, the polymer chains are extended.

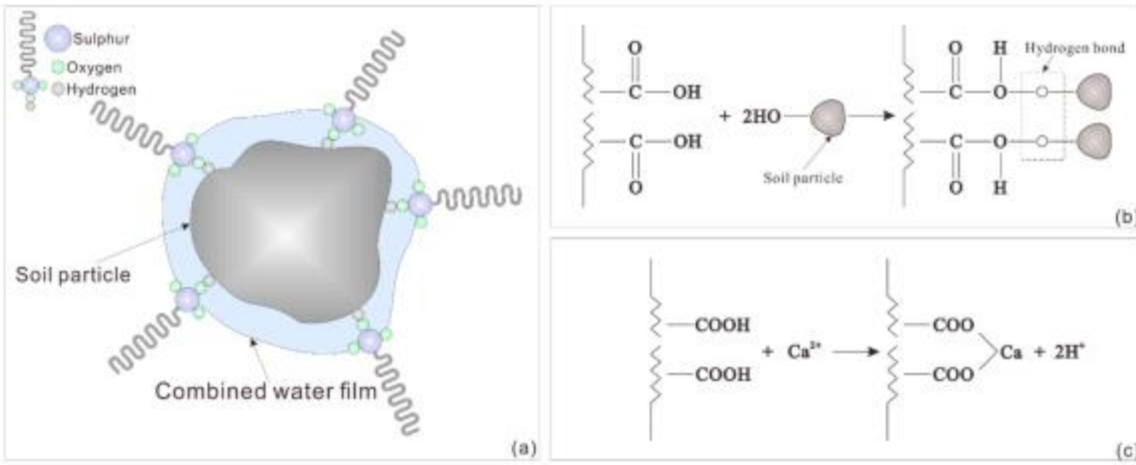

Fig.2: The interaction between polymer and soil particle: (a) Schematic diagram; (b) formation of hydrogen bonds; (c) cation substitution reaction.

1.2 ROCAMIX Polymer

ROCAMIX(http://www.rocamix.com/seguridad.php?l=en) was conceptualized in France at the beginning of 2000 by Ing. François Lasserre with the help of a group of engineers and doctors in science of various nationalities. That creation in France yielded a patent by the Institut National de la propriété industrielle (INPI - France). It Is a Semi-Viscous product form by several catalyzers and ionic changes and piercing accelerators. Rocamix - Octadecyl Trimethyl Ammonium Chloride 50% (OTAC 50%). Liquid solution of mixed poly-molecular interfacial active substances solvents, emulator and catalysis CAS 112-03-08 with a determined content of cellulose acetate CAS 9004-35-7 and complex carbohydrate composed of long chains of glucose units, joined by chemical glycoside links and unique components rocamix. The Data of physical and chemical properties were gived by the society. The data results are shown in the table 4.

Table 4: The data of physical and chemical properties of ROCAMIX.

pH of 10% aqueous	Boilling point	Flash point	Relative density	Solubility	Odor	Appearance
5-9	Not available	Not available	0.88	Miscible with water and lower alcohols.	Not available	colorless to light yellow liquid.

The Rocamix system it is a simple copy of what the nature does. Being all the ground made of rocks that has pass through a chemical and mechanical process and has being transform in the ground, and again in a perpetual cycle, the nature transformed back in rocks fig.3.

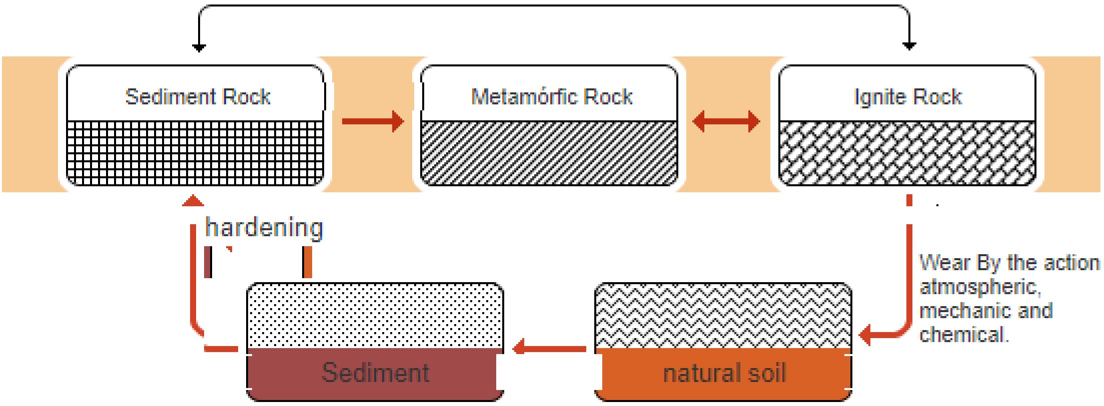

Fig.3: Nature circle

The only problem it is that this takes millions of years
The Rocamix System had reduce this time to zero

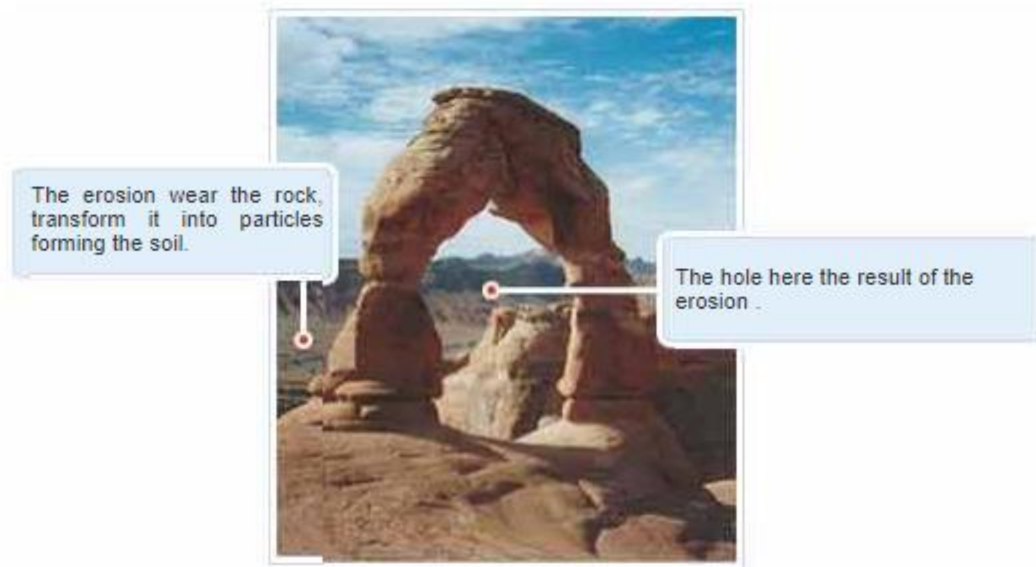

Fig.4: The transformation process on the rock.

The idea is to find a quick way to haste the process of hardening of the treated soil to reach the petrification. In chemistry the processes that need time and energy such as the transformation of the rock in ground can be modify and also be haste thanks to the addiction of some catalyzers. Imitating the nature and using chemistry knowledge, specially the activation agents, the ground can be modify despising it composition. During years, the investigation and the development made in the labs, has lead us to effectives solutions and results in the stabilization coefficients and in the duration of the treatment with looks like it will last for at least 100 years . . ...

1.3 TECOFIX Polymer

TECOFIX (https://issuu.com/landfix/docs/new_manualaplicaciontecofix_eng2) is 3rd generation soil stabilizer to compact dirt road and it gives them a hardness similar to cement. It is a polymer derivative,

capable of achieving similar results to those obtained in stabilization with lime and or concrete, but without the problems or cracking or incompatibility with the natural soil (gypsum of organic matter). TECOFIX as a co-polymer ionic, organic, non-polluting emulsion which enables a continuous process in which the preparation of the sub base, the base and the compaction can take place uninterrupted. TECOFIX has the appearance of a viscous white liquid. TECOFIX forms a plastic layer around soil particles and especially clay particles. This facilitates the compaction of the soil and allows any matter, which is often found around these particles, to be released from this matrix. During the process the soil can be compacted to a higher density. TECOFIX neutralizes the electrical charges that occur between the soil particles, this allows it to be compacted to the highest degree.
For reasons of trade and competition of products in soil stabilization we could not know the chemical composition of the polymer tecofix.

1.4 Soils Sample

The soil samples were taken in the city of Bamako in Mali in three different communes which are: MAGNANBOUGOU, KALABAN-CORO and YIRIMADJO-SEMA. Those are: lateritic soil, fine red soil, clay soil and soil with fine crushed sand. Subsurface layers of these zones mainly consist of high plastic fine-grained soil at shallow depths which often were subjected to periodically freeze-thaw phenomenon. Based on the grain size distribution analysis (Table 1), about 87.0% of soil particles are finer than 0.075 mm (ASTM D422-63, 2007). According to Unified Soil Classification System, this soil was categorized as high plastic silt (MH) (ASTM D2487, 2011). Some physical properties of used soil are shown in Table 5. (10)

Table 5: Some physical properties of used soil

Sand fraction(%)	13.00
Silt fraction (%)	45.00
Clay fraction (%)	42.00
Specific gravity (Gs)	2.62
Maximum dry density (KN/m^3)	13.64
Optimum moisture (%)	31.50
Liquid limit (%)	76.50
Plastic limit (%)	37.00
Plasticity index (%)	39.50
pH	6.90

An investigation into the geotechnical and engineering properties of some laterite of Eastern Nigeria by Madu (11) showed that the physical and chemical characteristics properties of collected sample are summarized in table 6.

Table 6: The physical and chemical properties of the nature Laterite soil.

Engineering and physical	Values	Chemical	Values (%)
pH (L/S=2.5)	4.86	SiO_2	33.55
Specific gravity	2.73	Al_2O_3	22.31
Surface area	$57.89 m^2/g$	Fe_2O_3	19.43
LL	71.8 %	MgO	2.0
PL	34.60 %	P_2O_5	0.11
PI	37.20 %	K_2O	16.71
British Standard Classification	MH	SO_3	1.98
ICL	5.00%	CO_2	3.65
MDD	$1.35 mg/m^3$		

OMC	33.4 %		
UCS	290KPa		

1.5 Equipment in the laboratory and field

The materials used in this work are: the sieve of standard ASTM, the cup with a CASSAGRANDE cam **T0030/F** of controlab reference **NF P94-051**, the roller **T0041** of controlab reference **NF P94-051**, CBR compactor **BS 1377- ASTM D4429** of controlab reference **NF P94-078**, grader leveler **140-G**, Caterpillar tractor **RM-300**, compactor tractor **CB-534C**, membrane densitometer **S0230** of controlab reference **ASTM D2167**, **AASHTO NF P 94-061-2.**

2. Methods

The polymeric products ARTS LLC EPS PM 50 and PM 70, ROCAMIX and TECOFIX were used respectively on the pavements soils: MAGNANBOUGOU, KALABAN-CORO, and YIRIMADJO.

a. Application of polymer ARTS LLC, (EPS PM 50 and EPS PM 70) on the pavements soils of MAGNANBOUGOU

The use of EPS PM50 and EPS PM70 products does not require prior classification of the soil to be treated. Nevertheless, all elements with a diameter greater than 50 mm must be removed from the ground before applying the product in order to guarantee its effectiveness. The results obtained are recorded in Table 7.

One liter of EPS PM50 product is diluted in 2 liters of water. The product-soil dosage is 3 liters of EPS PM50 solution per square meter for a compacted thickness of 15 cm. One liter of concentrated EPS PM70 product is diluted in 1 liter of water and sealing is carried out due to 2 liters of diluted EPS PM70 per square meter.

A construction of a three hundred and two meter (302 m) board is carried out on the extension of the MAGNANBOUGOU asphalt road near the football field. The board is subdivided into three sections: the first is one hundred and eight meters (108 m), the second one hundred and ten meters (110 m) and the third is eighty-four meters (84 m).

The preliminary work consists in the recognition of the ground on site. For this, five surveys were carried out along the PK0+100, PK0+300, PK0+500, PK0+700 and PK0+900 sections. The recognition results are reported in Table 7.

Four soil samples of different natures taken at random were selected and classified according to HRB standards (table 8) in order to identify the materials that constitute them.

A compression test after 28 days of cure is performed in accordance with the ARTS, LLC technical document.

The compression of molded samples of soil of different natures taken at random is carried out as follows:

- the lateritic soil with product is compressed in 55 strokes, 25 strokes, 12 strokes; lateritic soil without product in 55 strokes;
- clay soil with product in 55 shots; clay soil without product in 55 strokes;
- the red fine ground with product in 55 moves, 25 moves, 12 moves; the fine red soil without product in 55 moves, 12 moves;

- ground with fine crushed sand with product in 55 shots;
- ground with fine sand crushed without product in 55 strokes;
- the superimposition of clay soils and fine sand with product in 55 strokes.

The results are recorded in Table 9 below.

The compactness of the soil before and after treatment of the products ARTS are recorded in Tables 10 and 11. The molding water content of the materials and the diluted polymer content are recorded in Table 12.

b. Application of polymer ROCAMIX on the pavements soils of KALABAN-CORO

Before using the ROCAMIX product, it is imperative to have the results of the classification according to the American Association of State Highway and Transportation Officials ‹‹AASHTO››(www.rocamix.fr/folleto-manual-ensayos.php) standard of the soil to be treated.

The ROCAMIX system is based on the results of this classification to then classify soils into three groups R1, R2, R3 (ROCAMIX classification). This classification identifies the proportions of the various elements used in the manufacture of the mixture, namely the concentrated ROCAMIX product, cement, water and lime.

Soil classified R1: 0.40 L of concentrated ROCAMIX per m^3 and 5 to 15 kg of cement or lime mixture or mixture of both per m^3;

Soil classified R2: 0.50 L of concentrated ROCAMIX per m^3 and 15 to 20 kg of cement or lime mixture or mixture of both per m^3;

Soil classified R3: 0.60 L of ROCAMIX concentrate per m^3 and 20 to 30 kg of cement or lime mixture or mixture of both per m^3.

Each dose of the ROCAMIX product is mixed with 20 doses of water. This amount of water can be increased until the optimum Proctor water is reached.

A board of 400 m is made as follows:

- The first 200 m are made with the application of the ROCAMIX polymer;
- The second 200 m are made without polymer additive.

Three surveys were carried out along the section at PK0+100, PK0+400 and PK0+500 for soil identification.

A quarry was discovered to the left of the site where the project is being carried out: PK0+800. On this site, two soundings per well of one (01) m (survey N°1 and N°2) were carried out and a sampling on heap survey N°3 was carried out. The recognition results are collated in Table 13 below.

Quantity of materials needed to make the board

Punched soil volume

It was determined according to the height of the layer of compacted soil provided after compacting the board (20 cm), the width of the board (08 m); then the volume V of punched soil evaluated for the 400 m of board is:

$V = 1.25 \times 400 \times 8 \times 0.2 = 800\ m^3$ with a punching coefficient of 1.25.

Quantity of concentrated ROCAMIX product

The quantity of the ROCAMIX product (QR), for the first 200 meters was determined according to the input soil retained (quarry survey 2+3) and R2 (ROCAMIX classification):

$Q_r = 0.5 \times 0.2 \times 8 \times 200 = 160$ L

Amount of cement

The quantity of cement (QC) used for a ratio of 15 kg per m3 of compacted soil:

$Q_c = 15 \times 200 \times 8 \times 0.2 = 4800$ kg or 4.8 tonnes

Amount of water

The amount of water (Qe) needed to complete the first 200 m:

$Q_e = V_s \times \gamma_{dmax} \times (TE_{opt} - TE_{nat})$ – Qr

Q_e = (200 × 8 × 0.2) × 1980 × (13.30 - 12) – 160 = 8077l

V_s = Soil Volume

γ_{dmax} = Maximum dry Density (γ_{dmax} = 1980t/m^3)

TE_{opt} : Optimal water content Proctor (TE_{opt} = 13.30%)

In accordance with the manufacturer's technical specification, six soil specimens from the quarry were made in Laboratory:

- Two specimens without product additives;
- Two test specimens with the normal dose of ROCAMIX from the production of the experimental bed (dose corresponding to a soil of class R2‹‹ 0.5 L/m^3 of ROCAMIX and 20 kg/m^3 of cement››);
- Two test specimens at the maximum dose of ROCAMIX (0.6 L/m^3 of ROCAMIX and 30 kg/m^3 of cement);
- Three specimens are placed in water, each specimen for observation of water absorption and the three others are subjected to the CBR test.

The results of these studies are grouped in Tables 14 and table 15 below.

c. Application of polymer TECOFIX on the pavements soils of YIRIMADJO

Recognition was achieved by performing the following test:

- Soil sample collection by coring;
- Determination of the apparent density of carrots;
- Compression of core samples.

  There was no soil contribution. The lateritic soil in place was scarified and implemented. the contribution of polymer (TECOFIX) per square meter of pavement is always 1L(1L/m^2). It should be noted that the last 100 m of the section were executed with a contribution of sandstone pebbles. Seven (07) days after the completion of the section experimental, we proceeded to take a sample of the soil treated by coring in-situ.

At the level of the part reinforced with the stones, the sampling by heap could not be carried out. In the laboratory, the samples taken were subjected to uniaxial or simple compression tests to determine the resistance. The results are recorded in Table 16 below.

III. Results and discussion

a. ARTS LLC, (EPS PM50 and EPS PM70) Polymer

Table 7: identification and bearing capacity of the soil treated

Designation		Granulometry % passant (mm)												*AL		*CHRB	*GI	*MP		*CBR A%		
		40	31.5	25	20	10	5	2	1	0.5	0.4	0.2	0.08	*LL	*PI	A-2-6	0	*DD (t/m^3)	*W(%)	92	95	98
PK0+100		100	97.4	92.35	84	44.95	38.5	32	30.8	30.5	29.75	26	23.5	33.38	13.06			2.16	8.7	8	20	52
PK0+300		100	97.2	95.65	91.95	69.90	51.65	34.1	29.55	24.65	24.05	16.95	15.65	33.7	12.93	A-2-6	0	2.16	10.80	15	28	86
PK0+500		100	97.05	94	90.6	79.90	63.4	48.45	44.45	40.5	39.9	34.2	28.45	34.05	12.96	A-2-6	0	2.13	10.5	18	30	60
PK0+700		100	97.04	90.95	88.1	74.65		41.1	37.05	32.5	31.6	24.65	21.95	31.67	12.81	A-2-6	0	2.16	10.7	17.50	20	32
PK0+900		100	93.4	89.3	86.5	65.75		30.95	27.75	24.05	23.7	19.35	16.8	33	12.5	A-2-6	0	2.18	10.60	14	31	54
Fuseau	Max	100	97.4	95.65	91.95	79.9	63.4	48.45	44.45	40.5	39.9	34.2	28.45	34.05	13.06			2.18	8.70	18	38	86
	Min	100	93.4	89.3	84	44.95	38.5	30.95	27.75	24.05	23.7	16.95	15.65	31.64	12.5			2.13	10.80	8	20	32

*DD- Dry Density

*W(%)-water content of modified proctor

*AL- ATTERBERG Limits

*PI- Plasticity Index

* GI- Group Index

*LL- Liquidity Limits

*CHBR- Classification Health Based Routing

* PM- Modified Proctor

*PK: Mileage Point

As shown in Table 7, particles with a diameter greater than 20 mm are pebbles; those which have a diameter varying from 20 mm to 2 mm are classified as gravels, those which have a diameter varying from 2 mm to 0.4 mm are soils with coarse sands and finally those which have a diameter varying from 0.2 mm to 0.08 mm are known as fine crushed sand soils. The plasticity index varies from 12.50% to 13.06%. According to the pavement design practice guide, an average plasticity of soils varies from 5% to 15%. The CBR values are higher than 25% whereas it is considered that the bearing capacity is already very high at a CBR value of 25% (practical guide for pavement design). The apparent densities of the samples of lateritic soils in PM and in-situ dry density before treatment are all greater than $2t/m^3$ (12). Those which confirm a good density of these soils. In view of these results, the samples of the soils analyzed before treatment can be used in the stabilization of pavement soils.

Table 8: Soils Identification

N° SAMPLE	GRANULOMETRY		ATTERBERG LIMITS			*CHRB	Type of Soils
	Refusal to the sieve 20mm	Refusal to the sieve 80µm	*LL	*PL	*PI		
1	0	-	-	-		-	Lateritic Soil
2	0	89.1%	29	13	26	A-6(9)	Clay Soil
3	0	65.7%	26	10	26	A-4(8)	Fine Red Soil
4	0						Soil with Fine Crushed Sand

*****Plasticity Liquid

After treatment of the soils with EPS PM50 and EPS PM70 products, the plasticity values given in Table 8 show that the clay soil and the fine red soil all have a high plasticity (16%). This confirms that clay soil and fine red soil can be used in the stabilization of pavements, the average required for a soil with high plasticity varying from 16% to 35%.

Table 9: Compression Test

DESIGNATION	Diameter (cm)	Height (cm)	Mass(g)	Volume (cm3)	Density (g/cm^3)	Section (m^2)	Effort (dan)	Contraint Break up (Bars)
Lateritic Soil with polymer 55 shots	15.171	11.621	4515	2100.537	2.15	180.76	6020	33.30
Lateritic Soil with polymer 25 shots	15.180	11.675	4415	2111.113	2.09	180.97	5270	29.12
Lateritic Soil with polymer 12 shots	15.181	11.676	4121	2113.354	1.95	181.01	3830	21.16
Lateritic without polymer 55 shots	15.179	11.555	4459	2091.054	2.13	180.97	2060	11.38
Clay Soil with polymer 55 shots	14.897	11.229	3685	1957.141	1.88	174.29	6270	35.97
Clay Soil without polymer 55 shots	14.776	11.178	3723	1916.616	1.94	171.47	5080	29.63
Fine red Soil with polymer 55 shots	15.168	11.680	3906	2110.366	1.85	180.69	2160	11.95
Fine red Soil with polymer 25 shots	15.209	11.702	3699	2126.002	1.74	181.67	1390	7.5
Fine red Soil with polymer 12 shots	15.281	11.653	3575	2137.192	1.67	183.40	1010	5.51
Fine red Soil without polymer 55 shots	15.233	11.678	3920	2128.189	1.84	182.24	500	2.74
Fine red Soil without polymer 25 shots	15.221	11.678	3707	2124.930	1.74	181.76	470	2.70
Fine red Soil without polymer 12 shots	15.135	11.678	3561	2101.079	1.69	179.92	120	0.67
Soil with Fine Crushed Sand with polymer 55 shots	15.247	10.997	4075	2008.006	2.03	182.59	4620	25.30
Soil with Fine Crushed Sand without polymer 55 shots	Molding not possible	0	0					
Overlay Clay Soil, Soil with fine crushed sand with polymer 55 shots	15.204	10.997	3861	1996.609	1.93	181.55	5540	30.51

The simple compression results shown in Table 9 reveal an increase in the resistance of the different samples with the use of the polymer products PM50, PM70. This increase is especially marked for high compaction energies (55 strokes), it is:

- 192% for lateritic soil;
- 21% for clay soil;
- 336% for fine red soil;
- 25% for ground with fine crushed sand.

For compaction energy of 25 blows, the resistance of the red fine soil shows an increase of 196%.

According to these results, the EPS PM50 and EPS PM70 Polymers contribute to increasing the mechanical resistance of the soil

Table 10: Soil compactness before treatment

Désignation		Proctor Modified		In-sity Dry Density	Compactness
		*DD(t/m^3)	*W(%)	*DD(t/m^3)	%
PK0+100		2.16	8.7	2.11	98
PK0+300		2.16	10.8	2.09	97
PK0+500		2.13	10.5	2.09	98
PK0+700		2.16	10.7	2.13	99
PK0+900		2.18	10.6	2.18	100
Fuseau	Max	2.18	10.8	2.18	100
	Min	2.13	8.7	2.09	97
Moyen		2.16	10.3	2.12	98

Table 11: Soil compactness after treatment

Désignation		Modified Porctor		In-sity Dry Density	Compactness
		DD(t/m^3)	W(%)	DD(t/m^3)	%
PK0+50		2.16	10.80	1.94	90
PK0+75		2.16	10.80	1.99	92
PK0+125		2.16	10.80	1.91	88
PK0+225		2.16	10.80	1.84	85
PK0+275		2.16	10.80	1.99	92
Fuseau	Max	2.16	10.80	1.99	92
	Min	2.16	10.80	1.84	85
Moyen		2.16	10.80	1.93	90

The results recorded in Tables 10 and table 11 confirms good compactness of the lateritic soils before and after PM treatment because the dry density is greater than 2 t/m^3. The samples of lateritic soils treated with EPS PM 50 and EPS PM 70 show a good dry density in situ before treatment at high compaction energies compared to the low compaction energies of the treated lateritic soil samples. This is due to the effectiveness of the EPS PM50 and EPS PM70 product which is a thermosetting polymer.

Table 12: Water content of molding materials

Désignation	Lateritic Soil	Clay Soil	Fine red Soil	Soil with Fine crushed Sand
Water content of molding materials	10.6%	13.4%	7.75%	
Diluted polymer content	10.6%	13.4%	7.75%	7%

The results shown in Table 12 show that clay soil and lateritic soil all have high absorption capacities compared to fine red soils and ground with fine crushed sand because the usual values vary from 5% to 12%. Thus, it can be deduced that lateritic soil and clay soil can be used as road construction materials.

b. ROCAMIX Polymer

Table 13: CHBR

Désignation	Granulometry : % de passant en mm										ATTERBERG Limits			Classification		Modified Proctor		CBR(%) Compact Ness		
PK	40	31.5	25	20	10	5	2	1	0.5	0.2	LL	PL	PI	HRB	ROCAMIX	$*\Upsilon_d$ (t/m^3)	*W(%)	92%	95%	98%
PK+100	100	97.5	96.4	95.2	84.4	64.4	50.6	47.05	41.8	32.7	18.42	12.01	6.41	A-2-7	R2	2.22	6.69	8	11	17
PK+400	100	91.55	90.5	82.6	65	38.65	24.35	22.7	20.2	16.8	20.3	14.29	6.01	A-2-6	R2	2.37	7.44	10	23	47
PK+500	100	90.15	88.1	84.25	70.95	50.95	36.55	32.35	27.95	21.6	23.48	16.54	6.94	A-2-4	R2	2.09	8.00	15	35	45
Career PK0+800 G* Survey N° 1 et 2	100	89	89	84.9	66	46.15	35.85	31.25	27.2	22.9	39.77	26.62	13.15	A-2-4	R2	1.98	13.30	22	38	39
Career PK0+800 G TAS N°3	100	100	100	84.9	66	46.15	35.85	31.25	27.2	22.9	44.35	30.16	14.19	A-2-4	R2	1.94	15.48	22	23	27

Table 13 shows a low plasticity of the PK+100 to PK+500 sections. It varies from 6.41% to 6.94% compared to the PK+800 G (by drilling) and PK+800 G (by heap) quarries which, in turn, vary from 13.15% to 14.19%. Thus, the application of ROCAMIX to the last two will result in better compactness. Lift and density are all high.

Table 14: Variation of the mass of the samples under the effect of water absorption

Samples	Dry Mass	Mass after 3H	Mass after 6H	Mass after 24H	Mass after 48H	Mass after 72H	Mass after 144H
0	4691	4616	4653	2258	1685	485	0
R	4606	4695	4710	4742	4800	4832	4847
RM	4460	4574	4599	4624	4708	4711	4713

O- Sample without ROCAMIX additive; R- Sample with dose normal ROCAMIX; RM- Sample with maximal dose ROCAMIX

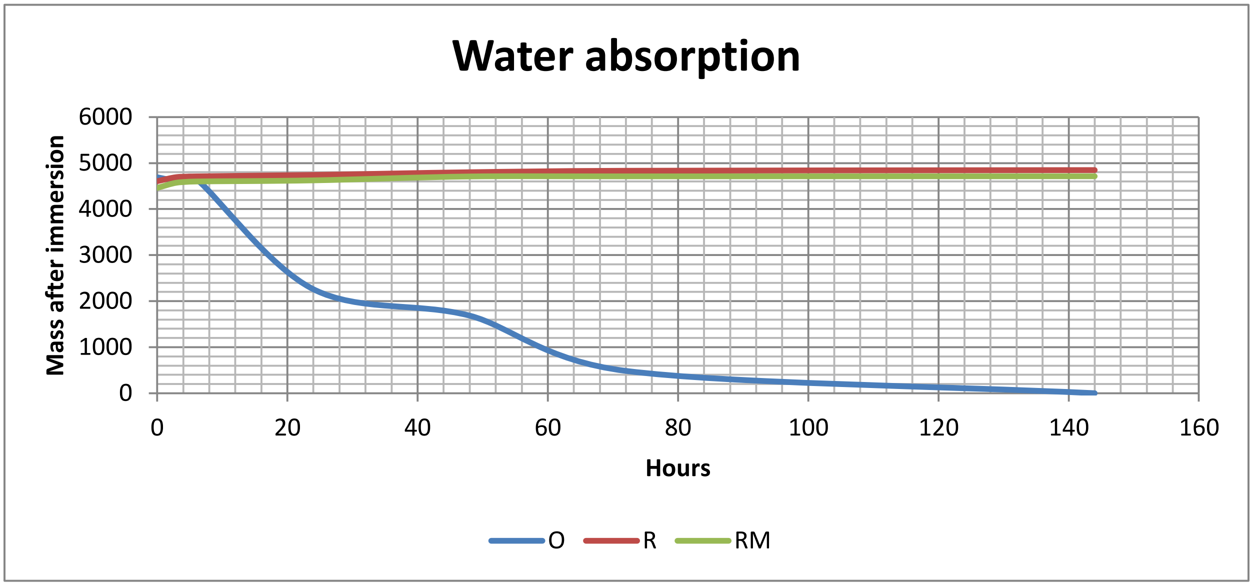

Fig. 5: Curve of Water absorption of sample mass after immersion as a function of time.

Table 14 and Fig.5 show the total water absorption of the O sample as well as its destruction, compared to the R and RM samples which retain water but are not destroyed. Therefore, these results confirm that the ROCAMIX polymer product helps the soil to acquire retaining-water properties.

Table 15: Variation of CBR according to the dosage of the polymer

Samples	Dry Mass in 11H00mn	Mass after inhibition in polymer 14h00mn	Indice CBR
O	4699	-	30.61
R	4760	-	42.19
RM	4461	-	69.12

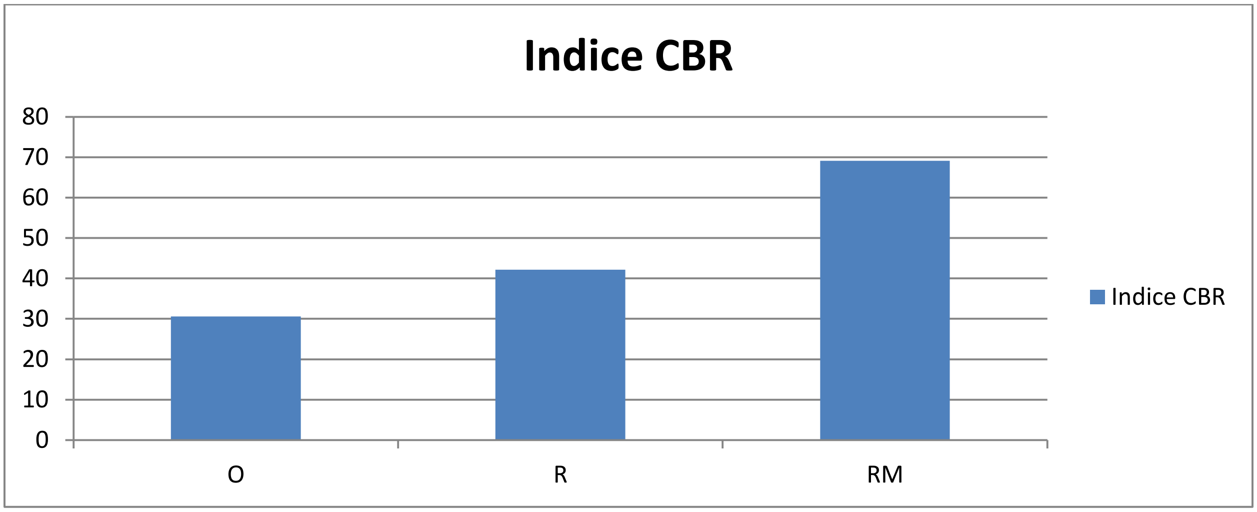

Fig. 6: Variation Index CBR according dosage of polymer.

As shown in Table 15 and Fig. 6, the assay of ROCAMIX polymer samples before and after inhibition shows an increasing ICBR. This increase shows a good bearing capacity of the soils, because the higher the dry density, the more the ICBR increases and the higher the bearing capacity. Thus, the ROCAMIX polymer increases the bearing capacity of soils.

c. TECOFIX Polymer

Table 16: Compression test in Laboratory of Soils treated with TECOFIX polymer

N° Carrots samples	Diameter cm	Height cm	Density g/cm^3	Breaking load (dan)	Bearing Surface(cm²)	Contraint break up (MPa)	Contraint break up(bars)
1	7.377	10	1.91	860	42.74	2.01	20.1
2	7.377	7	1.81	1080	42.74	2.53	25.3
3	7.377	7	1.89	720	42.74	1.68	16.8
4	7.377	8	1.92	740	42.74	1.73	17.3
5	7.377	7	1.88	820	42.74	1.92	19.2
Average compressive strength							19.7

Table 16 shows that the average simple compressive strength is 19.74bar. The average required by the practical pavement design guide for tropical countries is a range of 18 bars to 30 bars (13). Thus, we can affirm that the TECOFIX polymer fully fulfills the role of stabilizer by increasing the mechanical characteristics of the soil and reducing the pollution of the immediate environment.

In the same Table 16, the slenderness (H/D), i.e. the ratio of the height (H) to the diameter (D) is less than 2 and varies between 1.36 and 1. This is due to the thickness of the treated layer which is 10 cm after compaction and the minimum internal diameter of the crowns which is 7.37 cm.

Seven (07) days after the application of the TECOFIX product on the YIRIMADIO-SEMA site, according to the survey carried out among local residents and users, there is a clear reduction in dust and the road is passable after the rain (road not degraded and no sludge formation).We therefore recommend the continuation of its experimentation on a larger scale on rural roads.

IV. Conclusion

The evaluation of polymers (ARTS LLC, EPS PM 50 and EPS PM 70, ROCAMIX, TECOFIX) was applied to the soils of MAGNANBOUGOU, KALABANCORO and YIRIMADJO-SEMA. The polymers applied to these soils showed excellent physical and mechanical properties. The grain size analysis allowed us to identify the nature of the soils. The results revealed that ROCAMIX can enhance the water-retaining property. ROCAMIX, TECOFIX, and EPS PM50-PM70 polymers can enhance strength property of soil, all of which increase with the increase of polymer concentration. In addition, field tests proved that ROCAMIX, TECOFIX, and EPS PM50-PM70 polymers were good effects on soil engineering. These results could be applied as a reference for ROCAMIX, TECOFIX, and EPS PM50-PM70 polymers-improved soil engineering.

V. Recommendation

If, in addition, the application of the quantity of EPS PM 50 has reduced the humidifier to excess the soil, it is therefore necessary to wait for a loss of natural water content before this application. For the use of EPS PM70 as surfacing, it is preferable to mix the gravel with reduced PM 70, then to spread the mixture with a paver to ensure uniformity in the thickness of the surfacing layer while giving a uniform appearance of the surface.

Given the effectiveness of these polymeric products in stabilizing pavement soils, we recommend the continuation of experiments on a larger scale in rural tracks, betimes roads and cobblestones. The availability of more experienced equipment and laboratories will make it possible to synthesize these commercial polymers and to make them, if possible, into more effective products for the consolidation of our soils. The measurement of the rate of CO_2 released into the atmosphere after the use of the products on the floors was an asset in the but of power compared to those of the floors made of cement or lime.

VI. Acknowledge

My thanks go to the national center for research and experimentation in building and public works (CNREX-BTP) Mali for the availability of personnel, equipment and its laboratory. The structure spared no effort for the success of this work.

VII. Declaration of conflict of interest

We declare any conflicts of interest including fees paid or ownership of shares that could constitute a conflict of interest.

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