

# Geotechnical characterization of an innovative soil stabilization product (Aggrebind/Road Master) usable in the construction, rehabilitation and maintenance of road infrastructure and the construction of social housing in Cameroon

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## ABSTRACT

Building roads in developing countries has always been very expensive. An efficient and more affordable method is needed. AggreBind's soil stabilization solutions, known as RoadMaster (RM1 / RM2) and AggreBind (AGB-WT/BT) are offered. The objective of the present study was to make a geotechnical characterization of this product with a view towards its use in the construction, rehabilitation and maintenance of road infrastructure in Cameroon.

A series of laboratory tests were carried out; soil identification tests (particle size analysis, Atterberg limits), lift tests (Proctor and modified CBR test), determination of the optimum water content of the material, maximum dry density, immediate CBR index and the CBR index after immersion for 4 days. Only the 95% OPM CBR test was carried out on the soil with the additive AGB-WT/RM1 in order to characterize the effects of the product on the soil.

In conclusion, AggreBind/RoadMaster can provide stable, dust-free roads and stabilized base courses for general roads and highways that meet or exceed the bearing capacity requirements of international road specifications. In addition, the use of this product reduces the cost of road construction by 40% to 60% and increases in-situ load bearing capacity by 400% to 600%.

**Keywords :** Geotechnical characterization, soil stabilization, Aggrebind / Roadmaster, road infrastructure, Cameroon

Received: 18/12/2021

Accepted: 13/01/2022

DOI: <https://dx.doi.org/10.4314/jcas.v17i3.5>

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## RESUME

La construction de routes dans les pays en développement a toujours été très coûteuse. Une méthode efficace et plus abordable est nécessaire. Les solutions de stabilisation des sols proposées par AggreBind, connues sous le nom de RoadMaster (RM1/RM2) et AggreBind (AGB-WT/BT) sont proposées. L'objectif de la présente étude était de faire une caractérisation géotechnique de ce produit en vue de son utilisation dans la construction, la réhabilitation et l'entretien des infrastructures routières au Cameroun.

Une série d'essais en laboratoire a été réalisée : tests d'identification du sol (analyse granulométrique, limites d'Atterberg), essais de portance (Proctor et essai CBR modifié), détermination de la teneur en eau optimale du matériau, de la densité sèche maximale, de l'indice CBR immédiat et de l'indice CBR après immersion pendant 4 jours. Seul le test CBR 95% OPM a été réalisé sur le sol avec l'additif AGB-WT/RM1 afin de caractériser les effets du produit sur le sol.

En conclusion, AggreBind/RoadMaster peut fournir des routes stables et sans poussière ainsi que des couches de base stabilisées pour les routes générales et les autoroutes qui satisfont ou dépassent les exigences de capacité portante des spécifications routières internationales. En outre, l'utilisation de ce produit réduit le coût de la construction des routes de 40 à 60 % et augmente la capacité de charge in situ de 400 à 600 %.

**Mots clés :** Caractérisation géotechnique, stabilisation des sols, Aggrebind/Roadmaster, infrastructures routières, Cameroun

## 1. INTRODUCTION

The soil is the outermost layer of the earth's crust resulting from the interaction between the lithosphere, the atmosphere, the hydrosphere and the biosphere (Duchaufour, 2001); it can also be defined as being the volume which extends from the surface of the Earth to the depth marked by the appearance of hard or soft rock, little altered, or little marked by pedogenesis (Philipponat & Hubert, 2007). It is not only the support of microbial biodiversity, plant and animal life, but also human activities such as the construction of roads, building foundations, dams etc. It is therefore a living entity, a natural resource, little or slowly renewable, of different types depending on the source bedrock and the type of alteration which, to serve as a support for the human activities mentioned above must be naturally stable or stabilized. Several soil stabilization techniques have been developed in order to limit the excessive and uncontrolled use of soils (and aggregates); this stabilization process involves the addition of binding materials or aggregate fractions in order to improve the physical and mechanical properties of soils (Firoozi *et al.*, 2017).

Road infrastructures, which are works allowing the movement of goods and people, have a limited lifespan and are built at very high cost, must guarantee safety and comfort. They therefore require materials with better geotechnical characteristics in their construction because the durability of roads depends on the quality of the materials used. This construction also faces the problems of acquiring various equipment and materials such as graded aggregates, laterite, bitumen, cement, lime and others, generally requiring considerable financial resources. Quality and quantity of quarries and quarry products are not always available near project sites. Therefore, improvement through the soil stabilization processes using materials available near the work

sites could reduce these problems.

In Cameroon, its anticipated emergence by 2035 requires the construction of large-scale infrastructure for the development of its territory, the development of infrastructure such as highways, and roads, increasingly essential by the growing volume of the exchanges experienced by the latter. New constraints appear, including the scarcity of materials meeting the requirements of the Technical and Particular Clauses (CCTP) and the expensive cost generated by the transport of said materials. The use of certain soils (laterites) as construction materials in road geotechnics is starting to make it a scarce resource in some parts of Cameroon. The search for solutions to these problems has resulted in soil improvement techniques grouped into two categories, mechanical stabilization and stabilization through the use of different types of additives (Afrin, 2017).

It is therefore important that in Cameroon we have innovative strategies using innovative soil stabilization products and the AggreBind product by its characteristics; totally ecological, adaptable to almost any type of soil is uniquely positioned as a solution. This objective was carry out through the examination of the geotechnical characterization of the AggreBind / RoadMaster product which can be used in the construction, rehabilitation and maintenance of road infrastructure.

## 2. MATERIAL AND METHODS

### 2.1. MATERIALS

#### Site Study

This study was carried out as part of a geotechnical and hydraulic data acquisition mission relating to the Yaoundé-OBALA Road duplication project (40 km), in the Center region. This section (Yaoundé-OBALA) of the national road n°1, located in the central region, the

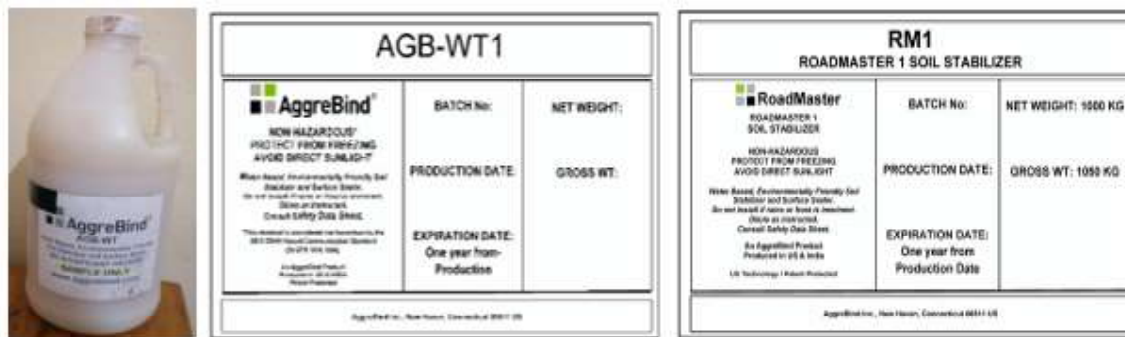
departments of MFOUNDI and LEKIE forms one of the major axes of the road structuring network of Cameroon, given its importance in transporting goods and services, both nationally and internationally with neighboring countries. It is also important to Cameroon's agricultural production basin with, in particular, the exploitation of wood and food crops.

**Soil sampling**

The Yaoundé-OBALA Road duplication project (40 km) begins after the end of the right central

median where pk 0 + 000 is located (781 573 m; 437 972 m; 683 m) and ends before the OBALA junction (PK 40 + 000) where the construction of an interchange is in progress. The soil sample used for the geotechnical characterization of the AggreBind / RoadMaster product is reddish clay in the area of the Yaoundé-OBALA Road duplication project and corresponding to PK 5 + 000. Sampling was carried out using traditional drilling tools such as a pickaxe and shovel over an area of one square meter to a depth of 15 cm below the plant layer.

**Product AggreBind/RoadMaster (AGB-WT / RM1)**



**Figure 1 : Product AggreBind / RoadMaster (AGB-WT / RM1)**

The AggreBind product used was AGB-WT / RM1. It is a white liquid, intentionally non-biodegradable (to function for a long time), characterized by its particular non-aggressive odor, a slow evaporation rate, non-oxidizable, miscible with water because it is non-toxic, viscous and has a temperature of evaporation equal to that of water (100 ° C). Its relative density at 20°C is 1.05 and its pH varies between 7.7 and 8.3.

**Natural soil**

The natural soil sample used for the experiments came from the EBANG II neighborhood in the Municipality of SOA, Yaoundé, Cameroon.

**Improved soil**

The improved soil used was a mixture of the natural soil and the emulsion (binder) in very precise proportions. The emulsion being the mixture of AGB-WT / RM1 + water.

Figure 1 gives the dosage rate of AggreBind / RoadMaster polymer per cubic meter of soil treated as a function of the percentage of fines contained in the soil sample.

The volume of the emulsion, approximately 4 liters per m3 of material (V emulsion), when diluted, must correspond to the optimum water content of the soil (W opt) determined by the Proctor test and is calculated by the following equation:

$$V \text{ emulsion} = W \text{ opt} * ms / 1000$$

Where: V emulsion is expressed in ml; ms is the mass of dry soil and is expressed in grams;

W opt is expressed in % ;

The volume of the product AGB-WT (V AGB - WT) is calculated by the following equation:

$$V \text{ AGB - WT} = \text{Polymer dosage rate} * ms / Ps$$

Where: V AGB - WT is expressed in ml; Ps is the dry density of the soil and is expressed in kg / m3;

The volume of added water (V water) is calculated by the following equation :

$$V \text{ water} = V \text{ emulsion} - V \text{ AGB-WT}$$

Where: V water is expressed in ml.

## 2.2. METHODS

Atterberg's grain size analysis and limits tests identified the natural soil, while the modified Proctor and CBR tests provided its compaction parameters. And finally, the CBR test according to the AggreBind / RoadMaster product laboratory testing protocol allowed to characterize the improved material.

### 2.2.1. Particle size analysis

#### By sieving

This analysis makes it possible to represent the size and the respective percentages of the different families of grains constituting the sample of the material using a grain size curve. It is a representation of the percentages of the sieves or those of the cumulative rejects (percentages by weight of the total dry mass of the material after washing and drying) on the sieves as a function of the mesh openings of the sieves (NF P 94-056. 1996).

The test consists in separating the agglomerated grains of a known mass of material by stirring under water, in dividing this soil, once dried, by means of a series of sieves and successively weighing the residue accumulated on each sieve. The cumulative residue mass on each sieve is related to the total dry mass of the sample submitted for analysis (NF P 94-056. 1996).

Calculation of curvature and uniformity factors were performed by the material passing through the 63 mm sieve exhibited more than 50% residue on the 80  $\mu$ m sieve. The sizes of the sieves corresponding to d<sub>10</sub>, d<sub>30</sub> and d<sub>60</sub> were interpolated graphically on the curve. The curvature factor was calculated from the equation:  $C_c = (d_{30})^2 / (d_{10} * d_{60})$  and the uniformity factor from the equation:  $C_u = d_{60} / d_{10}$  (NF P 94-056. 1996).

#### By sedimentation

The purpose of this standard is to determine the weight distribution of the size of fine particles in a soil. It uses the fact that in a liquid medium at rest, the speed of settling of fine grains is a function of their size. Stokes' law gives, in the case of spherical grains of the same density, the relationship between the diameter of the grains and their sedimentation rate. By convention, this law is applied to the elements of a soil to determine equivalent particle diameters (NF P 94-057. 1992).

### 2.2.2. Atterberg Limits

Atterberg limits are geotechnical parameters intended to identify a soil and characterize its condition by means of its consistency index. The test is carried out in two phases: (1) Investigation of the water content for which a groove made in soil placed in a cup of prescribed characteristics, closes when the cup and its contents are subjected to repeated shocks; (2) Research of the water content for which a roll of soil, of fixed dimension and made manually, cracks (NF P 94-051. 1993).

### 2.2.3. Modified Proctor test

This test made it possible to determine the compaction characteristics of a material. These characteristics are the optimum water content and the maximum dry density. Depending on the compaction energy applied to the specimen, two types of tests can be distinguished which lead to different pairs of values: the normal Proctor test and the modified Proctor test. This standard applies to materials defined in the NF P 11-300 classification, of which the dimension of the largest elements (D max) does not exceed 20 mm, whether they are natural or treated with lime and / or binders or hydraulic (NF P 94-093. 1999).

These tests consist in humidifying a material with liquid / water contents and in compacting it, for each of the water contents, according to a method and a conventional energy. For each of

the values of water content considered, the dry density of the material is determined and the curve of the variations of this density is plotted as a function of the water content. This curve, called the Proctor curve, presents a maximum value of the density of the dry material which is obtained for a particular value of the water content. These two values are called the optimum normal or modified Proctor compaction characteristics depending on the test carried out.

For each compacted specimen, it is necessary to calculate: the water content; the mass of dry material contained in the mold and the density of dry material taking into account the actual volume of the mold used, determined from geometric measurements made to the nearest 0.1mm.

The values of the densities of the dry material and the corresponding water contents are plotted on a graph  $P_d = F(W\%)$ . The scale ratio is 2% water content for 0.1 t / m<sup>3</sup> density. The curve fitted to the experimental points is then plotted. Except in the case of very permeable materials, this curve has a maximum, the coordinates of which are respectively called optimum dry density and optimum water (moisture) content (often called OMC). This result is expressed to the nearest 0.01 t / m<sup>3</sup> for the density and to the nearest 0.1 point for the water content (expressed as a percentage). Equation curves should also be shown on the graph  $P_d = F(W\%)$ :  $P_d = S_r * P_s / S_r + w * (P_s / w)$ ; where  $P_w = 1t / m^3$  established for  $S_r = 100$  and 80% / m<sup>3</sup> and for  $P_s = 2.70t / m^3$ . If the measured value of  $P_s$  of the material considered is available, it will be used to establish these two curves (NF P 94-093. 1999).

#### 2.2.4. CBR test

This test allows the determination of the immediate CBR index, the CBR index after immersion of a soil or of a granular material used in the construction of earthworks or road

foundations. It applies to soils, rocky materials, industrial by-products defined in standard NF P 11-300 and provided that the proportion of elements whose  $D_{max}$  exceeds 20 mm does not exceed 30%. It also applies to these same materials when they are mixed with different products such as aerial lime, hydraulic or pozzolanic binders, fibers (NF P 94-078. 1997).

The test consists of measuring the forces to be applied to a cylindrical punch to make it penetrate at constant speed into a test piece of material. The particular values of the two forces having caused two conventional depressions are respectively related to the values of the forces observed on a reference material for the same depressions. The desired index is conventionally defined as being the greatest value, expressed as a percentage, of two ratios thus calculated. The values of the parameters (punch section, driving speed, conventional driving, forces observed on the material) are standardized and specified in articles 6 and 7. The CBR test after 4 days of immersion measures the resistance to puncture soil compacted with different water contents then submerged for 4 days. It characterizes the evolution of the load-bearing capacity of a compacted soil and / or subjected to variations in water regime. The desired CBR index is by convention the greatest value between: **Penetration force at 2.5 mm sag (in KN) \* 100 / 13.35 and Penetration force at 5 mm sag (in KN) \* 100 / 19.93**. If necessary, make an original correction.

#### 2.2.5. CBR test according to the soil stabilization protocol with AggreBind / RoadMaster product

The 95% Optimum Modified Proctor (OPM) CBR test (according to NF P 94-078) will be used to characterize the soil treated with the AggreBind product. The only difference is that the saturation and swelling phase of the soil according to the CBR standard does not apply when using the AggreBind / RoadMaster product. Thus, the test pieces should not be immersed in water and should be stored in a ventilated place without

being directly exposed to sunlight, and on a flat surface to allow hardening. This characterization will involve determining the immediate CBR index, and the CBR index after air drying for 3 days, 7 days, 14 days, 21 days and 28 days. This is in order to observe the evolution of the load-bearing capacity of the soil over the hardening time (NF P 94-078. 1997).

#### 2.2.6. Statistical analysis

The data collected were entered and analyzed using Microsoft Excel analysis software, version 2020.

### 3. RESULTS AND DISCUSSION

#### Site description

##### Geographical location

The soil sampling site is on the platform area of the Yaoundé-Obala road doubling project (40 km). The project platform is still occupied by vegetation (trees, grasses, crops), the population (houses, businesses etc.) and electric poles etc. (figure 2). After visiting the site and investigating the field, it was noted that the platform soil is clayey in nature but we also found in the Ebang II zone lateritic soils marked by the imposing presence of a lateritic borrow site from the main track.



Figure 2 : Soil sampling

#### Geological description

The soils identified in the locality of EBANG II are ferralitic soils where the hydrolysis of the minerals of the rocks by the waters of the abundant and hot rains is complete. These are poor, exhausted, and infertile soils characterized by a low nutrient content (pH between 4 and 6). They are deep due to the presence of organic matter, red clay, loose and permeable. The soil is made up of large parts of granite stones. Erosion is easy there. Some plantations grow well there, such as oil palms. The quality of the soil and the presence of rocks offer possibilities for the creation of quarries such as the AKAK quarry and the RAZEL quarry.

#### Weather

The climate of the locality of EBANG II is of the humid equatorial type. It is a four-season climate of the Cameroonian plateau. So, it rains most of the year, with two maximum periods, one in October (long rainy season) and the other in March-April (short rainy season). The drought peaks are in December-January (long dry season) and July-August (short dry season).

#### Relief

The relief is that of a dissected plateau which slopes from the Center to the North, passing from 740m to 800m in the small massif of Ndogo, at the extreme Center-East from 580m to 600m above sea level at the northern tip of the rounding following a gentle slope of 0.66%.

The average altitude is 675m. The relief of the district of Soa is struck with its many deep valleys suitable for fish farming. There are also steeply sloping areas at Ebogo III, Nkolbewa, Nkolzie by Mbansan II, Mbansan I, Otonton, Ndi, Nso'o by Ntouessong VI and the main hills of Ndeedzala, Minsole, Bomena and Nkonda. Risk areas are present in Soa Commune, these are the ravines of Akak II, Ovangul, Ting Melen and Mbansan II.

**Hydrology**

The hydrographic network is organized around the Afamba river and its main tributaries, the Mbende and the Foulou. Several rivers water the Municipality, and these rivers collect stream water and drain it towards the Sanaga in the north.

forests in Ntouessong V, Ebang I, Koulou, Mebougou and Ngoungoumou. However, there are still woody species such as Abissia, Fraqué, Ilomba, Ficus, Antiaris, Dabema. There are also many valuable species, including Bibolo, Padouk, Fraque, Canarium, Osmoso, Hévea, Ilomba, Sapeli, Iroko.

**Vegetation**

The forest is semi-deciduous with sterculiaceae and ulmaceous. It has large trees with straight boles and gray bark. In fact, there are some primary forests in Ntouessong V and secondary

**Soil identification**

Table 1 below shows the various geotechnical identification tests carried out on natural soil.

Table 1 : Identification of the soils

Nature du sol	Analyse granulométrique par tamisage (ouverture des tamis en mm)														Limites d'atterberg			Proctor modifié		CBR à 95%de TOPM		Classification AASHTO					
	20	16	12,5	10	8,3	4	3,15	2,5	0,8	0,63	0,4	0,2	0,16	0,08	LL(%)	LP(%)	IP(%)	densité sèche (Kg/m <sup>3</sup> )	Teneur en eau optimale (%)	CBR immédiat	CBR après 4 jours d'immersion						
silt argileux	Pourcentage des passants (%)														23	14	9	1890	15	30	23	A-4(2)					
	Analyse granulométrique par sédimentation (diamètre équivalent de particules en mm)																										
	0,0297	0,0211	0,0149	0,0122	0,0094	0,0087	0,0089	0,0027	0,0019	0,0016	0,0012	0,0006															
Pourcentage des passants (%)																											
	100	99,8	99,6	99,3	98,7	98,5	98,4	98,3	95,2	91,6	80,2	67,9	59,9	51,2													



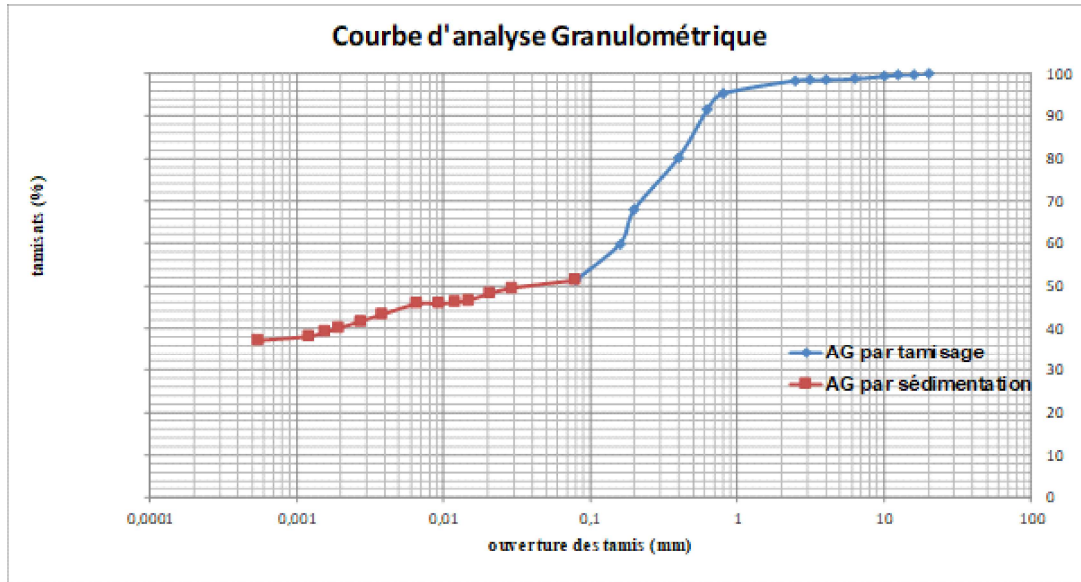


Figure 2: Particle size analysis curve

The curvature and homogeneity factors are not calculated because our soil sample has more than 50% sieve in an 80 μm sieve, i.e. 51.2%. The soil therefore contains 51.2% fine particles qualified as silty and 39.9% clay (particles smaller than 2 μm), it is therefore a class A-4 soil; AT 5 ; A-6 or A-7. (While AggreBind / RoadMaster has a wide bandwidth of soil characteristics, 35% fines passing through a # 200 screen, size 75 microns, is preferred.)

**Atterberg limits**

Figure 3 shows that the liquidity limit corresponds to a number of strokes equal to 25. This water content is 23.3%, ie a liquidity limit of 23%.

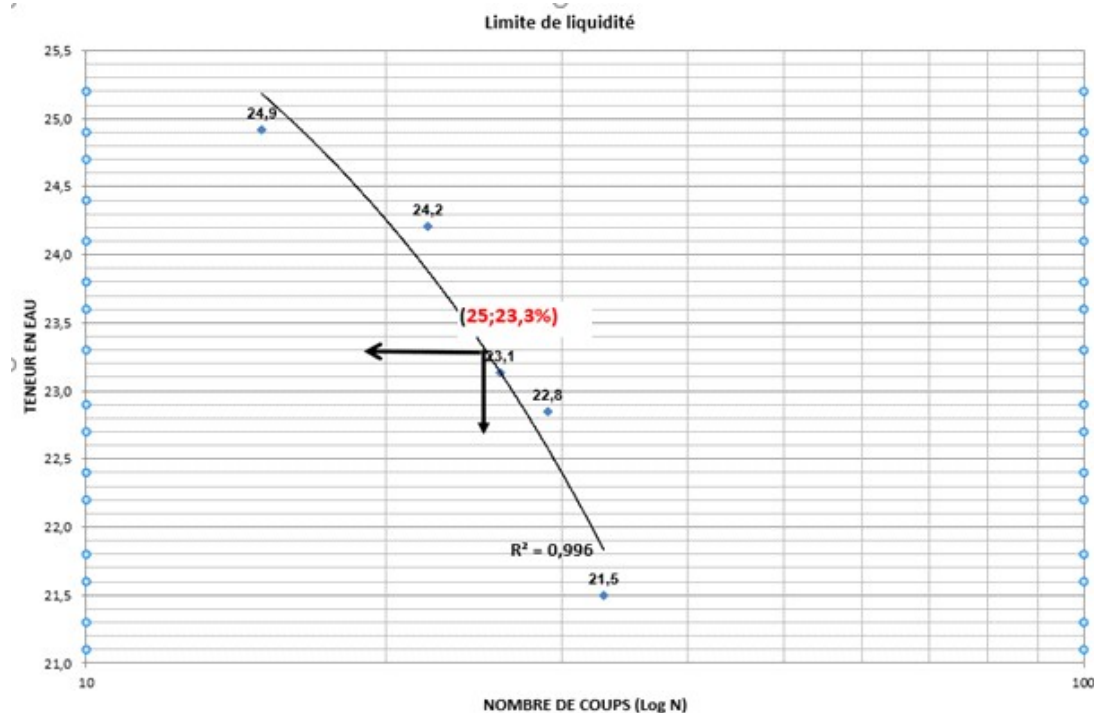


Figure 3 : Cup liquidity limit

**Plasticity limit**

Table 2 shows the plastic limit

Table 2 : Plasticity limit

	Water content	
Tare number	3	4B
Total wet weight (g)	15.92	16.25
Total dry weight (g)	15.56	15.85
Tare weight (g)	12.87	13.07
Water weight (g)	0.36	0.4
Dry material weight (g)	2.69	2.78
Water content (%)	13.38	14.39
Plasticity limit (%)	14	

**The plasticity index**

It is calculated by the difference between the liquidity limit and the plasticity limit. With a liquidity limit of 23 and a plasticity equal to 14, we obtain a plasticity index (PI) equal to 9 (less than 11). And knowing the percentage of passers-by through the 80 μm sieve given by the particle size analysis, the AASHTO classification system concludes that this soil is a class A-4 weakly plastic clay loam (2). The group index (equal to 2) being close to 0 and 20, the potential performance of this soil as a road infrastructure could be qualified as good compared to a material of the same group. (While AggreBind / RoadMaster has a wide bandwidth of the ground characteristics, an PI of 15 or less is preferred.)

**Ground lifting**

**Modified Proctor test**

The compaction curve shown in Figure 4 identifies references to the modified Proctor optimum, such as optimum water content and dry density.

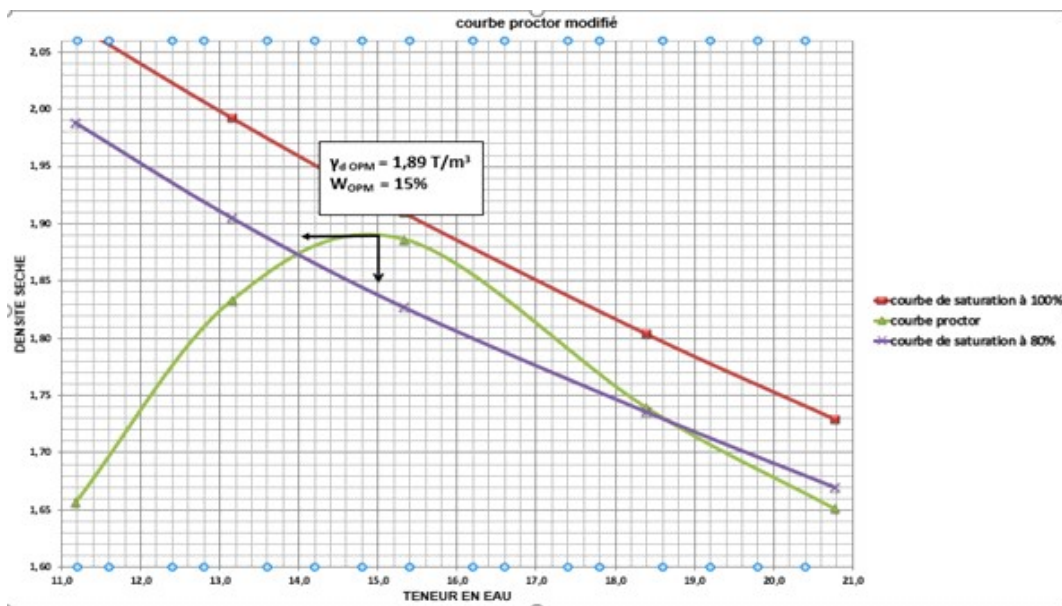


Figure 4: Modified Proctor curve

At the optimum, the water content and the dry density are respectively 15% and 1.89 T / m3. This corresponds to a state of saturation of more than 80%.

**CBR test**

The CBR test was performed at 95% Optimum Modified Proctor (OPM) or 5-stroke compaction using 25 strokes per layer in a CBR mold.

**Immediate CBR**

It characterizes the evolution of the bearing capacity of a compacted subsoil (or pavement component) with an optimal water content. Punching is carried out immediately after compaction and the data collected (see appendix 1) allow the force-penetration curve to be drawn as shown in Figure 5.

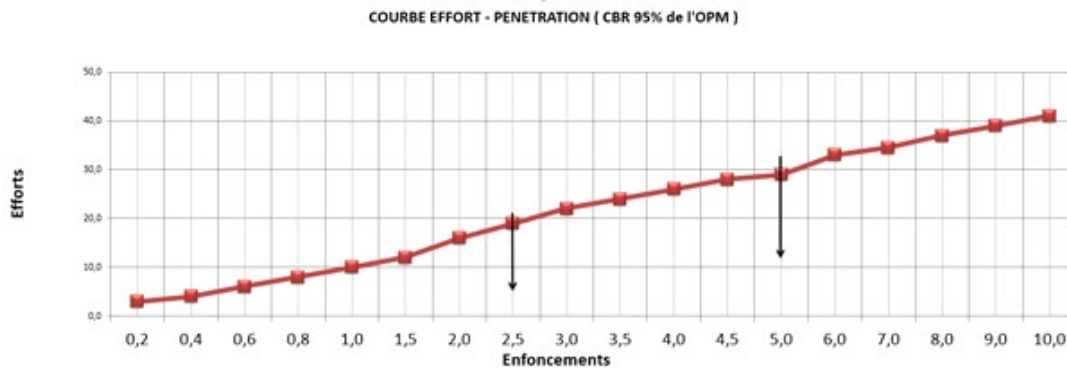


Figure 5: Force-penetration curve

This curve makes it possible to determine the forces necessary for a depression of 2.5 mm and a depression of 5 mm in order to determine the immediate CBR index. Its value and that of the dry density achieved are listed in table 4.3.

**Table 3** : Immediate 25-stroke CBR results

Calculation of the CBR index at 25 shots		
Sinking (mm)	2.5	5
Effort (KN)	4	6
Calculated CBR	29	30
CBR Index	30	
Dry density (kg/m <sup>3</sup> )	1827	

**CBR after immersion for 4 days**

It characterizes the evolution of the bearing capacity of a support soil (or pavement component) compacted with the optimum water content and subjected to variations in water regime. After 4 days of immersion, the test tube is removed from the water then drained and punched. The data collected from the punching makes it possible to plot the force-penetration curve illustrated in Figure 2.

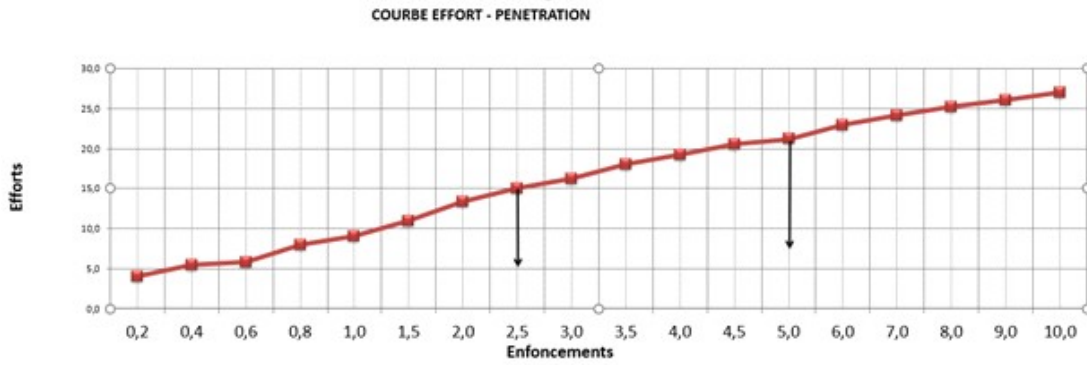


Figure 6: Force-penetration curve after immersion

This curve makes it possible to determine the forces necessary for a depression of 2.5 mm and a depression of 5 mm in order to determine the CBR index after immersion. Its value as well as that of the dry density and swelling are listed in Table 5.

Table 4: CBR after immersion

Calculation of the CBR index at 25 shots		
Sinking (mm)	2.5	5
Effort (KN)	3	4
Calculated CBR	23	22
CBR Index	23	
Dry density (kg/m <sup>3</sup> )	1877	
Swelling	0.18	

The CBR index at 25 shots after immersion is equal to 23 (between 15 and 30) which makes this soil an S4 class. The dry density obtained is 1877 kg / ie a degree of compactness am ^ 3 equal to 99% relative to the dry density at OPM.

**Soil treatment with AGGREBIND / ROADMASTER (AGB-WT / RM1)**

The specimens were carried out according to the standards for lift tests (modified Proctor and CBR). The only difference is that the saturation and swelling phase of the soil according to the CBR standard does not apply when using the AggreBind / RoadMaster product. Thus, samples should not be submerged in water and should be stored in a ventilated area with or without direct sunlight exposure on a flat surface to allow moisture to escape and the mold to harden.

**Results Features**

**Emulsion formulation**

The emulsion is the AGB-WT / RM1 + water mixture (Figure 7). Thus, the volume of emulsion should correspond to the optimum soil water content (OMC) determined by the modified Proctor test. And from the ratio of 4 liters of AggreBind / RoadMaster per soil we will determine the volume of m ^ 3 AGB-WT / RM1 concentrate necessary for a sample of dry soil of 6000g knowing its dry density at the optimum. Finally, the volume of water required will be the difference between the volume of emulsion corresponding to the optimum soil water content (OMC) and the volume of AGB-WT / RM1 calculated previously. The results are listed in Table 5.



Figure 7: AGB-WT / RM1 + water mixture (emulsion) for mixing

Table 5: Formulation of the emulsion

Mass of dry soil sample (g)	Emulsion volume (ml)	Volume of AGB-WT / RM1 (ml)	Water volume (ml)
6000	900	13	887

### Manufacturing of test specimens

After diluting the AGB-WT / RM1 product in water up to the optimum water content to obtain the emulsion, mix it with the soil sample by mixing carefully, so as to homogenize the whole. Finally, apply a compaction at 95% of the OPM in a CBR mold divided into 5 layers at the rate of 25 strokes per layer (according to NF P 94-053). Figure 4.10 shows the specimens obtained at the end of compaction. Thus, there will be 7 copies of CBR distributed as follows:

- A test tube made of material treated for punching after immersion for 4 days,
- A test specimen in treated material for immediate punching,
- A test piece of material treated for punching after air drying for 3 days,
- A test piece of material treated for punching after air drying for 7 days,
- A test piece of material treated for punching after drying in air for 14 days,
- A sample of material treated for punching after air drying for 21 days,
- A test piece of material treated for a 28-day air punching.



Figure 8: CBR evidence of soil treated with AggreBind/RoadMaster

**95% OPM CBR test results**

The data collected during the punching of all 7 specimens are presented in Table 6.

Table 6: Summary of the results of the CBR tests carried out on the specimens

95% opm CBR test results						
Number of movements	25	25	25	25	25	25
Number of days	0	3	7	14	21	28
CBR Index	29	30	62	121	146	156
Dry density (kg / m3)	1814	1855	1881	1886	1888	1893
Compactness rate (%)	96	98	100	100	100	100
Water content (%)	14,7	13,4	10,6	9,8	8,4	7,4

Table 7: Results of the CBR test after immersion for 4 days

Number of movements	CBR index after immersion	Dry density (kg / m3)	G swelling (%)
25	25	1843	0,22

**Results interpretation**

Stress-strain curve as a function of time

The punching carried out during the CBR tests on the specimens of treated material makes it possible to plot the stress-strain curves (figure 9) and to observe the evolution of the stresses applied to the material during the curing time.

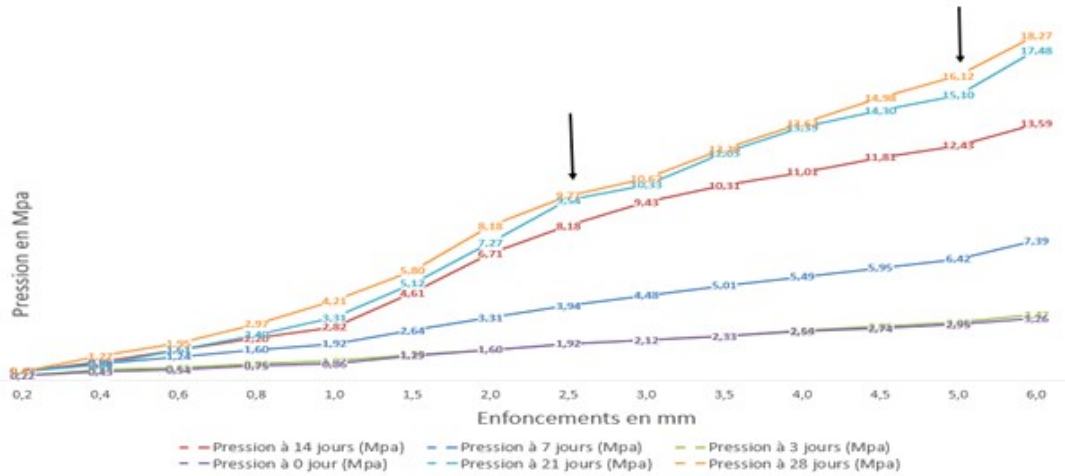


Figure 9: Pressure-strain curves

FIG. 9 generally shows an increasing evolution of the stresses applied to the material treated from the 1<sup>st</sup> day to the 28th day, ranging from 2.95 Mpa to 16.12 Mpa for a depression of 2.5 mm. Although no evolution of the stresses was observed during the first 3 days, this is due to the fact that the nature of the material remained unchanged but begins to change after the 3rd day thus causing a sudden and rapid evolution of the stresses applied for the same deformation.

### CBR evolution curve over time

The evolution of the CBR of the material treated with AggreBind / RoadMaster over the dry air curing time is shown in Figure 10.

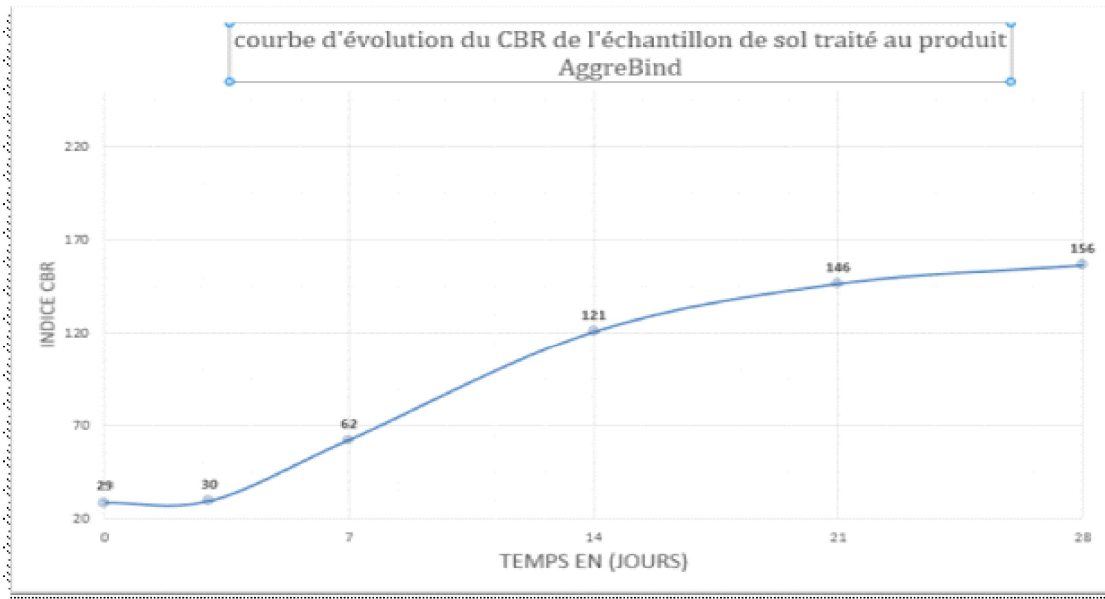


Figure 10: Evolution curve of the CBR as a function of time

After 3 days of curing in dry air, the CBR index of the treated material has hardly changed, it remains close to its immediate CBR index. From the 7th day of curing forward there is a sudden and exponential increase in CBR ranging from 30 to 156 until the 28th, which shows that the AGB / RM crosslinking

technology (molecular action) does not start immediately after compaction, but in about 3 days thereafter, and very quickly increases the CBR index of the material from CBR 30 to CBR 156, an increase of 538%. And, from a baseline CBR of 26 on day 1 to a CBR of 156 on day 28, demonstrating a 600% increase.

**Dry density evolution curve over time**

FIG. 11 describes the change in the dry density of the material treated during the curing time in dry air.

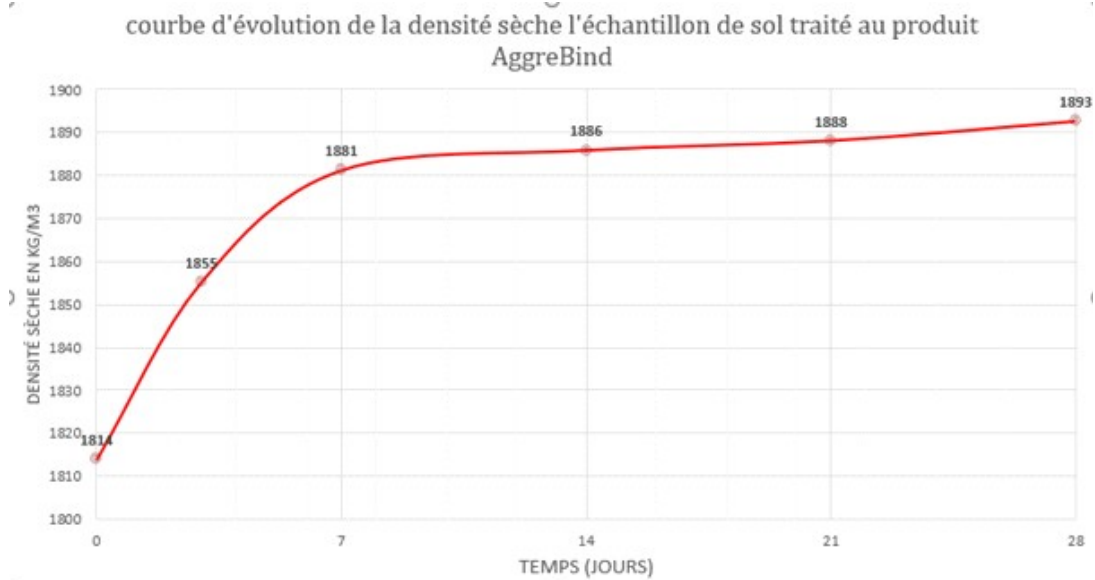


Figure 11. Dry density evolution curve as a function of time

Figure 11 shows an increasing change in the dry density of the material treated up to day 7 and a slowing of growth between day 7 and day 28. This slowing down of growth proves that the material treated is approaching its dry density; optimal after treatment of the soil, reaching a value well above the maximum dry density of natural soil. Thus, on the 28th day, the dry density reached is 1893 kg / m<sup>3</sup>, which corresponds to a compactness rate of 100.2% for a CBR test carried out at 95% of the compaction energy around the modified Proctor optimum (OPM).

**Evolution curve of the water content as a function of time**

The water content is variable since the treated material is dried in dry air and at constant temperature, it will therefore be necessary to study its behavior over time through figure 12.



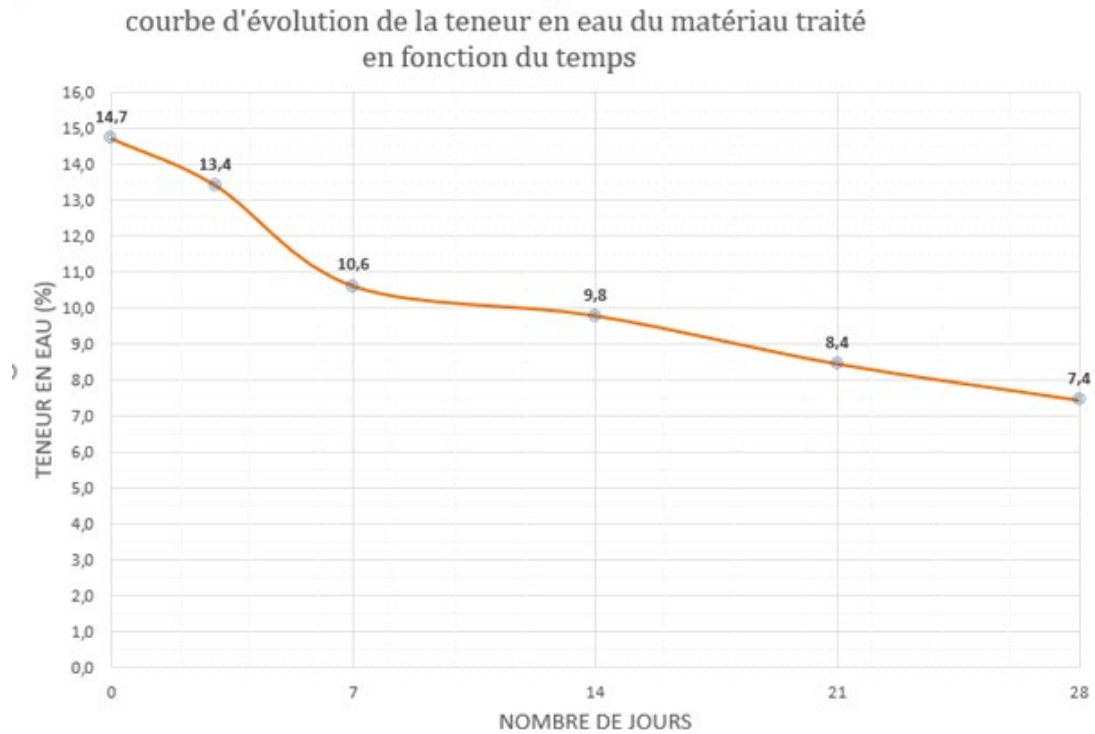


Figure 12. Evolution curve of the water content of the treated material as a function of time

Figure 12 shows a slight decrease in water content (1.3%) within 3 days after compaction and a rapid decrease in water content (2.8%) between the 3rd and 7th day after compaction. It can be assumed that the crosslinking of the AGB / RM, which started on the 3rd day caused dehydration of the material which had the consequence of accelerating the decrease in the water content of the latter.

The decrease in the water content becomes progressive again between the 7th and the 21st day, which shows that the molecular reactions of the AGB / RM product with the soil gradually fades and gives way to natural dehydration of the material by the air. As the moisture is dehydrated, the chemical reaction (crosslinking) of AggreBind / RoadMaster increases, thus increasing the CBR over the 28-day test period.

**Minimum quality requirements for the characteristics of the layers making up the pavement**

Treating the soil with the AggreBind / RoadMaster product increased our material's CBR rating from 26/30 to 156 in 28 days, moving it from the S4 road soil class to the S5 road soil class. It is possible to assess the use of our treated material on the pavement by Table 8.

Table 8. Minimum quality requirements for the characteristics of the layers making up the pavement.

Couches de chaussées	Granularité	Indice de plasticité P	Limite de Liquidité	CBR	Gonflement linéaire	Pourcentage de fines	Spécification
Plateforme		<40	<70	>2	<2%		dépend de la nature du sol et ne dépend pas du trafic. Et pour les sols devant être traités à la chaux, ciment ou au bitume
Couche de forme	<150mm	<30		<5 ou ≥10	<2%	<35% ou 45%	
Couche de fondations	≤60mm	<30		≥30 ou 25 pour le trafic T1	<2,5%	<50%	
Couche de base	≤50mm	<30		≥80 ou 60 pour le trafic T1	<2%	<40%	

This table shows that the granular distribution of the soil, the plasticity index, the linear swelling and the CBR index of the soil obtained after treatment with the AGB / RM product meet the minimum quality requirements for use on all soil / pavement layers and for all types of traffic.

## CONCLUSION

The study showed that the treatment of clay silts for use in pavement layers is possible with the AggreBind/ RoadMaster product because the product increases the soils' mechanical characteristics. The soil sample used is a u5n class A-4 (2) clayey loam with low plastics processing whose Proctor characteristics modified at 95% of the OPM are 15% for the optimum water content, 1890 Kg / m<sup>3</sup> for the maximum dryness density and its immediate CBR index and after immersion are respectively 30 and 26.

The present research was limited to improving the CBR bearing capacity of the soil, as it represents the use of the soil in the different pavement layers. This treatment with the AggreBind / RoadMaster product increases the load bearing capacity of the soil by more than 520% in 28 days (i.e., 600%), thus allowing the use of clay silts on all layers of the pavement, while respecting certain conditions for the load-bearing capacity required for use as a base layer which can thus replace crushed gravel on road construction sites.

## Author Contributions

Conceptualization, CDBN, and RDF; methodology, BN and MM; validation, CDBN, MM and RDF; formal analysis, CDBN, BN and MM; investigation, CDBN and BN; data curation, CDBN and MM; writing original draft preparation, CDBN; All authors contributed in the revision of the manuscript and approved the final version of the manuscript prior to submission.

**Acknowledgements:** The authors would like to thank all the staff of the laboratory of the National Polytechnic School of the University of Yaoundé1 and all the staff of the laboratory of the National Advanced School of Public Work, Yaoundé, Cameroon.

**Conflicts of Interest:** The authors declare no conflict of interest.

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