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Determination of Secant Moduli of Agbelouve Silty Sand Stabilized With Cement Used as a Roadway Layer in Togo

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***Abstract:** The soil stabilization use is necessary in the presence of lesser quality soils. This stabilization has the effect of modifying the soils properties, in particular the strain modulus. For road dimensioning using rational method, it is necessary to know secant modulus of the soil which is not often done in Togo. In this paper, it is determined the secant modulus at different ages of silty sand stabilized with cement at different rates. For this, specimen of silty sand stabilized with cement at rates of 2.5; 3.5 and 4.5% are subjected to the Modified Proctor test and measurement of compressive strength with strain measurement to estimate the modulus at 7, 28, 60 and 90 days of age. The results show that moduli increase with age and cement rate. From different correlations, we estimate the dimensioning modulus of Agbélouvé silty sand stabilized with cement. These estimated moduli allow saying that the cement rate studied are satisfactory from the modulus viewpoint. This study completes the information on Togolese materials needed for road dimensioning by rational methods.*

***Keywords:** cement stabilization, dimensioning modulus, secant modulus, silty sand, strain.*

I. INTRODUCTION

Stabilization is a soil improvement technique that consists of a mixture of this soil and hydraulic binder (cement and / or lime) or clay or hydrocarbon binder (bitumen) to improve this soil performance with its behavior modification: the soil becomes more or less long term semi-rigid [1]–[3]. It is often considered in the presence of soils with characteristics lower than those required by the specifications. This improvement is increasingly being considered in Togo because of the increasing scarcity of good quality natural materials.

For road dimensioning by rational methods (through ALIZE software for example), in addition to traffic data, length of life and supporting soil bearing, it is necessary to know borrow materials characteristic like: tensile strength, CBR index, fatigue resistance and modulus [4]. Information on Togolese materials characteristics is scarce and the limited information available concern only tensile strength and CBR index but not modulus. To evaluate modulus, the relationship (1) given below by the pavement design guide for tropical countries [4] is often used:

$$E = K \times CBR \quad (1)$$

Where E is the dimensioning modulus
K is a coefficient between 5 and 10 and usually taken as 5
CBR is the CBR index after 4 days of immersion**.**
In this work, it is envisaged the strain modulus determination of Agbélouvé silty sand stabilized with 2.5; 3.5 and 4.5% cement (dosage commonly used in Togo).

II. MATERIALS AND METHOD

The silty sand used in this study is taken from Agbélouvé quarry, located 60km north of Lomé, the capital of Togo. The binder used is CPJ35 cement from CIMTOGO of Togo. Table I and Fig. 1 show silty sand identification tests results. The material contents 13% of fines and its sand gleichwert is 28. It can be used as a sub-base course (CBR> 5) or as a base course for light traffic (CBR> 25) [4].

Table- I: Studied silty sand characteristics

Passed-by ≤ 80µm (%)	Passed-by ≤ 2mm (%)	Sand gleichwert with Piston	Proctor optimum density (g/cm^3)	Proctor optimum water content (%)	CBR at 4 days of imbibition (95% OPM)
13	100	28	2,00	5,8	26

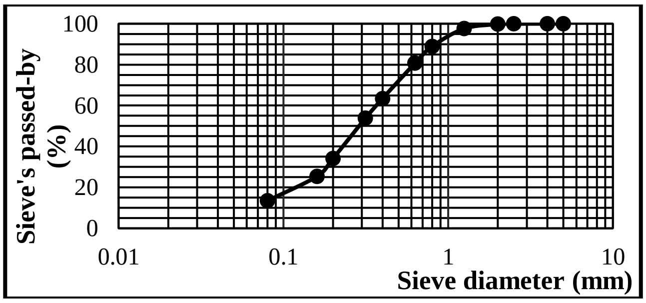

Fig. 1.Studied silty sand grading curve

To achieve our objective, we proceeded to the cement mass variation compared to the silty sand dry mass at rates of 2.5%, 3.5% and 4.5%.

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Then, we determine the compaction optimal water content by the Proctor test Modified according to standard NF P 94-093 [5] and the compressive stress with strain measurement according to standard NF EN 13286-41 [6]. From these measurements, we determine the moduli [6]–[8].
The simple compression tests were carried out using a semi-automatic CBR press at a speed of 1.27 mm / min (Fig. 2) on cylindrical specimens with a height of 12.75 cm and a diameter of 15.2. cm is a slenderness of 0.84. The test piece is placed between the piston of the press whose lower plate is movable. The piston of the press being about 5 cm in diameter, a rigid disk is placed on the upper face of the test piece to evenly distribute the force over its entire surface. A torque ring with a capacity of 100 kN is used to measure the compressive force by means of the Ring Force-strain calibration curve. Comparator microphones graduated to 1/100 mm are fixed on the press moving plate to measure the longitudinal displacement of the test specimen. The test is stopped when the force measured by the sensor has decreased by at least 10% of the greatest measured force. This makes sure that we have gone to the test piece break. Throughout this test, displacement is read on the comparator placed on specimen surface.

Fig. 2.Device of the compression test

The strain is the ratio between displacement and specimen height measured before the test and the stress is determined by making the ratio between the applied force and the specimen surface S:

$$\varepsilon = d/h \quad (2)$$

$$\sigma = F/S \quad (3)$$

Where d denotes displacement (mm)
h, specimen height (mm)
Ɛ, strain (dimensionless)
F, applied force (N)
S, specimen surface of the test piece (mm^2)
σ, stress (MPa).
In order to make a comparative study between the different moduli used by finite element calculation software to characterize the stiffness of the material, we have chosen to determine 4 types of moduli:
• The secant modulus at 30% of the breaking load
• The secant modulus at 50% of the breaking load
• The secant modulus at break
• The maximum modulus.
The secant moduli at 30% and at 50% of the breaking load are respectively given by the following formulas:

$$E_{30} = 0.3\,\sigma_c/\varepsilon_{30} \quad (4)$$

$$E_{50} = 0.5\,\sigma_c/\varepsilon_{50} \quad (5)$$

Where σ_c denotes breaking stress (MPa)
$Ɛ_{30}$ and $Ɛ_{50}$, the deformations corresponding to 30% and 50% of the breaking load read on the stress-strain curve
E_{30} and E_{50}, respectively, strain moduli at 30% and 50% of the breaking load (MPa)
The secant modulus at break is defined as the slope of the line connecting the origin to the ordinate point σc. It is given by the following formula:

$$E = \sigma_c/\varepsilon_C \quad (6)$$

Where σ_c denotes breaking stress (MPa)
$Ɛ_c$, strain at break
E, strain modulus at break (MPa).
The maximum modulus is determined by following the line of greatest slope of the stress-strain curve as illustrated in Fig. 3.

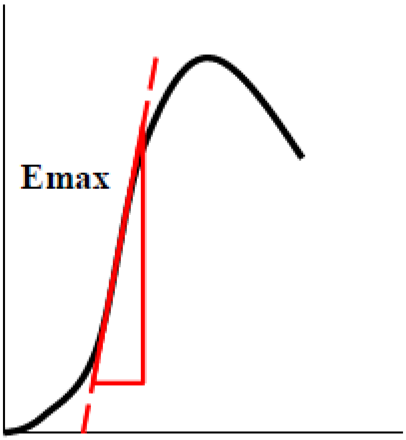

Fig. 3.Maximum modulus determination method

The tests are performed on specimen at 7, 28, 60 and 90 days of age. The stabilized materials are kept for 7 days in a plastic film and the rest of the time at ambient temperature in the room [6].

III. RESULTS AND DISCUSSIONS

Table II presents the results of Modified Proctor tests performed on stabilized silty sand. There is a slight increase in water content and optimum density depending on the cement content. Indeed, Proctor's optimum density increases with cement content of $2.05g/cm^3$ for 2.5% cement at $2.08g/cm^3$ for 3.5 and 4.5% cement, as well as in optimal water production (Table II). It is at these respective water contents that the specimens are manufactured for the mechanical tests.

Table- II: Results of the Proctor test on silty sand stabilized at different cement rates

Cement rate (%)	Proctor optimum density (g/cm^3)	Proctor optimum water content (%)
2.5	2.05	5.9
3.5	2.08	6.0
4.5	2.08	6.1

The strain and stress tests results are presented in Tables III to VI. Each result is the average of three values.

Table- III: Strain and stress at 7 days of age according to cement rate

Cement rate: 2.5%		Cement rate: 3.5%		Cement rate: 4.5%	
Strain (10^{-6})	Stress (MPa)	Strain (10^{-6})	Stress (MPa)	Strain (10^{-6})	Stress (MPa)
0	0,0000	0,0000	0,0000	0,0000	0,0000
1,96	0,1320	19,600	0,0953	19,600	0,1027
3,92	0,3080	39,200	0,3887	39,200	0,4327
5,88	0,4547	58,800	0,7490	58,800	0,9617
7,84	0,6977	78,400	10,057	78,400	13,283
9,80	0,8793	98,000	13,430	98,000	17,617
10,51	10,000	117,600	16,510	117,600	20,183
		145,867	20,867	137,300	23,720
				147,050	27,550

Table- IV: Strain and stress at 28 days of age according to cement rate

Cement rate: 2.5%		Cement rate: 3.5%		Cement rate: 4.5%	
Strain (10^{-6})	Stress (MPa)	Strain (10^{-6})	Stress (MPa)	Strain (10^{-6})	Stress (MPa)
0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
0,2000	0,0880	0,2000	0,1173	0,2000	0,1540
0,3900	0,1907	0,3900	0,2420	0,3900	0,3007
0,5900	0,3153	0,5900	0,3813	0,5900	0,4693
0,7800	0,4547	0,7800	0,5503	0,7800	0,6903
0,9800	0,6093	0,9800	0,7490	0,9800	0,9543
11,800	0,7417	11,800	0,9763	11,800	12,110
13,700	0,9030	13,700	12,110	13,700	14,530
15,700	10,717	15,700	14,310	15,700	17,030
17,600	12,623	17,600	16,663	17,600	19,747
19,600	14,457	19,600	19,307	19,600	22,533
21,967	16,577	21,600	22,167	21,600	25,173
23,500	17,185	23,500	25,173	23,500	27,817
25,500	17,180	25,500	27,593	25,500	31,050
27,500	18,300	27,500	30,243	27,500	34,130
		29,400	32,517	29,400	36,697
		31,400	34,790	31,400	39,340
		33,300	36,403	33,300	42,060
		35,300	37,650	35,300	44,773
		37,300	38,603	37,300	46,387
		39,200	40,137	39,200	47,840
		40,400	41,200	41,200	49,100
				43,100	50,640
				45,100	52,050

Table- V: Strain and stress at 60 days of age according to cement rate

Cement rate: 2.5%		Cement rate: 3.5%		Cement rate: 4.5%	
Strain (10^{-6})	Stress (MPa)	Strain (10^{-6})	Stress (MPa)	Strain (10^{-6})	Stress (MPa)
0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
0,2000	0,0953	0,2000	0,1247	0,2000	0,1467
0,3900	0,2053	0,3900	0,2567	0,3900	0,2713
0,5900	0,3520	0,5900	0,4327	0,5900	0,4620
0,7800	0,5283	0,7800	0,6683	0,7800	0,7417
0,9800	0,6973	0,9800	0,9177	0,9800	10,497
11,800	0,9030	11,800	12,110	11,800	13,797
13,700	11,010	13,700	15,853	13,700	17,840
15,700	13,210	15,700	19,380	15,700	21,213
17,600	15,340	17,600	22,680	17,600	24,293
19,600	17,617	19,600	26,057	19,600	27,743
21,600	19,890	21,600	28,847	21,600	31,123
23,500	22,167	23,500	32,150	23,500	34,277
25,500	23,853	25,500	34,863	25,500	39,267
27,500	24,750	27,500	37,430	27,500	42,427
29,400	26,900	29,400	40,443	29,400	45,873
		31,400	42,647	31,400	48,953
		33,300	45,800	33,300	51,673
		35,300	48,293	35,300	54,683
		37,300	50,867	37,300	57,543
		39,467	53,787	39,200	59,593
		40,800	55,065	41,333	61,723
		41,600	56,675		

Table- VI: Strain and stress at 90 days of age according to cement rate

Cement rate: 2.5%		Cement rate: 3.5%		Cement rate: 4.5%	
Strain (10^{-6})	Stress (MPa)	Strain (10^{-6})	Stress (MPa)	Strain (10^{-6})	Stress (MPa)
0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
0,2000	0,1247	0,2000	0,1393	0,2000	0,1540
0,3900	0,3007	0,3900	0,3667	0,3900	0,3887
0,5900	0,5280	0,5900	0,6093	0,5900	0,7270
0,7800	0,8297	0,7800	0,9763	0,7800	11,817
0,9800	11,010	0,9800	14,090	0,9800	16,807
11,800	14,677	11,800	18,717	11,800	22,533
13,700	19,087	13,700	23,927	13,700	28,700
15,700	23,120	15,700	29,947	15,700	35,230
17,600	28,110	17,600	35,450	17,600	41,250
19,600	32,150	19,600	40,590	19,600	46,827
21,600	34,727	21,600	45,947	21,600	51,747
23,233	36,163	23,500	50,717	23,500	55,930
24,300	37,430	25,500	55,123	25,500	59,820
		27,500	59,523	27,500	63,857
		29,400	62,753	29,400	67,307
		31,400	65,987	31,400	70,533
		33,300	69,653	33,300	73,543
		35,300	72,957	35,300	76,557
		36,500	73,985	36,767	78,610
				39,200	80,370

From the results of Tables III to VI, we plot the stress-strain curves (Fig. 4 to 7) for each mixture and at each age to determine the different secant moduli.

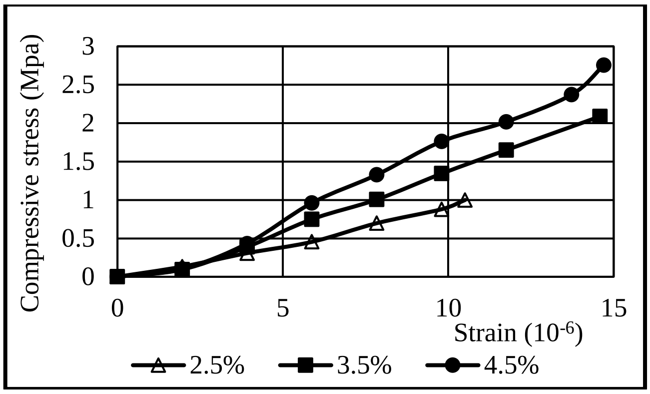

Fig. 4.Stress - strain curve at 7 days

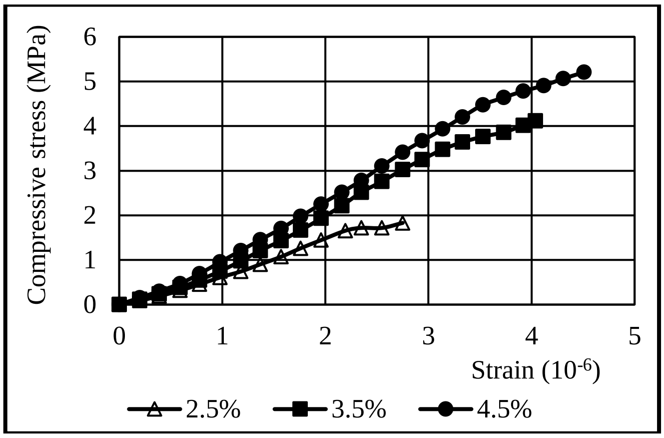

Fig. 5.Stress - strain curve at 28 days

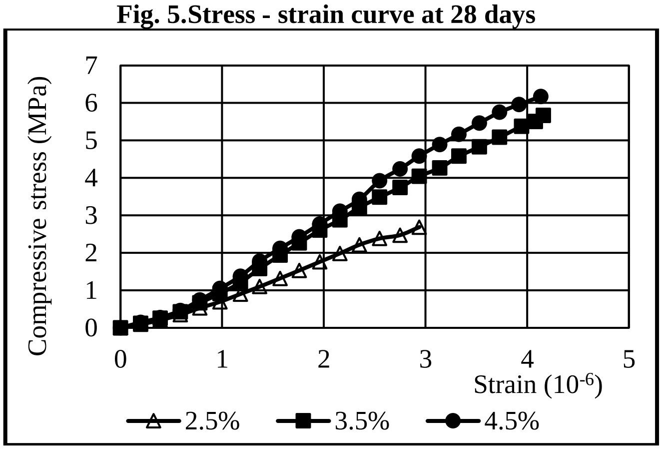

Fig. 6.Stress - strain curve at 60 days

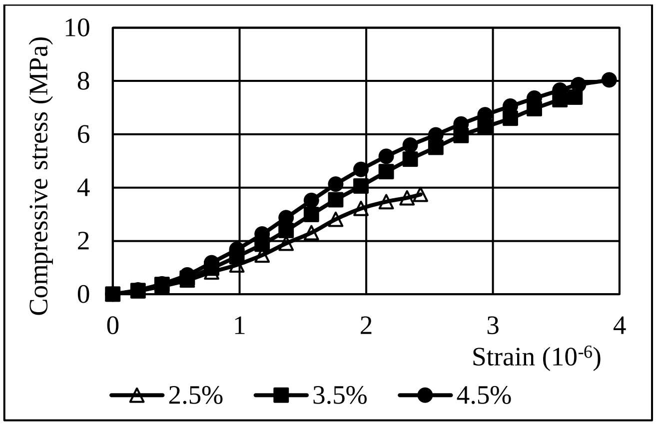

Fig. 7.Stress - strain curve at 90 days

The moduli calculation results are presented in Table VII.

Table- VII: Secant moduli according to age and cement rate

Age (days)	Cement rate (%)	Secant modulus at 30% of the breaking load (MPa)	Secant modulus at 50% of the breaking load (MPa)	Secant modulus at break (MPa)	Maximum modulus (MPa)
7	2.5	80	81	95	122
	3.5	119	130	143	210
	4.5	161	184	189	247
28	2.5	614	662	742	923
	3.5	904	1011	1026	1327
	4.5	1056	1171	1182	1536
60	2.5	737	853	952	1091
	3.5	1183	1348	1368	1739
	4.5	1328	1428	1494	1876
90	2.5	1138	1376	1554	2298
	3.5	1718	2040	2055	2795
	4.5	1972	2316	2108	3193

From this table, we deduce, for each age, the variation curves of the moduli according to the cement rate illustrated in Fig. 8 to 11.

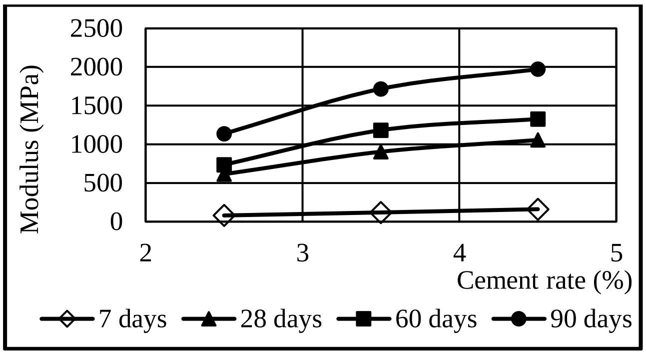

Fig. 8.Secant modulus at 30% of breaking load evolution as a cement rate function

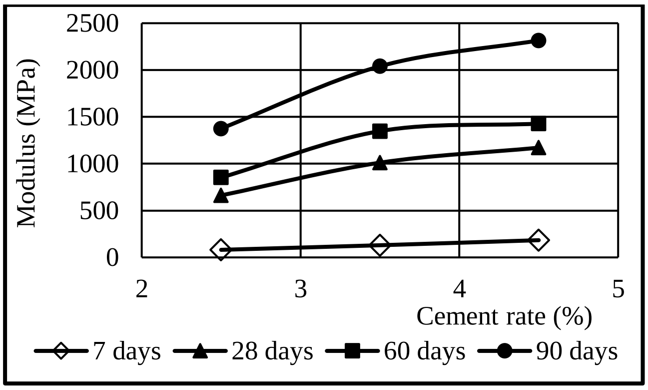

Fig. 9.Secant modulus at 50% of breaking load evolution as a cement rate function

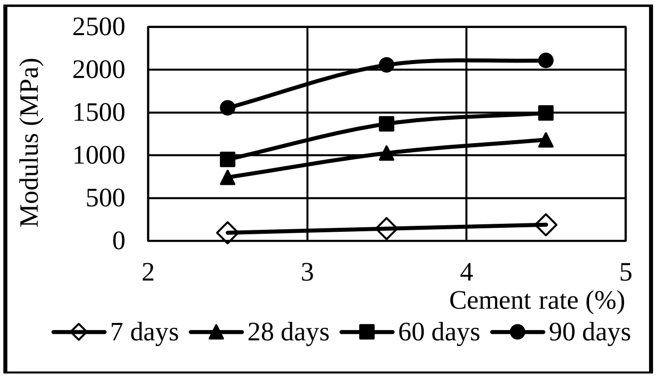

Fig. 10. Secant modulus at break evolution as a cement rate function

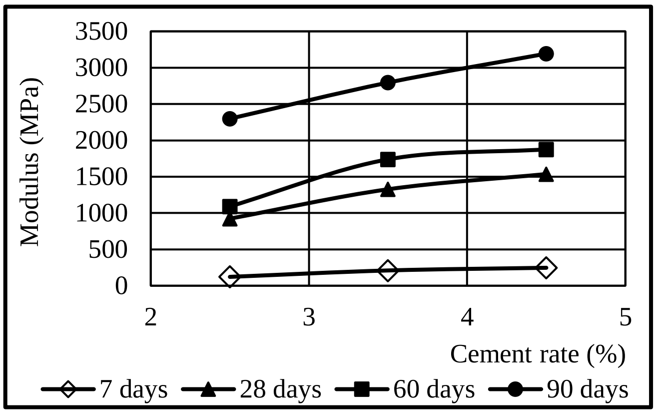

Fig. 11. Maximum modulus evolution as a cement rate function

In Fig. 8 to 11, it is noted that moduli increase with the cement dosage:

- for moduli at 30% of the breaking load, the increase for the 3.5% dosage compared to the 2.5% dosage is of the order of 47% to 61% while the increase for the 4.5% dosage compared to the dosage of 3.5% is in the range of 12% to 36%;
- the increase of moduli at 50% of the breaking load for the 3.5% dosage compared to the 2.5% dosage is of the order of 48% to 61% whereas that of specimens dosed at 4.5% relative to the test pieces at 3.5% is in the range of 6 to 41%;
- the gain for the modulus at break of specimens dosed at 3.5% with respect to specimens dosed at 2.5% is of the order of 32% to 50% while that of specimens dosed at 4.5% with respect to specimens dosed at 3.5% is in the range of 3% to 32%;
- the maximum modulus of specimens dosed at 3.5% with respect to specimens dosed at 2.5% increases is of the order of 22% to 73% whereas that of specimens dosed at 4.5% with respect to specimens dosed at 3.5% has an increase between 8% and 18%.

These results show that at the same age, despite the same variation rate of cement (1%), the rate of moduli increase between specimens stabilized at 3.5% compared to those stabilized at 2.5% is significantly higher than the rate of moduli increase between specimens stabilized at 4.5% compared with those stabilized at 3.5%: this can be explained by the fact that the dry manufacture density of specimens stabilized at 3.5% is closer to that of specimens stabilized at 4.5% than that of specimens stabilized at 2.5%.

From Table VII, we plot in Figures 12 to 15, for each cement dosage, moduli variation curves as a function of age.

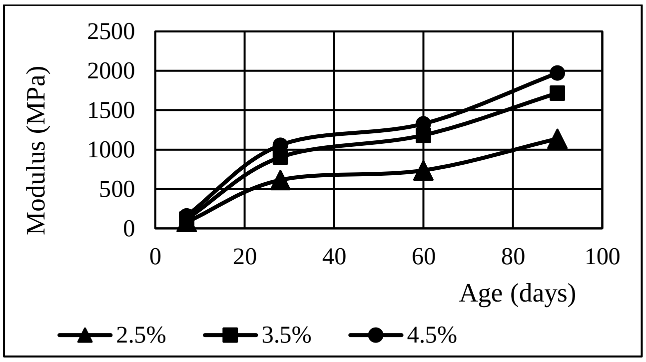

Fig. 12. Secant modulus at 30% of breaking load evolution as a function of age

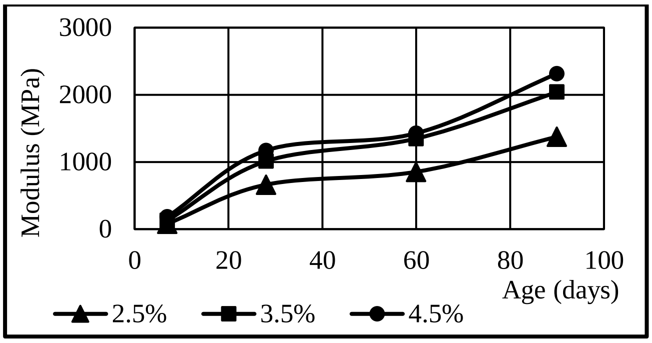

Fig. 13. Secant modulus at 50% of breaking load evolution as a function of age

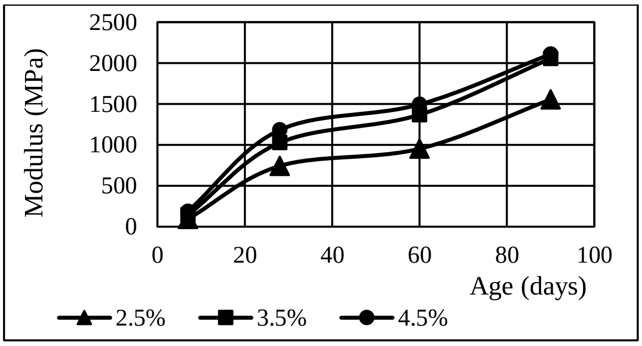

Fig. 14. Secant modulus at break evolution as a function of age

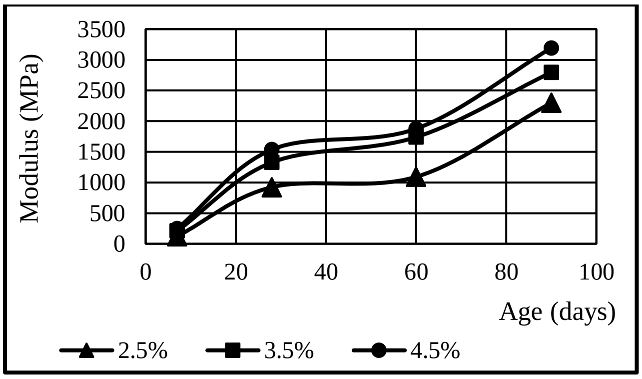

Fig. 15. Maximum modulus evolution as a function of age

Moduli values recorded at 7 days are very low; this is explained by a fairly large deformation obtained and certainly due to a rather slow hardening during the phenomenon of cement setting.

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There is a rapid increase in modulus between 7 and 28 days (more than 5 times the modulus at 7 days) which is explained by an increase in resistance following the phenomenon of setting and hardening of the cement which is almost complete at 28 days. This also explains the fact that beyond 28 days the rate of modulus increase is relatively low:

- indeed, between 7 and 28 days and depending on the dosage there is an increase in the modulus at 30% of breaking load of the order of 555% to 670% whereas it is 20% to 31% between 28 and 60 days and from 45% to 55% between 60 and 90 days;
- between 7 and 28 days and depending on the dosage there is an increase in the modulus at 50% of breaking load of the order of 536% to 715% while it is 22% to 33% between 28 and 60 days and 52% to 62% between 60 and 90 days;
- between 7 and 28 days and depending on the dosage there is an increase in the modulus at break of the order of 525% to 681% while it is 27% to 33% between 28 and 60 days and 41% to 63% between 60 and 90 days;
- between 7 and 28 days and depending on the dosage, there is an increase of the maximum modulus of the order of 522% to 659% whereas it is 18% to 31% between 28 and 60 days and from 60% to 111% between 60 and 90 days.

The modulus of elasticity offers many advantages over other index values, such as the AASHTO layer coefficients and the California Bearing Index (CBR), because it directly influences the analytical models used to predict the state of constraints. The modulus values used in pavement design will be deducted from the average values at 360 days. If values are not available at 360 days, the SETRA pavement design and dimensioning guide (LCPC-SETRA, 1994) proposes the following formula for sands-cement allowing to obtain the 360-day modulus from the at 90-days modulus [4]:

$$E_{90}/E_{360} = 0.93 \quad (8)$$

From the 360-day modulus, the modulus to be used in pavement design is given, for sand-cements, by [4]:

$$E_{dim} = 0.75E_{360} \quad (9)$$

The modulus used in (9) is the 360-days modulus at 30% of breaking load.

Applying (8) and (9), we obtain Table VIII from data in Table VII. We compare obtained dimensioning moduli to the minimum value of the dimensioning modulus requested in the road projects. In fact, for the materials stabilized with cement, a minimum value of CBR = 160 [4] is requested that is means a dimensioning modulus of 800 MPa by application (1).

Table- VIII.360-day and dimensioning moduli

Cement rate (%)	90-days modulus at 30% of breaking load (MPa)	360-days modulus at 30% of breaking load (MPa)	Dimensioning modulus (MPa)
2.5	1138	1223	917
3.5	1718	1847	1385
4.5	1972	2120	1590

Note that dimensioning moduli obtained for the different rates are higher than the estimated minimum, which means that the cement rate studied are satisfactory from the modulus viewpoint.

IV. CONCLUSION

The study of the stabilized cemented Agbelouve silty sand presented in this paper consisted in the determination of the modulus at different ages up to 90 days. The objective is the determination of the modulus to be used in the design of roadway by the rational method, in particular via Alize software. For materials used in Togo, this modulus is estimated by empirical formulas that may lead to design errors. For this purpose, the compressive stresses and the strains were determined on specimen made in CBR molds which allowed the determination of moduli at 30% of breaking load, 50% of breaking load and at break and the maximum modulus. From the modulus at 30% of breaking load, the modulus to be used for the design of the pavement layers is determined.

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