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Avlamè Lateritic Aggregate Stabilised with Cement, Technical Characteristics and Possibilities of Use in Road Construction

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Abstract

Benin, like many African countries south of the Sahara, has lateritic gravel that does not meet the technical specifications required for use in road bases. In fact, recourse to quarries with lower quality materials, such as the lateritic quarry of Avlamè, is felt with the exhaustion of good quality materials. Faced with this situation, it is important to enhance the value of the Avlamè lateritic aggregate by the cement stabilisation technique with a view to its use in the base layer of pavements in Benin. Thus, an experimental study on the lateritic aggregate of Avlamè with different cement dosages was carried out according to the standards in road construction. This characterization allowed to highlight the mechanical properties of the lateritic aggregate treated with cement at different dosages. The most important results are obtained with the dosage of 4.50% cement. These are dry density 2.34 t/m^3, plasticity index 8.98%, yield strength 27.33%, CBR 221.33%, direct tensile strength 0.28 MPa, compressive strength 4.30 MPa and secant modulus 1531.71 MPa all obtained at 95% of the modified Proctor optimum. Using the strength adjustment curves, the 6.50% cement content gives a direct tensile strength of 0.51 MPa against a compressive strength of 15.10 MPa and a secant modulus of 2163.36 MPa. These results show that Avlamè lateritic aggregate can be used as a base course for semi-rigid pavements when it is stabilised at a cement content of at least 6.50% in accordance with the specifications of the CEBTP 1984 guide and revised in 2019.

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Keywords

Avlamè lateritic gravel, Semi-rigid pavement, CBR index, Direct tensile strength.

Introduction

The construction of roads requires the use of large quantities of materials. Typical materials used include laterite, silty soil and granitic crushed stone. Among these, lateritic gravels are the most used because they are generally available at lower cost with good technical characteristics (Ahouet *et al.,* 2018; Ahouétohou *et al.,* 2020; Elenga *et al.,* 2019; Houanou *et al.,* 2022; Zolfeghari Far *et al.,* 2013). In 2009, studies carried out by the Centre National d'Essais et de Recherches des Travaux Publics (CNERTP) revealed that lateritic gravel is the most widely used material for road construction and asphalting in Benin.

This heavy exploitation leads to the depletion of the good quality lateritic aggregate. Similarly, Biswal *et al.,* (2018) found that sources of good quality aggregates are running out by the day in many parts of the world. Faced with this situation, the reserves of lateritic gravels of low technical characteristics that were previously abandoned are now being used (Babaliye, 2020; Kanazoé, 2011). Sometimes some materials are used either as sub-base or base course for paved roads or as wearing course for unpaved roads. This is the case of the lateritic gravel of Avlamè where it can be used only as a sub-base (Houanou *et al.*, 2022 under press). Thus, it is important to improve their technical characteristics according to the requirements of current road construction standards (Babaliye, 2020; Biswal *et al.*, 2016; Consoli *et al.*, 2021a; Disfani *et al.*, 2014; Liebenberg and Visser, 2003).

Several techniques for improving the technical characteristics of lateritic gravel for use in road construction, such as stabilisation with hydraulic binders, litho-stabilisation or stabilisation with plant products, are well documented in the literature (Agbede and Joel, 2011; Ahouet *et al.*, 2018; Biswal *et al.*, 2018; Caro *et al.*, 2018; Consoli *et al.*, 2021b; Fall *et al.*, 2008; Issiakou, 2016; Mengue *et al.*, 2017a; Ndiaye *et al.*, 2013; Portelinha *et al.*, 2012; Ratsifarehandahy *et al.*,).

These different methods were discussed in terms of their effectiveness, advantages and disadvantages. They can be used in soil stabilisation, particularly for road construction. However, some non-traditional and environmentally friendly stabilisers cannot be replaced. For example, some bio-cementation methods such as microbe-induced calcium carbonate precipitation (MICP) and enzyme-induced calcium carbonate precipitation (EICP) are environmentally desirable (Hasriana *et al.*, 2018; Islam *et al.*, 2020; Nafisi *et al.*, 2020; Sharma and Ramkrishnan, 2016). In addition, studies by Rahman *et al.*, (2020) have shown that microbe-induced calcium carbonate precipitation to stabilise high volumes of earthworks generates more C02 than using cement as a stabiliser.

As a result, cement could still be considered an effective stabilising agent in the construction of road infrastructure, which is a major consumer of earthworks materials (Al-Jabban *et al.*, 2017). In 2019, Al-Jabban *et al.*, in their research showed the effectiveness of cement in improving the engineering properties of fine-grained soils compared to Petrit-T, a by-product obtained from the manufacture of sponge iron. Although studies have been carried out to determine the optimum type of cement for stabilisation of materials for low-traffic roads according to normative requirements, few studies that have addressed the quantities of cement to be used have led to divergent results. Faced with this situation, it is important to enhance the value of the lateritic aggregate of Avlamè by the cement stabilisation technique with a view to its use in the base layer of pavements in Benin.

Materials and Methods

In this study, the materials used are lateritic gravel and cement

Lateritic aggregate

The lateritic gravel, which is the subject of this study, comes from the village of Dèmè in the arrondissement of Avlamè, commune of Zogbodomey. Located in the southern part of the Abomey plateau, the commune of Zogbodomè (Department of Zou) is bordered to the north by the communes of Bohicon and Zakpota, to the south by the communes of Toffo and Zè (Atlantic Department) and the commune of Lalo (Couffo Department), to the east by the communes of Covè, Zagnanado and Ouinhi (Zou Department) and to the west by the commune of Agbangnizoun (Zou Department).It lies between 6°56' and 7°08' North latitude, 1°58' and 2°24' East longitude. (See figure 1 below).

This lateritic gravel of Avlamè, according to the results of the studies conducted by Houanou *et al.*, (2022), is only suitable for use as sub-base.These technical characteristics are listed in Table 1.

Cement

The cement used is CEM II /B-LL 32.5 R (CPJ 35) as shown in figure 2. Its chemical composition, physical and mechanical characteristics, including compressive stress, are given in Tables 2, 3 and 4 respectively.

The equipment used for the work falls into two categories depending on whether it is for geotechnical or mechanical testing.

Experimental setup for geotechnical tests

The experimental set-up required for geotechnical testing of cement-treated lateritic gravel is in accordance with the following standards:

- NF P94-050, (1995). “Soils: investigation and tests, determination of the water content by weight of materials, steaming method”.

- NF P94-051, (1993). "Soils: reconnaissance and tests, determination of Atterberg limits: limit of liquid to the cup - limit of plasticity to the roller".

- NF P94-093, (1999). "Soils: reconnaissance and tests, determination of the compaction references of a material: normal Proctor test-Modified Proctor test".

- NF P94-078, (1997). "Soils: reconnaissance and tests, CBR index after immersion-Immediate CBR index-Immediate Bearing Index.

Experimental device for the production of the test pieces

The experimental device required for the preparation of specimens of cement-treated lateritic gravel complies with standard NF EN 13286-53 (2005) on mixtures treated and untreated with hydraulic binders - Part 53: method of preparation by axial compression of specimens of materials treated with hydraulic binders.

Within the framework of the present study, the press used is a PROVITEQ automatic electromechanical double screw multi-press machine with a capacity of 300 kN. Its adjustable displacement loading speed ranges from 10µm/min to 100mm/min (Figure 3 (a)).The additional accessories to the multi-press required to produce the test specimens are shown in Figure 3 (b).

Experimental device for mechanical tests

The experimental set-up required to perform the mechanical tests is in accordance with the following standards:

- NF EN 13286-42 2003relative to unbound and hydraulically bound mixtures-Part42: Test method for the determination of the indirect tensile strength of hydraulically bound mixtures(Figure 4 (a)) ;

- NF EN 13286-40: 2003 relative to unbound and hydraulically bound mixtures - Part 40: test method for the determination of the direct tensile strength of hydraulically bound mixtures.

- NF EN 13286-41: 2003 relative to unbound and hydraulically bound mixture – Part 41: Test method for the determination of compressive strength of hydraulically bound mixtures. (Figure 4 (b)) ;

- NF EN 13286-43 2003 relative to unbound and hydraulically bound mixtures - Part 43: Test method for the determination of the modulus of elasticity of hydraulically bound mixtures. (Figure 4 (c)).

Method of sampling lateritic aggregate

Samples of the lateritic aggregate were taken in accordance with standard XP P94-202: 1995, then air-dried in the laboratory before the actual tests were conducted.

Method of formulation

Seven steps are required for the formulation of lateritic aggregate /cement mixtures. They are listed below:

Step 1: Dry the lateritic aggregate samples in an oven at 50°C for 2 hours or in the air for a suitable time at room temperature.

Step 2: Define the different cement percentages empirically, for example: 2.0%, 2.5%, 3.0%, 3.5%, 4.0% and 4.50%. These percentages may be higher.

Step 3: Calculate the quantities of each mixture (lateritic aggregate and cement) according to the type of test.

Step 4: Determine the water content of the laterite aggregate.

Step 5: Take the quantities required for each type of test to be carried out.

Step 6: Mix manually to prevent grain size change in a short time.

Step 7: Pack the collected quantities of material in airtight plastic bags or self-closing polythene bags to keep the water content constant.

Geotechnical test method

The various geotechnical testing methods are carried out in accordance with the standards cited in § 2.2.1.

Method of making up the test pieces

The preparation of test specimens is regulated by standard NF EN 13286-53 (2005) cited in § 2.2.2.

Mechanical test method

The various mechanical tests are performed in accordance with the standards cited in § 2.2.3.

Results and Discussion

Geotechnical tests on cement-treated Avlamè lateritic gravel

The results of the Atterberg limit test are shown in Figure 5 below.

The analysis of Figure 5 shows that:

The liquidity limit drops with the increase of the cement dosage. For example, it drops from 34.33% for raw lateritic aggregate to 27.66% for a treatment with 4.50% cement. These values are all lower than the CEBTP (1984) specifications for both the sub-base and the base course (Figure 6). In other words, they comply with the CEBTP requirement for the liquid limit.

The results indicate that cement dosage significantly alters the geotechnical properties of lateritic gravels (Hamouche and Zentar, 2016). It is noted that this decrease is linear. It results in a good bearing capacity of the material (NF P 94 057). These results are confirmed by Dabou *et al.,* (2021); Do *et al.*, (2021); Dauda *et al.*, (2018) and Oluwasola *et al.*, (2020).

The plasticity limit increases with the cement dosage. It increases from 17.00% for raw lateritic gravel to 18.68% for a 4.50% treatment (Figure 7). However, a decrease of the plasticity limit is noted when the cement dosage is 2.50% and a stability of the values from 4.00%.

These values provide information on the behaviour of the material. These results show that the cement dosage significantly modifies the behaviour of lateritic gravels. They are similar and in perfect agreement with the results found by Dabou *et al.*, (2021); Do *et al.*, (2021); Oluwasola *et al.*, (2020); Caro *et al.*, (2018); Dauda *et al.*, (2018); Jerez *et al.*, (2018); Mengue *et al.*, (2017b).

The plasticity index decreases with the addition of cement (Figure 8). Indeed, the value of the plasticity index observed for raw lateritic gravel, i.e. 17.33%, decreases to 8.98% for a lateritic gravel stabilised with 4.50% cement. All these values are lower than 30%, in accordance with CEBTP requirements for sub-base layers. As for the base courses, these values are in conformity with the CEBTP requirements for cement dosages above 2.00% (CEBTP 1984 and the one revised in 2019). These results are similar to those found by Dabou *et al.*, (2021); Do *et al.*, (2021); Buritatum *et al.*, (2021); Oluwasola *et al.*, (2020); Caro *et al.*, (2018); Jerez *et al.*, (2018) and Mengue *et al.*, (2017) and Portelinha *et al.*, (2012).

Mechanical tests on the lateritic gravel of Avlamè, raw or treated with cement

Modified Proctor and CBR tests

The results of the modified Proctor test performed on the raw and cement-treated Avlamè lateritic aggregate samples are presented in Figure 9 (a).

The analysis of figure 9 (a) shows that the dry density of the Modified Proctor Optimum increases with the cement dosage. In other words, the dry density varies from 2.16 t/m3 for the raw lateritic aggregate to 2.34 t/m3 for the lateritic aggregate stabilised with 4.50% cement.

This is a variation of 8.33%. These different values are higher than 2.0 t/m3 according to the requirements of CEBTP 1984 revised 2019 concerning materials to be used in base courses. In fact, the addition of cement made it possible to increase the density of the lateritic aggregate (Figure 9 (b)). These results are in line with the work done by Dabou *et al.*, (2021); Do *et al.*, (2021); Buritatum *et al.*, (2021); Oluwasola *et al.*, (2020) and Caro *et al.*, (2018).

Figure 10 (a) shows the results of the CBR test carried out on the raw and cement-treated Avlamè laterite aggregate samples.

Figure 10 shows the progressive evolution of the CBR index after soaking as a function of the cement dosage. To illustrate, the CBR value obtained for raw lateritic aggregate, i.e. 58.00%, is multiplied by 3.8, i.e. 221.33%, when the lateritic aggregate is stabilised at 4.50% cement (Figure 10 (a)). From these results, it can be seen that this gravel can only be used as a base course from 3.50% cement (Figure 10 (b)). This trend in CBR is consistent with the work conducted by Maichin *et al.*, (2021) ; Mengue *et al.*, (2018) ; Portelinha *et al.*, (2012) ; Wahab *et al.*, (2021) ; Biswal *et al.*, (2018) and Joel and Agbede (2011). Only the stabilisation of the Avlamè lateritic aggregate with cement allows its characteristics to be raised for use as a base course (CEBTP 1984 reviewed in 2019).

Direct and indirect tensile strength

Figure 11 shows the development of the direct tensile strength as a function of the cement content. The direct tensile strength increases with the cement content and the curing time. For example, considering a curing time of 7 days, the direct tensile strength of the raw Avlamè lateritic gravel, i.e. 0.03 MPa, increased to 0.03 MPa, 0.07 MPa, 0.80 MPa, 0.10 MPa, 0.13 MPa and 0.28 MPa respectively for cement dosages of 2.0%, 2.50%, 3.00%, 3.50%, 4.00% and 4.50% of cement (Figure 10). It is noted that these values remain below the recommended threshold (> 0.30 MPa) for base courses by the CBTP 1984 and the 2019 threshold for the dosages targeted in this study (2.00% to 4.5%).

The analysis of figure 11 shows that the direct tensile strength develops exponentially. This trend is the same for the indirect tensile strength, as according to EN 13286-40 there is a linear relationship between it and the direct tensile strength.

Using the curve of direct tensile strength versus cement dosage for the 7-day cure, it was noted that the strength of 0.3 MPa is achieved for a cement dosage of 5.44%. Therefore, a cement dosage of 5.50% of the lateritic gravel of Avlamè would allow to obtain a direct tensile strength higher than 0.30 MPa, i.e. 0.31 MPa.

Compressive strength

Figure 12 shows the evolution of the compressive strength according to the cement dosage. This strength increases with the cement dosage and the curing time.

For example, at 7 days of curing time, the compressive strength of the raw Avlamè lateritic aggregate, i.e. 0.14 MPa, increased to 0.64 MPa, 1.25 MPa, 1.32 MPa, 1.60 MPa, 1.94 MPa and 4.30 MPa respectively for cement dosages of 2.0%, 2.50%, 3.00%, 3.50%, 4.00% and 4.50% cement (Figure 12). These results are in agreement with those obtained by Hareru *et al.*, (2022); Wahab *et al.*, (2021); Wang *et al.*, (2022); Latifi *et al.*, (2016); Oluwasola *et al.*, (2018); Sharma and Ramkrishnan (2016).

The compressive strength evolves exponentially with the cement dosage, regardless of the curing time (7 days, 28 days, 60 days and 360 days). This observed trend is similar to the work conducted by Agbede and Joel (2011); Ikhlef (2015); Leroy *et al.*, (2018); Louafi and Bahar (2018); Mengue *et al.*, (2018, 2017b).

In accordance with CEBTP requirements, the value of the compressive strength at 7 days of curing must be between 1.80 MPa and 3.00 MPa for a cement stabilised gravel. Within the framework of the present work, only the dosages of 3.50% and 4.00% in cement give respectively a compressive strength of 1.94 MPa and 2.59 MPa, which values respect the criteria of the CEBTP, (1984). Similar results were obtained by Mengue *et al.*, (2018).

This increase would be due to the increase of the maximum dry density and the decrease of the optimum moisture content (see § 3.3.1.).

Secant modulus

Figure 13 shows the evolution of the secant modulus as a function of the cement dosage. This modulus increases with the increase of the cement dosage and of the curing time. As an illustration, the secant modulus at 7 days of the raw lateritic aggregate of Avlamè, i.e. 88.33 MPa, increased:

- to 268.00 MPa for a cement dosage of 2.00%, i.e. an increase of about 303%.

- 280.00 MPa for a cement content of 2.50%, i.e. an increase of approximately 317%.

- 382.00 MPa for a cement proportioning of 3.00%, i.e. an increase of approximately 432%.

- 412.00 MPa for a cement proportioning of 3.50%, i.e. an increase of approximately 466%.

- 567.00 MPa for a cement proportioning of 4.00%, i.e. an increase of approximately 642% and

- 725.12 MPa for a cement content of 4.50%, an increase of approximately 821%.

The secant modulus changes exponentially with the cement dosage, regardless of the curing time (7 days, 28 days, 60 days and 360 days).

In accordance with the requirements of CEBTP 2019, the value of the secant modulus is taken at 360 days for the design of pavements. Thus, the values obtained at 360 days for cement dosages of 2.0%, 2.50%, 3.00%, 3.50%, 4.00% and 4.50% of cement respectively are as follows 652.85 MPa, 692.68 MPa, 725.61 MPa, 823.17 MPa, 879.27 MPa and 1531.71 MPa.

Table.1 Technical characteristics of the Avlamè lateritic aggregate used

Lateritic aggregate		Mean	Standard deviation
Particle size analysis	Dmax (mm)	31,50	0,00
	2mm (%)	35,67	6,03
	0,08mm (%)	27,77	4,04
AtterbergLimits	WL	35,00	1,00
	WP	17,33	0,58
	IP	17,67	0,58
Methylene blue value		0,21	0,02
Organicmatter		0,33	0,03
Dry density	γd (g/cm3)	2,20	0,26
Water content at Modified Proctor Optimum	*ωOPM*(%)	7,50	0,30
Dry density at Modified Proctor Optimum	γOPM (g/cm3)	2,17	0,17
CBR index after 96h soaking	*95%* OPM	61,00	1,00
	100% OPM	99,33	0,58
Indirectetensilestrength	360 days	0,14	0,00
Directe tensilestrength	361 days	0,11	0,00
Simple compressive strength	362 days	1,13	0,09
Secantmodulus	363 days	331,71	20,52

Table.2 Chemical composition

Designation	Values (%)
SiO_2	14.16
Al_2O_3	5.10
Fe_2O_3	2.61
CaO	60.55
MgO	1.76
SO_3grav	2.50
Insoluble residue	1.40
Loss on fire	9.85

Source: NOCIBE (2012)

Table.3 Physical characteristics

Designation	Values
Apparent density	1.073
Density (g/cm^3)	3.01
Initial setting	3h05
Final setting	4h39
Specific surface (Blaine) (cm^2/g)	3155
Expansion (mm)	1.50
Refuse on sieve 0,08	10.92
Refuse on sieve0,16	0.80

Source: NOCIBE (2012)

Table.4 Mechanic characteristics

Age (jours)	Compressive strength (bar)
2	132
7	242
28	330

Source: NOCIBE (2012)

Table.5 Summary of the mechanical parameters of Avlamè lateritic aggregate treated with cement according to the CEBTP 1984 guide revised in 2019 (Base layer)

Cement dosage	$I_{CBR-4days}$ (%)		$Rc_{7\ days}$ (MPa)		$Rt_{-7\ days}$ (MPa)		$E_{50\ 360\ days}$(MPa)		Observation
	Obtained	Required	Obtained	Required	Obtained	Required	Obtained	Required	
0.00%	58,00	>160	0.14	$1.8 \leq R_c \leq 3.0$	0.03	> 0.3	331.71	> 2000	Unable
2.00%	76,67	>160	0.64	$1.8 \leq R_c \leq 3.0$	0.03	> 0.3	652.85	> 2000	Unable
2.50%	96,67	>160	1.25	$1.8 \leq R_c \leq 3.0$	0.07	> 0.3	692.68	> 2000	Unable
3.00%	134,00	>160	1.32	$1.8 \leq R_c \leq 3.0$	0.08	> 0.3	725.61	> 2000	Unable
3.50%	169,33	>160	1.60	$1.8 \leq R_c \leq 3.0$	0.10	> 0.3	823.17	> 2000	Unable
4.00%	193,23	>160	1.94	$1.8 \leq R_c \leq 3.0$	0.13	> 0.3	879.27	> 2000	Unable
4.50%	221,33	>160	4.30	$1.8 \leq R_c \leq 3.0$	0.28	> 0.3	1531.71	> 2000	Unable
5.00%	251,38	>160	5.25	$1.8 \leq R_c \leq 3.0$	0.24	> 0.3	1402.33	> 2000	Unable
5.50%	281,33	>160	7.46	$1.8 \leq R_c \leq 3.0$	0.31	> 0.3	1620.35	> 2000	Unable
6.00%	311,28	>160	10.62	$1.8 \leq R_c \leq 3.0$	0.40	> 0.3	1872.27	> 2000	Unable
6.50%	341,24	>160	15.10	$1.8 \leq R_c \leq 3.0$	0.51	> 0.3	2163.36	> 2000	Able

Table.6 Summary of the mechanical parameters of Avlamè lateritic aggregate treated with cement according to the CEBTP 1984 guide revised in 2019 (Foundation layer)

Cement dosage	$I_{CBR-4days}$ (%)		$Rc_{7\ days}$ (MPa)		$Rt_{-7\ days}$ (MPa)		$E_{50\ 360\ days}$(MPa)		Observation
	Obtained	Required	Obtained	Required	Obtained	Required	Obtained	Required	
3.00%	134,00	>80	1.32	>0.25	0.08	-	725.61	-	Able
3.50%	169,33	>80	1.60	>0.25	0.10	-	823.17	-	Able
4.00%	193,23	>80	1.94	>0.25	0.13	-	879.27	-	Able
4.50%	221,33	>80	4.30	>0.25	0.28	-	1531.71	-	Able
5.00%	251,38	>80	5.25	>0.25	0.24	-	1402.33	-	Able
5.50%	281,33	>80	7.46	>0.25	0.31	-	1620.35	-	Able
6.00%	311,28	>80	10.62	>0.25	0.40	-	1872.27	-	Able
6.50%	341,24	>80	15.10	>0.25	0.51	-	2163.36	-	Able

Fig.1 Location of the quarry of Avlamè

(a) Benin map
Source : https://www.google.com

(b) Natural lateritic aggregate of Avlamè

(c) Location of the sampling site in the commune of Zogbodomey
Source : INSAE (2017)

Fig.2 Type of cement (CEM II /B-LL 32.5 R)

Fig.3 Equipment for the production of compressed specimens

(a) Multi-press machine

(b) : Accessories

Fig.4 Experimental device for the determination of mechanical parameters

(a) Splitting device for the indirect tensile strength test

(b) Device for the compressive strength test

(c) Secant modulus test setup for measuring displacements and strains

Fig.5 Atterberg limits of Avlamè lateritic aggregate treated with cement

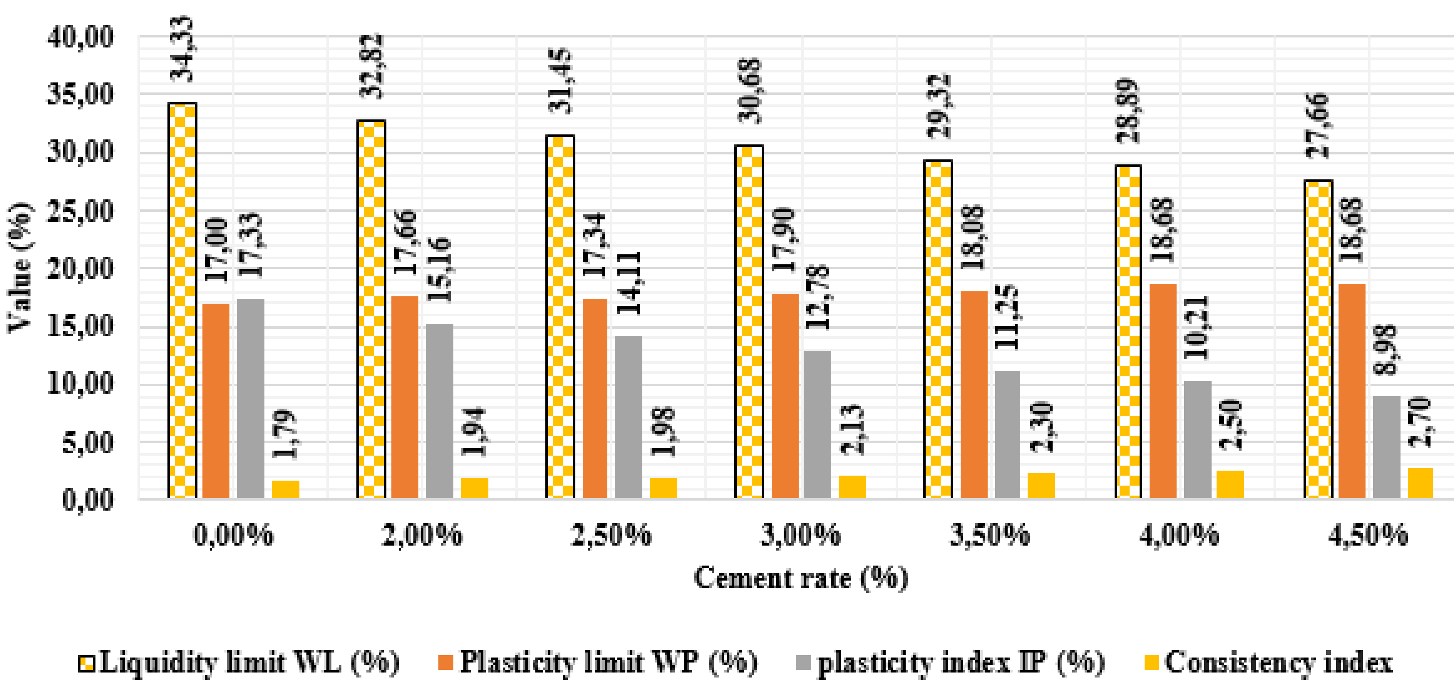


Fig.6 Liquidity limit of Avlamè lateritic aggregate treated with cement

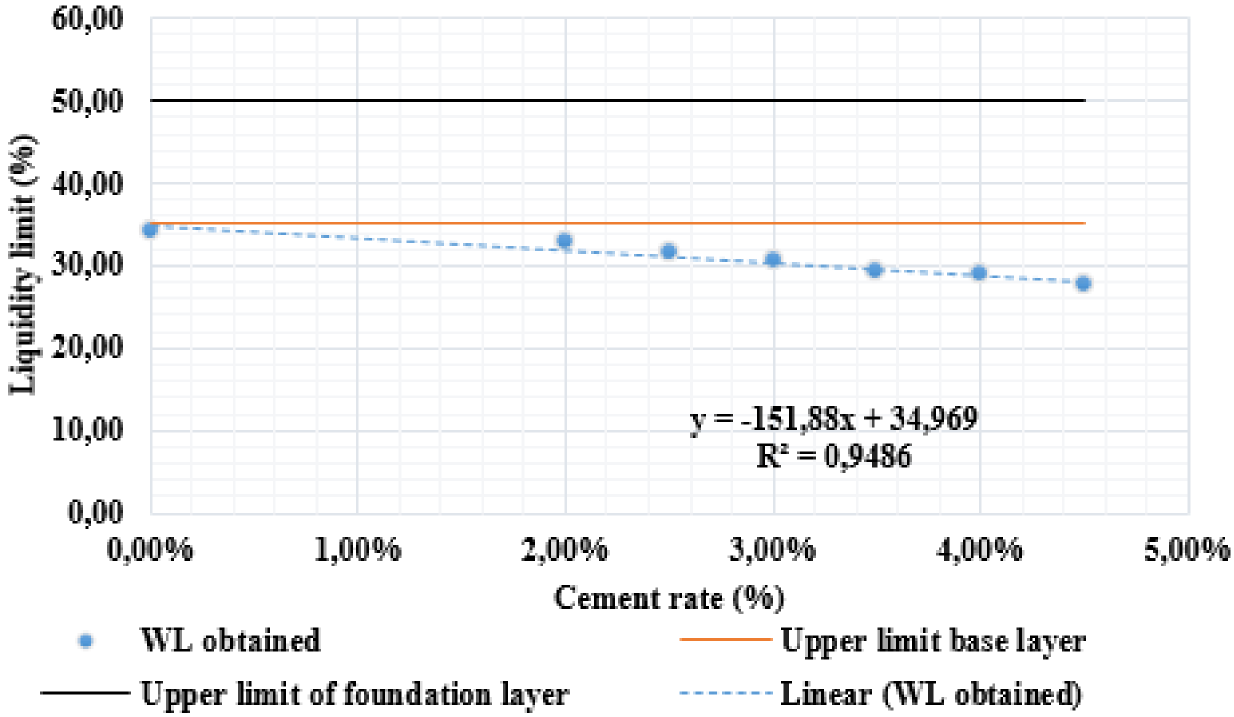


Fig.7 Plasticity limit of Avlamè lateritic aggregate treated with cement

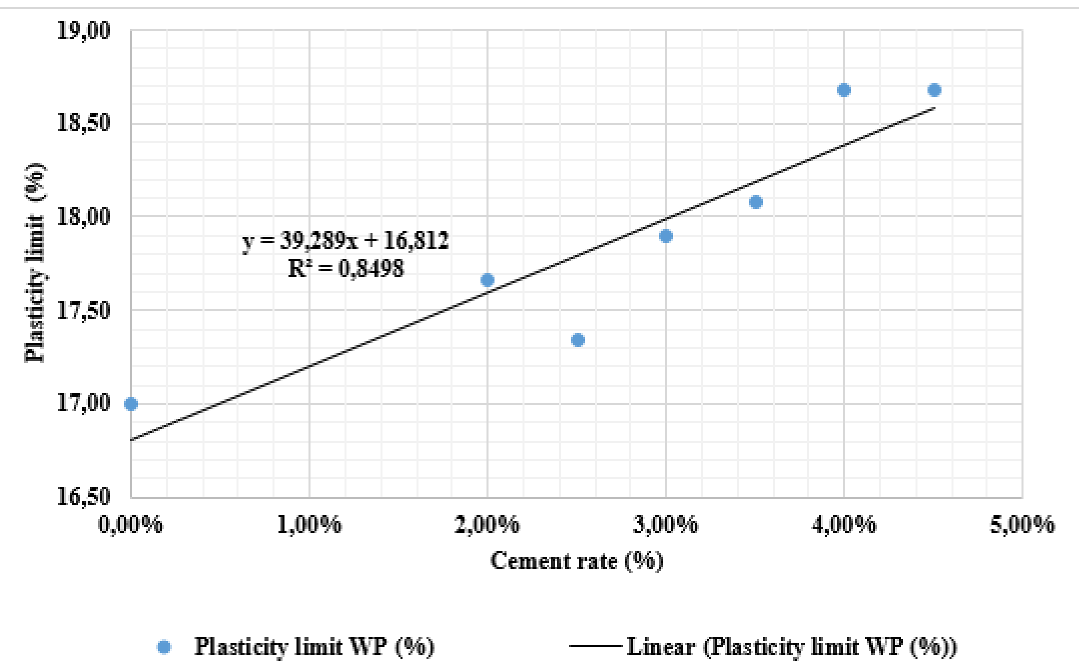


Fig.8 Plasticity index of Avlamè lateritic aggregate treated with cement

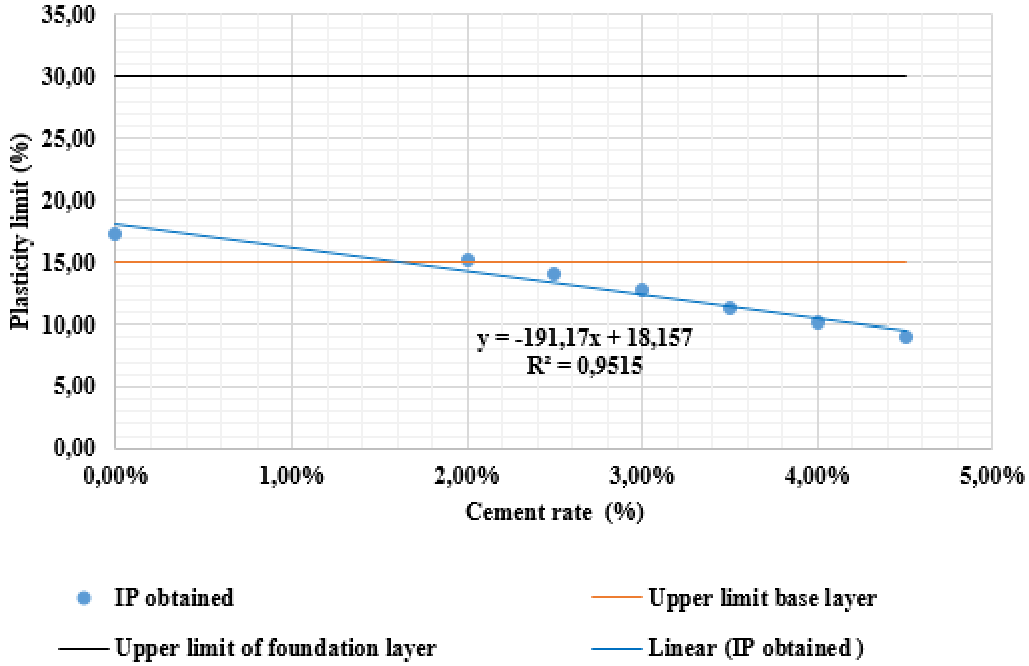
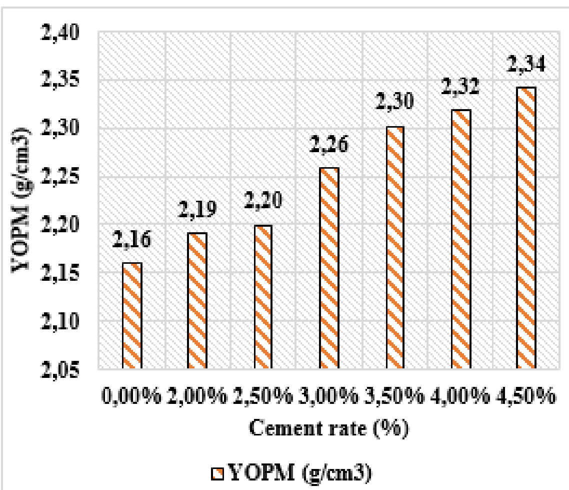
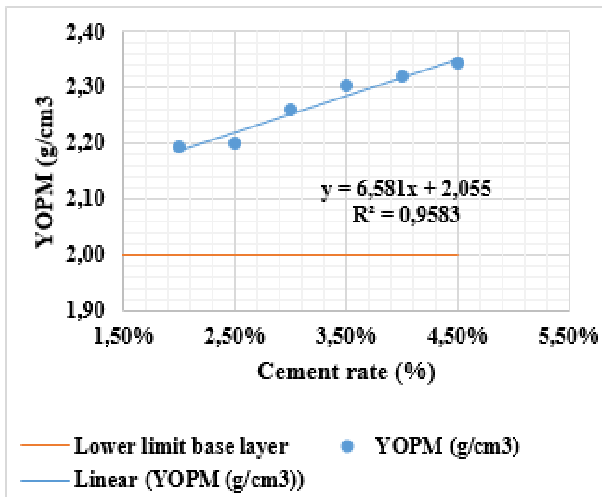


Fig.9 Dry density at OPM of the lateritic aggregate of Avlamè, raw or treated with cement

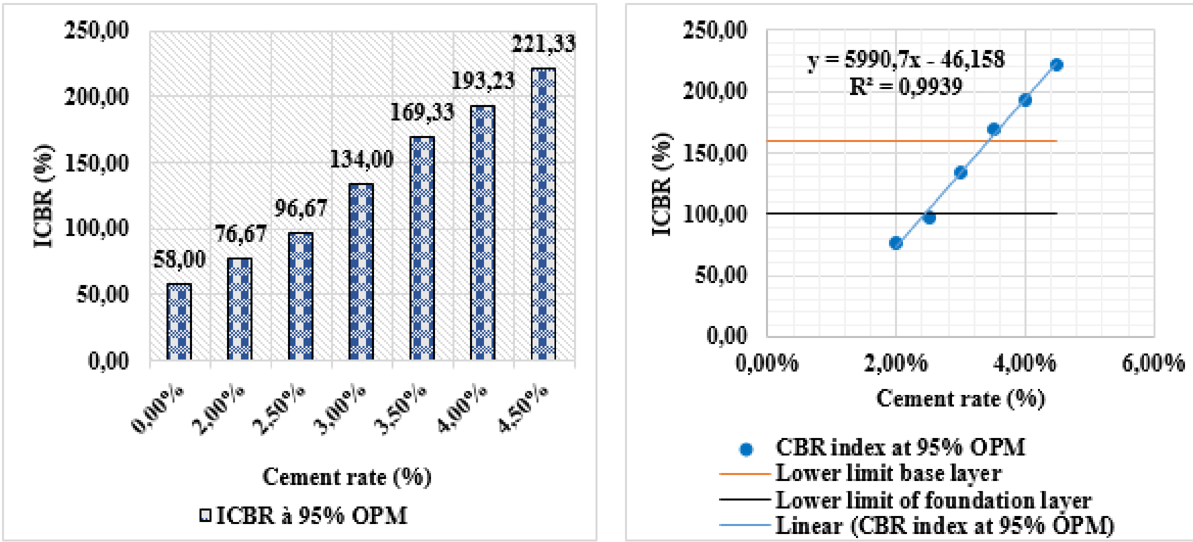


(a) Variation of the dry density of lateritic aggregate of Avlamè, raw or treated with cement



(b) Influence of the dry density of lateritic aggregate of Avlamè treated with cement

Fig.10 CBR index at 95% OPM of the lateritic gravel of Avlamè, raw or treated with cement



(a) Variation of the CBR index at 95% OPM of the lateritic gravel of Avlamè, raw or treated with cement

(b) Influence of the CBR index at 95% OPM of the lateritic gravel of Avlamè treated with cement

Fig.11 Evolution of the direct tensile strength of lateritic aggregate, raw or cement-treated

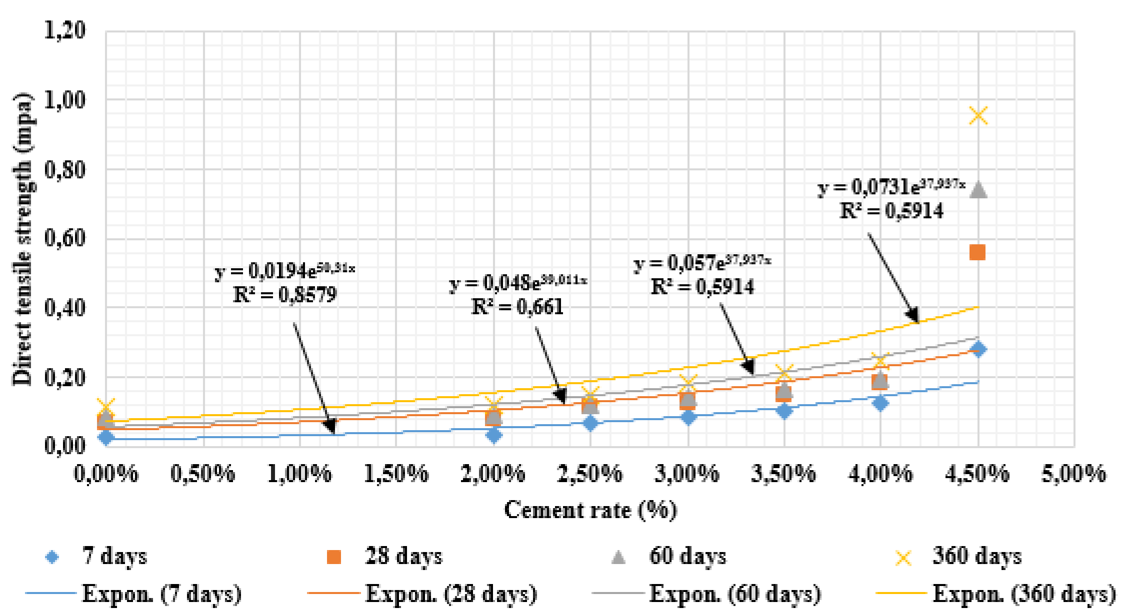


Fig.12 Evolution of the compressive strength of lateritic aggregate of Avlamè depending on the cement content

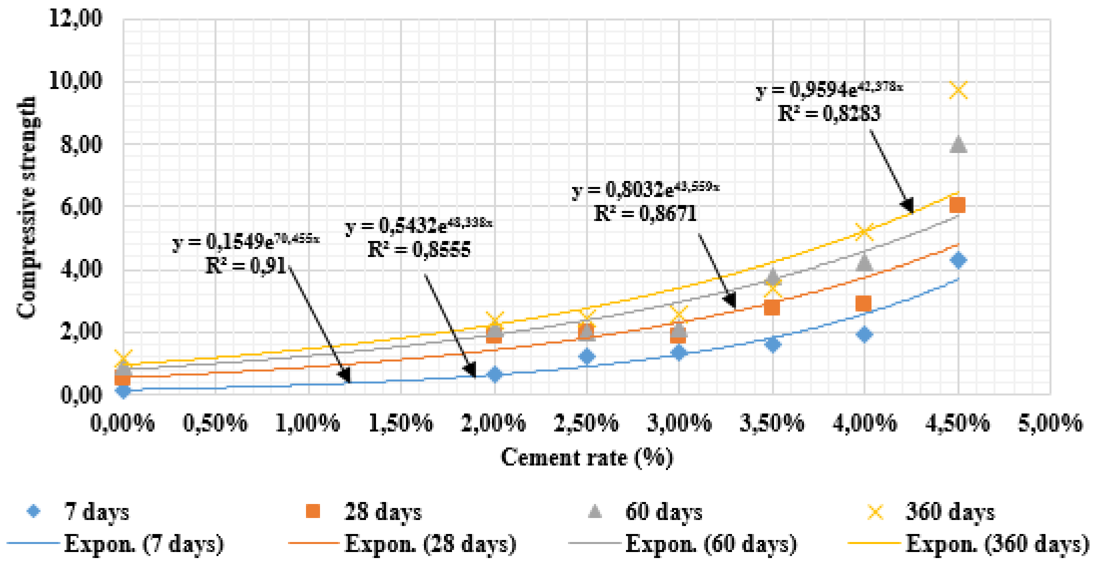
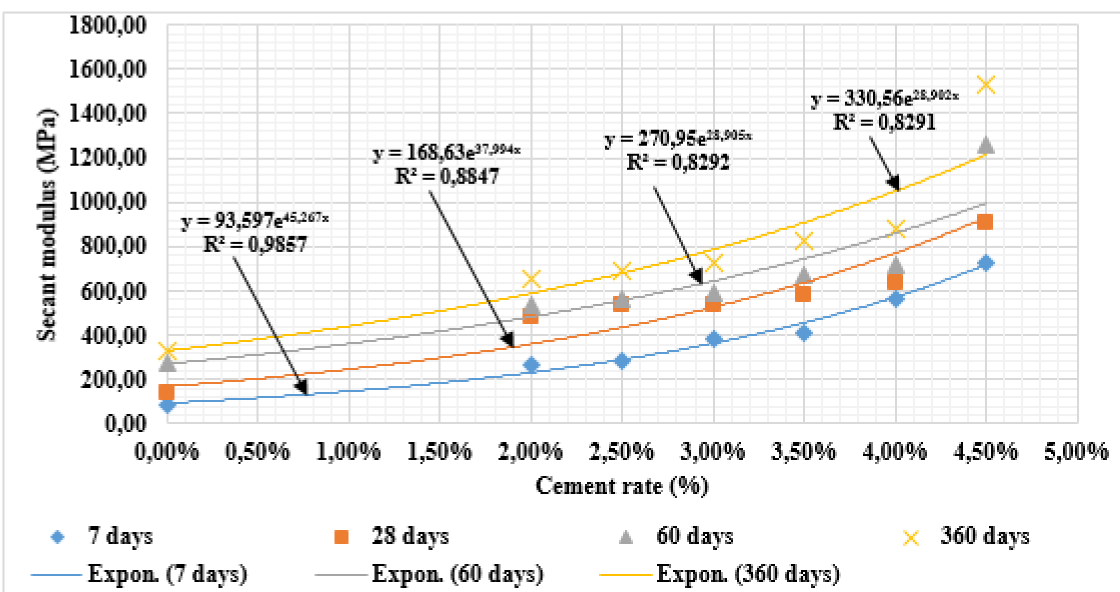


Fig.13 Evolution of the secant modulus of lateritic aggregate of Avlamè depending on the cement content



All these values are lower than 2000 MPa, the reference value of the CEBTP guide (2019). Therefore, these materials cannot be used as a base course for the studied cement dosages. Using the curve of adjustment of the secant modulus according to the cement dosage for the 360 days cure, it was noted that the secant modulus of 2000 MPa is reached for a cement dosage of 6.23%. Therefore, a cement dosage of 6.50% of the lateritic gravel of Avlamè would allow to obtain a secant modulus higher than 2000 MPa, that is 2163.36 MPa

In sum, Table 5 summarises the results of the analysis of the cement-treated Avlamè lateritic gravel with respect to the recommendations of the CBTP 1984 and 2019 guides.

From the analysis of this table, it appears that in accordance with the CEBTP 1984 guide revised in 2019, cement-treated Avlamè lateritic gravel cannot be used as a base course from 6.50% cement dosage. Indeed, it is noted that the compressive strength of the Avlamè lateritic gravel at 7 days is higher than 3.0 MPa.

However, cement-stabilised lateritic gravels with dosages ranging from 3.00% to 6.50% can be used as a sub-base for semi-rigid pavements according to the criteria of the CEBTP 1984 guide revised in 2019 (see Table 6). The present study was initiated to determine the quantity of cement to be used for the stabilisation of the lateritic aggregate of Avlamè for its use in the base layer of pavements.
The present study was initiated to determine the quantity of cement to be used for the stabilisation of the lateritic aggregate of Avlamè for its use in the base course of pavements.

Empirically, formulations were carried out at different dosages as follows: 2.0%, 2.5%, 3.0%, 3.5%, 4.0% and 4.5%.Thus, the results obtained from the road material characterisation tests led to the following conclusions:

- The plasticity index of Avlamè lateritic aggregate decreases with increasing cement dosage.

- The maximum dry density of Avlamè lateritic aggregate increases with the cement dosage.

- The CBR index of the Avlamè lateritic aggregate increases proportionally to the cement dosage.
- The indirect and direct tensile strength of Avlamè lateritic aggregate increases with the cement dosage and the maturation time.

- The compressive strength of Avlamè lateritic aggregate increases with the cement dosage and the curing time.

- The secant modulus of Avlamè lateritic aggregate increases with the cement dosage and the curing time.

- Avlamè lateritic aggregate cannot be used as a base course for flexible pavements in a stabilised or improved state.
The lateritic aggregate of Avlamè can be used as a sub-base for semi-rigid pavements when it is stabilised to a cement content of at least 6.50% in accordance with the specifications of the CEBTP guide 1984 and revised in 2019.

However, cement-stabilised lateritic aggregate with dosages ranging from 3.00% to 6.50% can be used as a sub-base for semi-rigid pavements according to the criteria of the CEBTP 1984 guide revised in 2019 (see Table 6).

Consequently, it is imperative to explore other techniques for improving the technical characteristics, for example lithostabilisation, of Avlamè lateritic aggregate for use in the base course of flexible pavements.

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