UNIVERSITÉ DE CERGY-PONTOISE

MASTER THESIS

"PHYSICAL AND MECHANICAL CHARACTERISTICS OF SOILCRETE: THE INFLUENCE OF CEMENT CONTENT AND CLAY INCLUSIONS"

Supervisors of L2MGC: Anne-Lise BEAUCOUR, Assoc. Prof. PhD Eng.

Javad ESLAMI, Assoc. Prof. PhD Eng.

Olivier HELSON, MSc. Eng., PhD Candidate

Carlo PELLEGRINO, Assoc. Prof. PhD Eng.

Liliana Tadio

2014-2015

Sommary

List of Figure

List of Tables

Chapter 1_ INTRODUCTION

1.1 BACKGROUND

With an exponential growth in the world population over the last decades, there is high demand for new territory on which to develop new infrastructures, commercial and residential areas. Also the infrastructures built in the 20th century need to be upgraded to accommodate to the new technologies like faster trains, wider motorways or to be repaired after special events like floods, landslides, explosions, earth quakes. The soil mixing is a cost effective, ecofriendly and durable soil improvement method which is the answer to the previous remarks.

The soil treatment called soil- mixing, consists in mixing a natural soil with a hydraulic binder, usually cement or lime using a wide range of techniques. It is cost effective and eco-friendly because it involves no or less soil movement than a traditional method like bored piles and a smaller quantity of cement per cubic meter than a usual concrete. Also a series of industrial by-products like different type of blast furnace ash or slag can be used as a binder, replacing partially or totally the cement.

As previously stated the on-site soil treatment can be used as a practical, economic and environmental solution for a wide range of engineering applications. Some of the soil-mixing applications are road/rail embankments, lime, cement or lime/cement columns to support excavations, marine clays improvement for offshore platforms, shallow foundations, dam reinforcement, increase in slop stability, silos foundations and reduction of seismic pile displacement.

In this context the physical, chemical and mechanical characteristic of the treated soils and the influence of different soil-mixing compounds are very important. Although large scale research programs are carried all over the world, due to the complexity and the variety of soils and their properties, the knowledge of the final product and its behavior is yet hard to be estimated. Furthermore a better understanding of the influence of different soil compounds, such as clay, silt or sand content, the long term pozzolanic reactions and durability of the deep soil mixing, is needed to increase the accuracy of design models that are now based mostly on empirical knowledge.

1.2 OBJECTIVES

The main aim of this project was to study the behavior of a stabilized soil, in particular the response of some mechanical characteristics to the changing of the cement quantity.

This was reached using artificial soils with different but controlled cement content that were mixed with different clay quantities.
In this research were studied the Unconfined Compressive Strength of the soil-mix, its density, and its dynamic modulus of Elasticity.

As the soil-mixing technique involves an in-situ mechanical mixing of the natural soil with an injected binder, the presence of soil inclusions is inevitable. The inclusions have a big influence over the Uniaxial Compressive Strength (UCS) of the soil mix, so in this study have been analyzed the resistance of a soil mix (with a fixed quantity of clay and cement) containing a certain amount of inclusions.
Another element that can influence the UCS of the soil-mix is the temperature. In particular it has been seen that the type of cement used in this research, gives a good response to the temperature. Then it was also studied the changing of the resistance in function of the temperature.

1.3 OUTLINE OF THIS REPORT

This report has been organized in six chapters that are presented down here:

- Chapter 2_ SOIL- MIXING

  This chapter gives an introduction of the history of the soil mixing and it also presents some of the main deep soil method used.

- Chapter 3_ LITERATURE SURVEY

  The third chapter presents the soil- mixing as a new material. It introduces the main characteristics of the soil and it explains which of those characteristics will be taken in count in this research.

- Chapter 4_ MATERIALS AND TESTING METHODS

  Here are shown all the experiments that have been done to study the behavior of the soil-mix. In particular have been shown all the characteristics of the materials used to make the soil-mix. In a second step have been presented all the essays done to test the properties of the new material just created. In a third step all the results have been shown and commented.

- Chapter 5_ CONCLUSION

  This chapter summarizes the major conclusions from this study and gives suggestions for future work related to this study.

Chapter 2_ SOIL MIXING

2.1 SOIL- MIXING HISTORY

In this chapter, a brief history of the main breakthroughs in soil improvement method that ease the development of the soil mixing as it is known today, is presented.

The foundation of the soil mixing concept was laid over 50 years ago in the United States but the main research, technic and modern soil-mixing meaning were largely developed and used in Japan and Sweden over the last four decades. (Bruce D. A., 2000). In 1954, Intrusion Prepakt Co. (United States) develops the Mixed in Place (MIP) Piling Technique. During the 60s researched on deep soil mixing have been made in Japan and Sweden, with laboratory and in situ investigations. In the 70s the following technologies were developed and use in commercial projects mainly in Japan and Sweden, Soil Mixing Walls (SMW), Deep Lime Mixing (DLM), Cement Deep Mixing (CDM). The Banchy Company in France develops Colmix. With this technology the cemented soil is compacted and mixed in the same time. This is the first European development outside Scandinavia. (Bruce D. A., 2000). Late 80s bring to techniques. In 1995 the Swedish government initiates the Swedish Deep Stabilisation Research Centre with the scope of creating a large database regarding stabilized soil properties, quality and work performance. In Wisconsin, United States (Bruce D. A., 2000). Further development during the 2000s of the technics previously reminded and also new technologies like Geomix, Trenchmix and Springsol which are Soletanche Bachy trademarks.

2.2 CLASSIFICATION

The large number of developed techniques over the last half century can be explained by the wide range of engineering applications but also the need to adapt to each type of soil and local conditions. Today, the techniques that involve the construction of column type elements are mostly used. Other techniques allow the construction of panels or blocks.

In the last several years some classification systems for deep mixing, have been proposed by researchers like (Topolnicki,2004) and (Chu, 2009) or organizations FHWA, 2000; CDIT, 2002 and AFNOR, 2005 (Guimond- Barrett, 2012).

Ground improvement with grouting type admixtures	1. Particulate grouting	Grouting granular soil or cavities or fissures in soil or rock by injecting cement or the other particulate grouts to either increase the strength or reduce the permeability of soil or ground
	2. Chemical grouting	Solutions of two or more chemicals react in soil pores to form a gel or a solid precipitate to either increase the strength or reduce the permeability of soil or ground
	3. Mixing methods (including premixing or deep mixing)	**Treat the weak soil by mixing it with cement, lime or other binders in-situ using a mixing machine or before placement**
	4. Jet grouting	High speed jets at depth erode the soil and inject grout to form columns or panels
	5. Compaction grouting	Very stiff, mortar-like grout bin injected into discrete soil zones and remains in a homogeneous mass so as to densify loose soil or lift settled ground
	6. Compensation grouting	Medium to high viscosity particulate suspension in injected into the ground between a subsurface excavation and a structure in order to negate or reduce settlement of the structure due to on-going excavation

TABLE 1 CLASSIFICATION OF GROUND IMPROVEMENT METHODS ADOPTED BY TC211 (CHU, 2009)

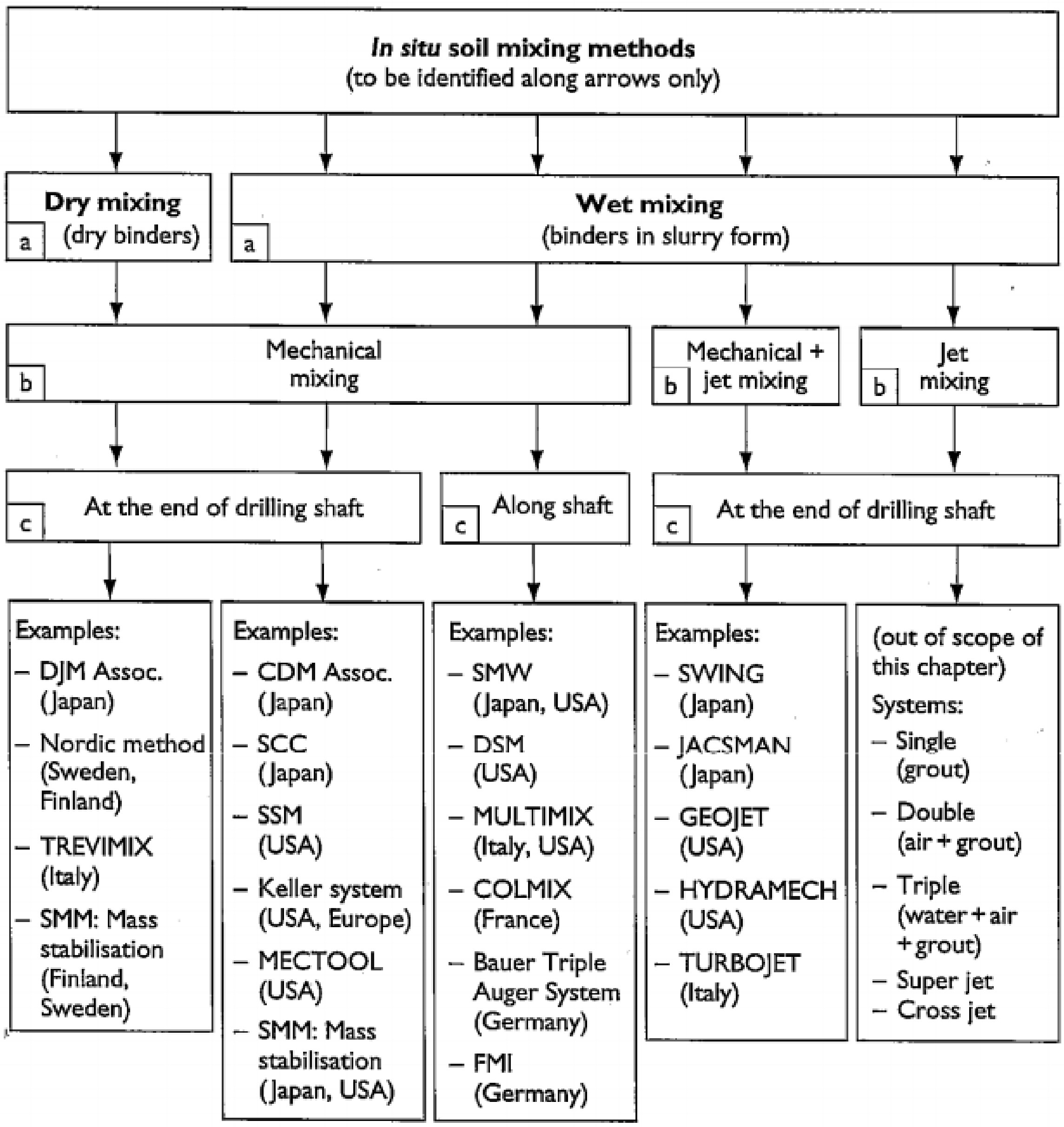

FIGURE 1 – GENERAL CLASSIFICATION ON IN SITU SOIL MIXING BASED ON (A) BINDER FORM, (B) MIXING PRINCIPLE AND (C) LOCATION OF MIXING ACTION, WITH SELECTED EXAMPLES OF METHODS DEVELOPED IN VARIOUS COUNTRIES (TOPOLNICKI, 2004)

2.3 DEEP SOIL MIXING METHODS

Because of the auto compacting characteristic, when using a Deep Soil-Mixing method, there is no need to further compact the resulted material. As (Bergado et al., 2005) affirms to obtain an auto compacting state, the material must have an elevated water quantity. The inferior limit of the water quantity that allows an auto compacting state, is the water quantity of the liquid limit (wl) for the binder-soil material. Thus, the liquid limit is a benchmark in calibrating and controlling the workability of a soil-mix.

2.3.1 BAUER TRIPLE AUGER MIXED-IN-PLACE METHOD

The Mixed-in-Place was one of the first soil mixing methods used and numerous patents concerning the construction method and the applied equipment have been registered.

Bauer uses a triple auger to drill and mix the soil using a binding agent suspension.

As it drills, a homogenization process is carried out by changing the rotation direction of the individual augers. Thus, a circular material flow is produced in the trench.

The Double pilgrim step working sequence ensures a solid and seamless wall. This production protocol ensure that each part of the wall is mixed at least twice with primary and secondary cuts.

FIGURE 2 BAUER TRIPLE AUGER

2.3.2 KELLER DEEP SOIL MIXING

The deep soil mixing developed by Keller can use basically two different mixing methods, dry mixing and wet mixing. The dry method implies mixing mechanically the soil with the binder as a powder and is generally preferable in soft soils with very high moisture content. The wet method on the other hand uses the binder in the form of a slurry and is more suitable in soft clays, silts and fine-grained sand with lower water content.

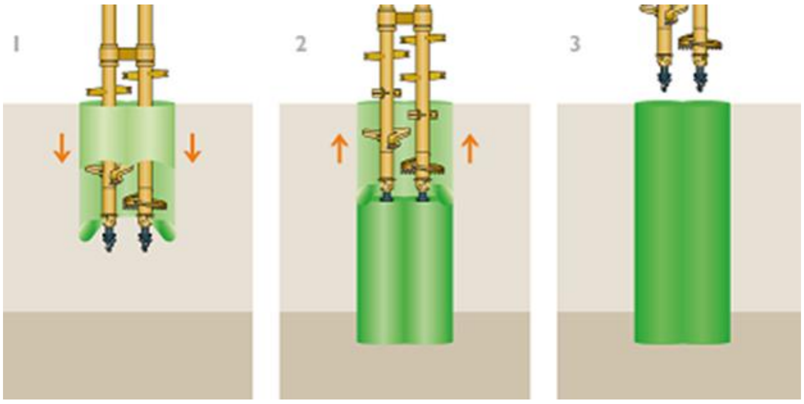

FIGURE 3 KELLER WET MIXING

The Keller wet deep mixing method uses a special tool that comprises a drilling rod with transverse beams and a drill end with a head. The drilling is carried out using a cement slurry which overflows from the nozzles at the end of the auger. After the drilling depth is reached, the mixing tool can move up and down thus improving the soil-mix homogeneity. This method can be used inside a tube when high-quality columns are needed.
The Keller dry deep mixing method uses a special tool attached at the end of a drilling rod. The binder is inserted into the soil be compressed air while withdrawing the mixing tool. In this phase the mixing tool has the rotation direction reversed to the penetration phase direction.

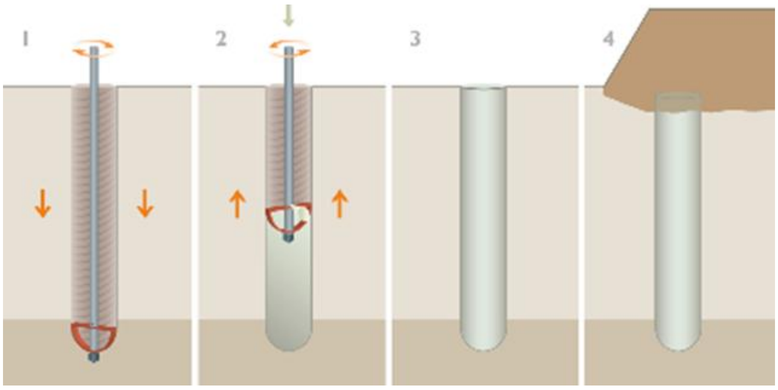

FIGURE 4 KELLER DRY MIX

2.3.3 SOLETANCHE BACHY- TRENCHMIX

The Trenchmix technique involves the construction, below ground, of trenches comprising soil mixed with binder. This technique can be used as a dry method or as a form of slurry known as the wet method. The resulted linear elements are

homogeneous and it works best in all types of loose soil, which must be free of coarse elements.
The areas of application are improvement of compressible soils, construction of cut off walls, construction of temporary ground support and increase in embankment slopes.

FIGURE 5 TRENCHMIX

2.3.4 SPRINGSOL

This technique was developed by Soletanche Bachy to reinforce the platforms of the old rail lines respecting exigencies like working under the power lines, drilling between the rail ways and protecting the ballast layer in the same time.
The construction of soil-mix columns by Springsol technique implies the use of a special tool. This tool allows drilling under the protection of a tube and when the desired depth is reached two arms are elevated under a certain angle which gives the final diameter of the soil-mix column. Further, with the help of the two arms, the mixing and drilling continues with the injection of a slurry.

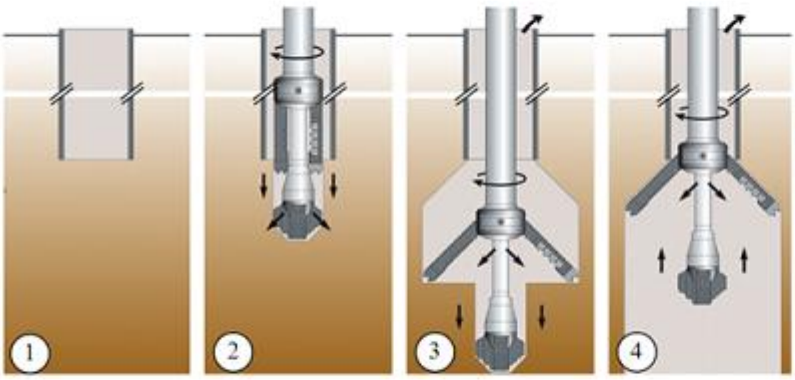

FIGURE 6 SPRINGSOL

Chapter 3_ LITERATURE SURVEY

3.1 SOIL MIXING AS A NEW MATERIAL

The components of a soil-mix material are basically soil and binder. The soil itself in its native state is a complex mixture of minerals, gases, liquids and in some cases inert organic matter or even living organisms. Thus the soil geotechnical properties vary in depth and from area to area. Also there is a wide range of binders that are commonly used in modern engineering practice. The binder used can be cement, lime, slag, flying ash, or even a mixture of different binders.

The mixture of these two types of materials, each with complex behavior, gives the new soil-mix material uncertainties regarding its physical, mechanical and chemical behavior. There are many factors that influence the new material parameters and characteristics. Some of the soil related characteristics are the type of soil (sand, silt and clay) the soil minerals, the Atterberg limits, the depth, the natural humidity, granulometry, its organic content etc. The binder related characteristics are mainly the type of binder and the quantity of binder. A major influence can derive from the mixing and curing conditions. The latter are easier to be controlled in a laboratory environment, but on site it presents certain weather and work related difficulties.

The large number of developed techniques in soil-mixing domain over the last half century, as presented in the previous chapter, is a combination of many different factors. The most dominant are the wide range of soils and engineering works in which soil-mixing technique can be used. Of course the development of new binders and a more eco-friendly approach in engineering have speed up the soil-mixing.

3.2 STABILISED SOILS BEHAVIOR

As previously stated the treated soil is new material which is formed after combining a soil with a binder, mostly cement. Thus the expected values of the engineering properties of this material lie between those of a soil and concrete.

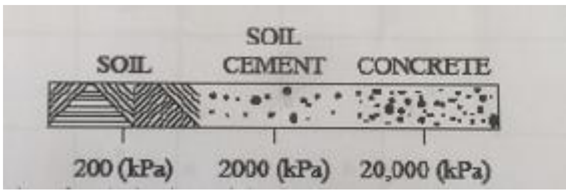

FIGURE 7 EXAMPLES OF TYPICAL VALUES OF STRENGTH OF SOIL, SOIL-CEMENT AND CONCRETE (RUTHERFORD)

Other required engineering parameters have been summarized by (Bruce and Bruce, 2003) and are shown in the following table:

Property	Typical range
Compressive strength qu (typically at 28 days)	0.2; 0.5 to 5 MPa
Tensile strength	8 – 14 %
Modulus of elasticity	350 to 1000 times qu for lab samples 150 to 500 times qu for fields samples
Permeability K	10-6 to 10-9 m/s

TABLE 2 BRUCE AND BRUCE, 2003

3.2.1 DENSITY

The concept of density is well known and refers to mass per unit volume. Important mechanical properties of soils depend on its bulk density, so to say the closeness of the grains. Soils that have a high proportion of voids will be weaker and more compressible than dense soils.

When using a soil-mixing technique we first “break” the soil and then we add a binder as a powder, when using the dry method or a slurry when using the wet method.

The density of a stabilized soil tends to increase when using the dry method but when the wet method is used, the density remains almost unchanged.

3.2.2 PARTICLE SIZE

The particles size of soils ranges from clay grains, that are smaller than 2 µm, to boulders that are larger than 200 mm.

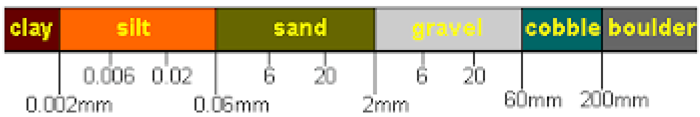

FIGURE 8 SOIL PARTICLES SIZE

The particle size distribution of the native soil is the first and major indicator of the soil improvement method to be used. In the courser soils, the jet-grouting is more appropriate whereas in fine-grained soils the deep soil-mixing are more effective.

The compaction of the new material is conditioned by the particle size distribution of the native soil. A soil with a particle size distribution closer to the Fuller ideal particle size distribution curve, means that treated material will be more compact with less voids. This means the stabilized soil is less permeable and more resistant.

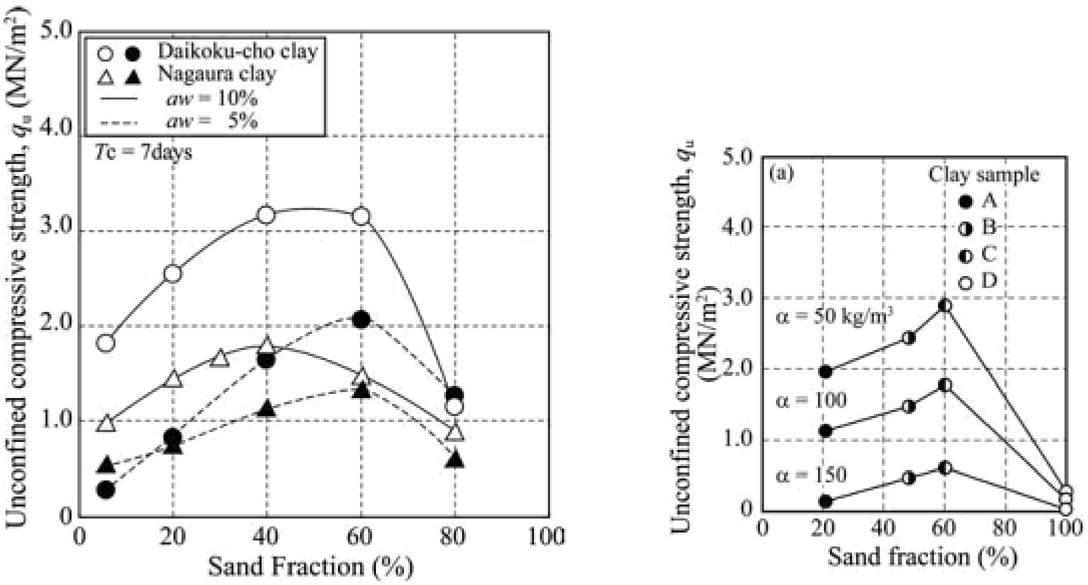

FIGURE 9 THE UCS EVOLUTION RELATED TO THE SAND FRACTION CONTAINED IN THE NATIVE SOIL (TERASHI ET AL. 1977) AND (KAVASSAKI ET AL, 1981)

3.2.3 UNCONFINED COMPRESSIVE STRENGHT

The compressive strength is the capacity of a material to withstand loads. It can be measured by plotting applied force against deformation in a testing machine. The behavior of each material is different, some materials fracture at their compressive strength limit, others deform irreversibly. The compressive strength of a material is a key value for design.

As shown in figure 7 examples of typical values of strength of soil, soil-cement and concrete the compressive strength of a treated soil, lies between UCS of the native soil and UCS of a concrete. When a binder is introduced in soil treatment, age-hardening behavior occurs. Consequently the mechanical resistance increase with time. In some cases, the mechanical resistance of treated soils may decrease because of variable curing conditions (temperature, hygrometry, moisture content or other perturbations) (Igles and Metcalf, 1972).

The increase in strength with time of the soil after treatment is influences by a series of factors. Depending on the type of soil, the type of binder will have a significant impact on the results. Some other factors that affects the increase of the strength in time are the amount of binder, the mixing effort, the temperature and the stress during curing (Ahnberg,Stress dependent parameters of cement and lime stabilized soils. Proceedings of the 2nd International Conference of Ground Improvement Geosystems: IS Tokyo ’96, Groung and deep Mixing, Tokyo, 1, 387-392,1996) (Babasaki et al., 1996).

Soil Type	Cement (kg/m3)	UCS 28 days (MPa)	Permeability k (m/s)
Sludge	250-400	0.1-0.4	1x10-8
Peat, organic silts/ clays	150-350	0.2-1.2	5x10-9
Soft clays	150-300	0.5-1.7	5x10-9
Medium/hard clays	120-300	0.7-2.5	5x10-9
Silts and silty sands	120-300	1.0-3.0	1x10-8
Fine-medium sands	120-300	1.5-5.0	5x10-8
Course sands and gravels	120-250	3.0-7.0	1x10-7

TABLE 3 TYPICAL FIELD STRENGTHS AND PERMEABILITY FOR DIFFERENT TYPES OF SOIL STABILISED BY THE WET METHOD (TOPOLNICKI, 2004)

The soil treatment using a soil mixing method affects the mechanical, physical and chemical properties. The execution process and the variation of soil properties together with the sampling and testing conditions influence the uniformity of the resulted material. Figure ()- Coefficient of variation evaluated from compression tests in a number of reported studies shows the coefficient of variation of compressive test results in a number of reported studies for samples taken from in-situ stabilized soil (Larsson, 2005). Thus a correct and coherent comparison of the results between different studies is difficult to be made.

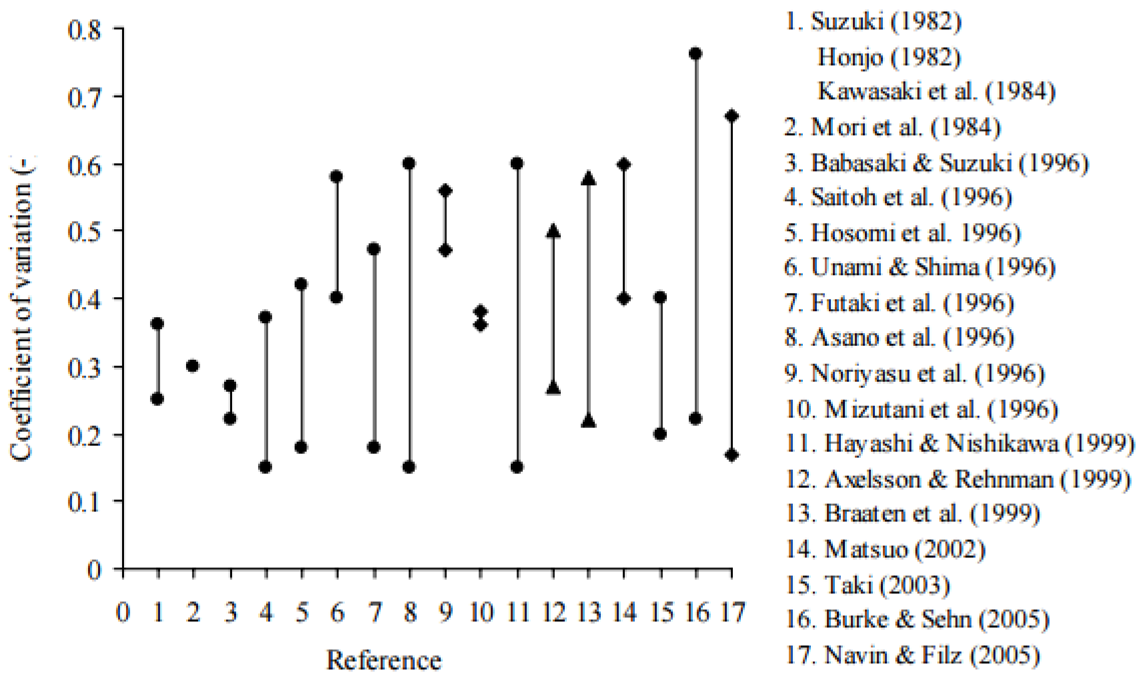

FIGURE 10 COEFFICIENT OF VARIATION EVALUATED FROM COMPRESSION TESTS IN A NUMBER OF REPORTED STUDIES (LARSSON, 2005)

The variation in strength increase with time in linked to differences in the chemical reactions taking place. The strength and stiffness increase in time after mixing with cementing agents have been widely studied in concrete research and empirical relations given in current standards in Europe are used in practice for concretes. However these correlations are rarely applied to stabilized soils (Denies et al. Soil Mix walls as retaining structures of ISSMGE – TC211. Recent research, advances & execution aspects of ground improvement works. 31 May – 1 June 2012, Brussels, Belgium, Vol. 3, 83-98, 2012).

3.2.4 UCS RELATED TO INCLUSIONS

Because of the specific mixing procedure of the soil-mixing technique and since a natural material is directly used as building material, the presence of soil inclusion is inevitable (unmixed and thus weaker parts). The volume percentage varies between 0% and 3.5% in sandy soils up to 35% and more in stiff clays. Apart from this, soil inclusions can be very small (a few millimeters), but large inclusions (up to 100-200 mm) also are found. As we can see from the picture there are two soil-mix cores originating from the same soil-mix panel executed in a sandy soil (with a length of about 550 mm).

FIGURE 11 TWO CORES WITH A LENGTH OF ABOUT 550 MM FROM THE SAME SOIL-MIX PANEL. THE SOIL IN THE INCLUSIONS WAS WASHED OUT DURING CORING. HISTOGRAM OF 31 UCS VALUES OF SOIL-MIX SAMPLES FROM A CONSTRUCTION SITE IN BELGIUM (LOAM)

In the upper core, a large inclusion, with a diameter of about 5 mm, was observed, while the size of the inclusions in the lower core were limited to a few millimeters. Note that both the inclusions, the execution parameters (amount of binder injected, water/cement ratio), and the type of soil influence the Uniaxial Compressive Strength (UCS) value. All of these factors can lead to a wide range of UCS values on one construction site. From the picture we can see the histogram of 31 UCS values for a Belgian construction site in a loamy soil.

Other characteristics that can influence UCS of a soil-mix are shape, number, and relative position. It has been studied that sharp-ended inclusions have a more negative impact on the strength and stiffness than rounded inclusions. Then, one large inclusion reduces strength and stiffness more than three smaller inclusions with the same shape and accounting for the same total volume percentage. Finally, diagonally-located and more-concentrated inclusions have a more negative impact on the mechanical behavior than vertically-aligned and widely-spread inclusions.

3.2.5 STIFFNESS

The elastic deformation modulus, describes tensile elasticity or the tendency of an object to deform along an axis when opposing forces are applied along that axis.
As the UCS, the elastic deformation modulus is a key parameter used to describe material behavior. The stiffness characteristic is essential for design as it is one of the input parameters in numerical models.
The relation between the E50 (Elastic modulus at 50% from the maximum load) and the unconfined compressive strength varies from 50-300 times the UCS28 for the samples with an UCS less than 2MPa and 300 to 1000 times the UCS28 for the samples with UCS over 2MPa (Topolnicki, 2004).

Reference	Relationship	Note
(Saitoh et al., 1996)	350 UCS< E50< 1000UCS	
(Eurosoilstab,2002)	100 UCS< E50< 200UCS	
(Asano et al., 1996)	50UCS< E50<500UCS	In situ samples
(Futaki et al, 1996)	140<E50<200 UCS	Cored samples
(Tan et al, 2002)	350UCS< E50<800 UCS	Laboratory samples
(Tatsuoka et al, 1996)	Emax<1000 UCS	Local strain measurement
(Topolnicki, 2004)	50UCS< E50< 300UCS	
(Terashi et al, 1977)	300UCS< E50< 1000UCS	
(Kawasaki et al, 1981)	350UCS< E50< 1000UCS	
(Bruce, 2001)	150 UCS< E50< 500UCS	In situ samples
(Jegandan et al, 2010)	55 UCS< E50< 500 UCS	
(Ganne et al, 2010)	600 UCS< E50< 1400 UCS	

TABLE 4 DEFORMATION MODULUS AND UNCONFINED COMPRESSIVE STRENGTH COMPARISON

The different values between the deformation modulus related to the unconfined compressive strength can be explained by the method used to measure the strains. As a common practice there are two ways to measure the strain: the first one is by measuring the displacement of the press and plates which is time saving and cost effective but can easily lead to errors, usually underestimating the modulus. Another method for measuring the strain is by using the strain gauges. This method is widely used because it gives reliable data over the full range of loading and/or unloading from very small strain to failure. However the use of strain gauges is expensive and time consuming. Many studies do not explicitly specify the

equipment used to measure the strain. (Bruce, 2001), (Jegandan et al. 2010) and (Topolnicki, 2004) determined the module E50 by measuring the displacement of the press and plates which lead to almost the same values.
Although local strain measurement using strain gauges gives better and reliable results, the external strain measurement is still widely used.
Underestimating the value of the modulus can lead to overestimations of settlements with unnecessary increase in steel, binder dosage, the depth of the treatment. Consequently it can lead to a major change in design.

3.2.6 INFLUENCE OF TEMPERATURE

The effect of the temperature on compressive strength has been studied by (Hirabayashi et al.,2009). An increase in curing temperature accelerates the cement hydration process and thus the development of strength in cement stabilized soils.

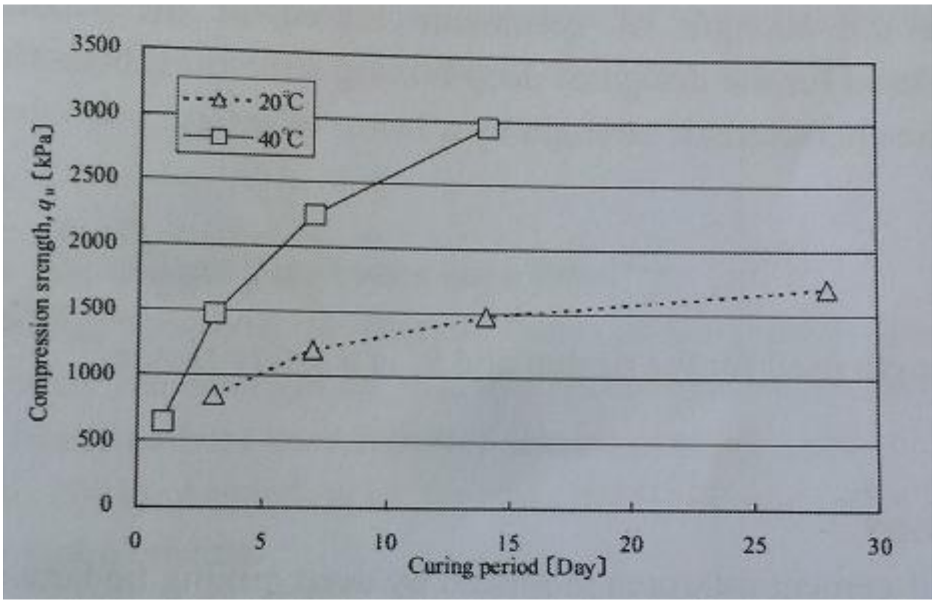

FIGURE 12 EFFECT OF CURING TEMPERATURE ON COMPRESSIVE STRENGTH (HIRABAYASHI ET AL, 2009)

Chapter 4_ MATERIALS AND TESTING METHODS

In this chapter are presented the materials and the texting methods that have been used in the essay. The experimental program is presented in detail in order to offer a better understanding of the tests and to provide a solid background for the test results. As pointed before, the soil type, the methods used to prepare, mix cure and test different parameters of the treated soil, have a significant effect over the mature material. Ignoring or changing one of this points, makes the obtained data unusable, as the resulting data can't be compared.

4 MATERIALS

4.1.1 CLAY

The clay used to create the artificial soil mixes is Kaolinite Spreswhite Kaolinite, which is a clay mineral, with a soft consistency and earthy texture. It has a low shrinking- swelling capacity and a low cation- exchange capacity. Kaolinite can be easily broken and moulded when moist. Its unit weight is of approximately 2600 kg/m³.

FIGURE 13 CLAY

4.1.2 SAND

The sand to create the artificial soil mixes is Fontainebleau 0/1, one of the purest sands, considered as being a reference in laboratory research. The Fontainebleau sand is a white colored silica sand, having round grains and a narrow particle size distribution (particle size usually lower than 1 mm). Its unit weight is of approximately 2650 kg/m³ and its water content is below 0.1%.

FIGURE 14 SAND

4.1.3 BINDER

For the purpose of this research, the binder used was cement, CEM III/C 32.5 N CE PM-ES NF , obtained by mixing clinker with a minimum amount of 81% granulated ground blast furnace slag, which offers slow strength development and initial setting time of 4 hours after hydration of the cement. This type of cement used in foundation works in France because of its high resistance to sulphate and chloride actions. It may be considered as well an eco-efficient and low-CO_2 emissions cement, as it has one of the lowest trigger factors in the industry. Its unit weight is of approximately 2900 kg/m³.

FIGURE 15 CEMENT

4.1.4 WATER

For this research, it has been used water from the water supply system. The unit weight of water is 1000 kg/m³.

4.1.5 SOIL

For this research, ten formulation of artificial soil were created in laboratory, in order to determine the influence of cement content on the physical and mechanical properties of the created materials.
Therefore, artificial soils were created containing 10, 50 % of kaolinite and the rest of the volume of soil being occupied by the Fontainebleau sand. It have been used five dosage of cement: 150, 200, 250, 300, 350 kg/m³.
One of the most important characteristics of the fresh soilcrete is the workability. The Cement/Water ratio (C/W) has a major impact in the workability of the soilcrete. Even though it is common in practice to use the same C/W ratio, keeping it constant implies substantial changes in the consistency of the material, whereas a low consistency is not desired when using a soil-mixing technique, due to the limited compaction and vibration possibilities. A self-compacting material is more desirable in order to ensure an even suspension of solid particle. Therefore, a constant

workability of 32 cm was used throughout the research, corresponding by correlation to a self-compacting concrete settlement between 60 and 80 cm, by replacing the size of the gravel particles with the size of the sand particles.

Formulation	Kaolinite %	Cement	Kaolinite Kg/m³	Sand	Water	C/W	W content %
K10/C150	10	150	132	1209	441	0.34	29.58
K10/C200	10	200	125	1144	451	0.44	31
K10/C250	10	250	119	1095	455	0.55	31
K10/C300	10	300	115	1059	452	0.66	31
K10/C350	10	350	113	1033	446	0.66	29.79
K50/C150	50	150	366	373	667	0.225	74.97
K50/C200	50	200	347	353	664	0.30	74
K50/C250	50	250	321	327	667	0.375	74.18
K50/C300	50	300	299	305	667	0.45	74
K50/C350	50	350	292	298	654	0.535	69.53

TABLE 5 QUANTITIES OF THE DIFFERENT MATERIAL FOR EACH SOIL MIXING FORMULATION

In order to test the workability of each soil-mix formulation, the Abrams cone method was used, applied on large scale to concrete but adjusted to this specific situation. Thus, a “mini-cone” was used, having the dimensions deducted by the dimensions of the Abrams cone by a homothetic ratio of 2 (upper diameter of 5 cm, lower diameter of 10 cm and 15 cm height).

FIGURE 16 MINI- CONE ABRAMS

In order to achieve the constant workability of 32 cm, trial tests were performed by varying of the C/W ratio. The settlement calibration tests were carried out on a volume of 1 liter of material. The dosage of each compound material of the soil mixes formulations were determined by using the following routine:

1. The chosen dosage of cement was 150 , 200, 250, 300, 350 kg/m³ of soilcrete;
2. A Cement/Water ratio was proposed by interpolating the values given by previous researcher in the field;
3. The cement and water volumes per m³ were calculated with the formula:

$$V_{cem} = \frac{m_{cem}}{\rho_{cem}} ; V_{water} = \frac{m_{water}}{\rho_{water}}$$

4. The volume of soil to be treated was calculated by knowing the final volume of 1 m³ of soilcrete;

$$V_{soil} = 1 \text{ m}^3 - V_{cem} - V_{water}$$

5. The volume of kaolinite and sand were calculated

$$V_{soil} = \%V_{kaolinite} + V_{sand}$$

After the mix was performed with the calculated quantities corresponding to 1 liter of material, it was tested using the mini cone. If the settlement was less or more than 32 cm, the water/cement ratio was adjusted, until a settlement of 32 cm was obtained. Each soil-mix was labelled as following:

K50/C200

Percentage of kaolinite in the volume of soil

Quantity of cement

A working example for K50/C200 is presented below:

Starting with cement for 200 kg/m³ and a cement/water content of 0.301, we can determine the volume of cement and water for cubic meter.

$$V_{ciment} = \frac{m_{cim}}{\rho_{cim}} = \frac{200\ kg}{2900\ kg/m3} = 0.0689 \text{ m}^3$$

$$V_{water} = \frac{m_{water}}{\rho_{water}} = \frac{\frac{m_{cim}}{C/W}}{1000\ kg/m3} = \frac{664.45}{1000} = 0.6644 \text{ m}^3$$

$V_{soil} = 1\ m^3 – V_{cim} – V_{water} = 1 – 0.0689 – 0.6644 = 0.2667\ m^3$

$V_{kaolinite} = V_{soil} \cdot 50\% = 0.13335\ m^3$

$m_{kaolinite} = V_{kaolinite} \cdot \rho_{kaolinite} = 0.1333 \cdot 2600 \frac{kg}{m\ 3} = 346.53\ kg$

$m_{sand} = V_{sand} \cdot \rho_{sand} = 0.1333 \cdot 2650 \frac{\mathrm{kg}}{m3} = 353.22\ kg$

4.2 TESTING METHODS

4.2.1 PREPARATION OF THE MIXES OF THE SAMPLE, STORAGE

The first phase of the mixing process is preparing the dry mixture, therefore mixing together dry kaolinite, sand and cement. Each of the materials is weighted separately and then all of them are placed together in a plastic container, in the following order: kaolinite, cement and sand from the finest to the thickest.

FIGURE 17 DRY MIX

The soils and binder are then mixed by hand for several minutes until a homogeneous dry material is obtained.

FIGURE 18 HAND MIXING

The mixing bowl is then filled with the necessary water quantity, according to the determined dosage.

FIGURE 19 Bowl with water

Afterwards, the dry mixture of soils and binder is carefully added into the mixing bowl where there's the water using a trowel, avoiding as much as possible causing the lifting of the fine particles in air.

FIGURE 19 WET MIXING

In this research it was used just the small mixer (0.5 – 2.5 litres).

FIGURE 20 MIXER 0.5 – 2.5 LITRES

The formulations were mixed for 5 minutes into the mixer at the lowest velocity. After the mixing process was finished, the fresh material was tested again for determining the settlement that has to be 32 cm.

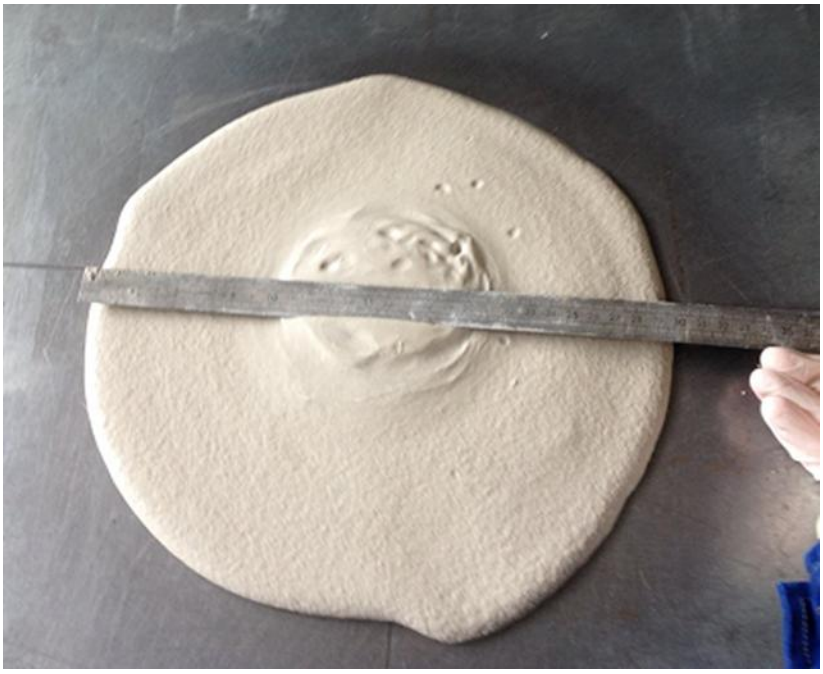

FIGURE 21 SLUMP

Here the results of the settlements for the different mixes:

Formulation	Cement(kg/m3)	Kaolinite(%)	Settlement (cm)
K10C150	150	10	29-30
K10C200	200		33-32
K10C250	250		33-33
K10C300	300		31-30
K10C350	350		33-32
K50C150	150	50	31.5-30
K50C200	200		31-31
K50C250	250		32-31
K50C300	300		32-31
K50C350	350		33-33

TABLE 6 SETTLEMENTS OBTAINED FOR THE DIFFERENT SOIL MIX

Afterwards, the soilcrete was poured into cylinder shaped carton molds, having 5 cm diameter and 10 cm height, as described into the following.
The material is poured into the mold in three steps, filling each time one third of the mold height. After each pouring, the mold is either tapped against the table for 15 times, technique commonly known as "tapping" (for self-compacting formulations, containing kaolinite), or vibrated for approximately 15 seconds using the vibrating table (for non-self-compacting formulations, which do not contain kaolinite).

FIGURE 22 MOLD 5X10 FILLED WITH FRESH MATERIAL

Between preparation and testing, the samples are stored in a controlled environment, with constant temperature of 19°C and with relative humidity that prevent samples from drying. The carton molds filled with fresh material are sealed with adhesive tape and are then stored into closed plastic bags in perfect vertical position. After 7 days, the mold is removed and the hard sample are wrapped in wet cloth and stored again into closed plastic bags until the desired curing age.

Figure 23 Moulds 5x10 and sample after 7 days of storage

FIGURE 24 STORAGE OF PREPARED SAMPLES IN CONTROL ENVIRONMENT

4.2.2 PREPARATION AND STORAGE FOR THE SAMPLES TESTED AT TEMPERATURE

The samples that have to be checked at temperature have been made with the same process just described for the sample tested at UCS but it has been used only a formulation: K10C200.

Formulation	Kaolinite (Kg)	Cement (kg)	Water(kg)	Sand(kg)	C/E
K10C200	1.496	2.400	5.41	13.725	0.443

TABLE 7 QUANTITIES OF DIFFERENT MATERIAL FOR THE FORMULATION K10C200

The 36 samples will be tested at UCS after 7; 28; 56; 90; 180 and 365 days. (The essay so is still ongoing).
As the number of samples made is high, the mix done has been mixed in the big mixer (15-20 liters capacity).

18 of them are stored in the same environmental as described above at 19 degrees with constant humidity and the others are stored in an oven that keeps the temperature constant at 10 degrees.
After 7 days the molds have been removed and the samples have been wrapped in wet cloths and then put into plastic bags in the control environment.

FIGURE 25 OVEN SET AT 10 DEGREES FOR THE STORAGE OF THE SAMPLES

4.2.3 PREPARATION AND STORAGE FOR SAMPLES WITH INCLUSIONS

The samples made for this essay have the formulations K10C200 with the following quantities:

Formulation	Kaolinite (Kg)	Cement (kg)	Water(kg)	Sand(kg)	C/E
K10C200	1.496	2.400	5.41	13.725	0.443

TABLE 8 QUANTITIES OF DIFFERENT MATERIALS FOR THE FORMULATION K10C200

The way of preparing the mix is exactly the same that was used for the samples above and also this time it has been used the big mixer having 15-20 liters of capacity.

During the taping phase, the little balls are assembled in the samples. The molds used are 14 cm height so the mix is poured into the mold for a height of about 2 cm with a syringe.

FIGURE 26 MOLD 7X14 FILLED UP OF FRESH MATERIAL WITH A SYRINGE

then tapped 5 times and then the first ball is placed into the mold with a pincers

Figure 27 Pincers used to put the inclusions

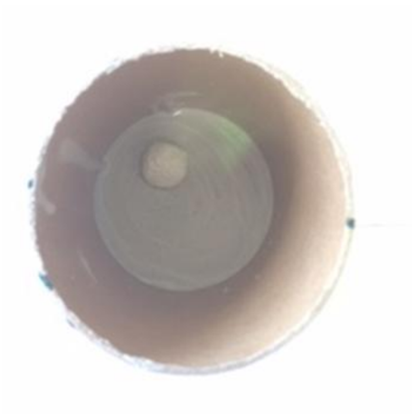

Figure 28 An inclusion on the first layer

Then again the mixture is poured for a 2 cm of height, then tapped 5 times then another ball is put and so on till the top.
The samples have been made with one, two or three spheres per layer as resumed in the following table:

Nombre de boulettes	Nombre échantillons	Volume occupé
« Sans boulettes »	2 résistances + 2 jauges	0%
1 boulette par couche	2 résistances + 2 jauges + 1 coupe	2%
2 boulettes par couche	2 résistances + 2 jauges + 1 coupe	4%
3 boulettes par couche	2 résistances + 2 jauges + 1 coupe	6%

TABLE 9 SUMMARY OF THE SAMPLES MADE WITH DIFFERENT PERCENTAGE OF VOLUME OF INCLUSIONS

Some of samples are made without any sphere. Those we will be the reference samples.
The clay spheres are put into the sample in a specific position as shown below

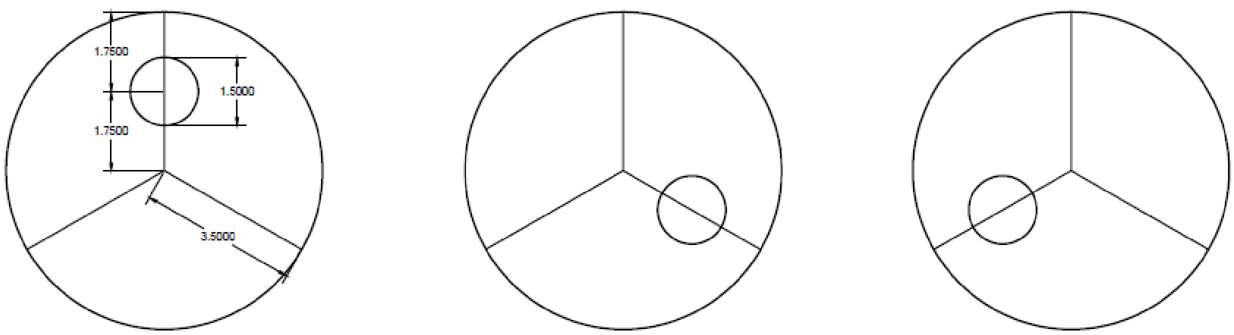

FIGURE 29- IT SHOWS THE POSITION OF THE SPHERE IN THE SAMPLE WITH ONE SPHERE PER LAYER

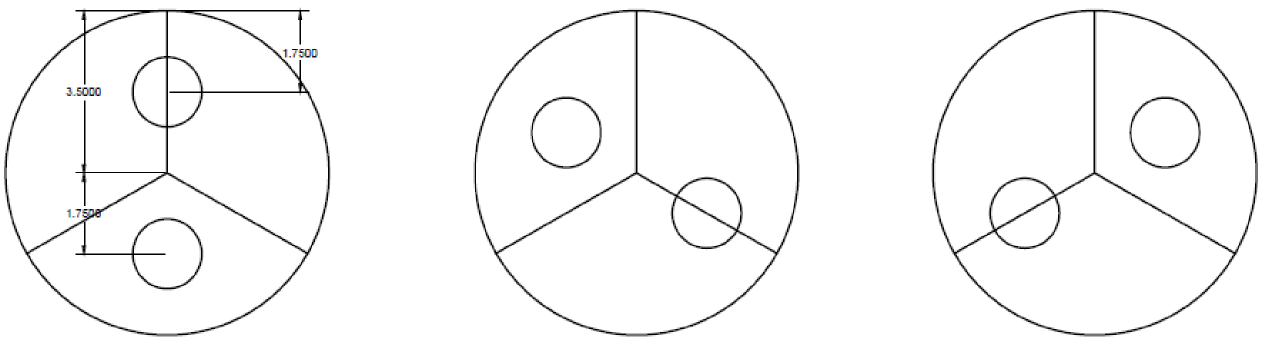

FIGURE 30-IT SHOWS THE POSITION OF THE SPHERES IN THE SAMPLE WITH TWO SPHERES PER LAYER

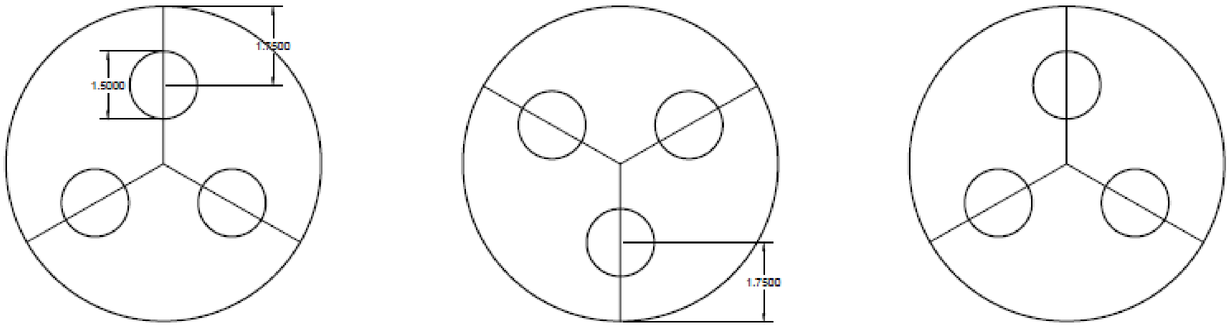

FIGURE 31- IT SHOWS THE POSITION OF THE SPHERES IN THE SAMPLE WITH THREE SPHERES PER LAYER

FIGURE 32 CUT OF SAMPLE WITH 1, 2, 3 INCLUSIONS PER LAYERS

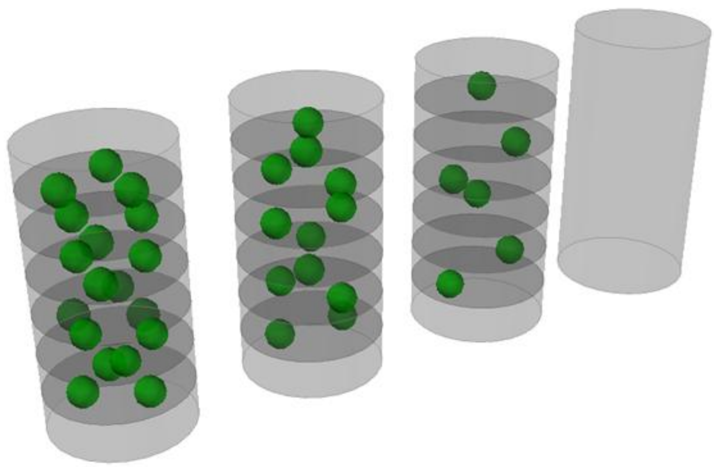

FIGURE 33 IMAGINE 3D OF THE SAMPLES WITH INCLUSIONS

It's been calculated the amount of volume that the spheres occupy in the sample:

For the samples with one sphere per layer:

$$\text{Vol\%} = \frac{nombre\ boulettes*\frac{4}{3}*pi*rb\text{^}3}{ht*R^2*pi} = \frac{6*\frac{4}{3}*\mathrm{pi}*0.75\text{^}3}{14*3.5\text{^}2*\mathrm{pi}} = 1.967\ldots\%$$

For the samples with two spheres per layer:

$$\text{Vol\%} = \frac{nombre\ boulettes*\frac{4}{3}*pi*rb\text{^}3}{ht*R^2*pi} = \frac{12*\frac{4}{3}*\mathrm{pi}*0.75\text{^}3}{14*3.5\text{^}2*\mathrm{pi}} = 3.935\ldots\%$$

For the sample with three spheres per layer:

$$\text{Vol\%} = \frac{nombre\ boulettes*\frac{4}{3}*pi*rb\text{^}3}{ht*R^2*pi} = \frac{18*\frac{4}{3}*\mathrm{pi}*0.75\text{^}3}{14*3.5\text{^}2*\mathrm{pi}} = 5.903\ldots\%$$

As the samples are surfaced before every essay, their height is not actually 14 cm but it's less so the volume occupied by the spheres is more than the one before calculated: for the sample with one sphere per layer is about 2.08%, for the samples with 2 spheres per layer is about 4.1% and eventually for the samples with 3 spheres per layer the amount is about 6.21%. The spheres have been made with a mixture of clay and water. The mixture has a plastic limit of 50% (=m_w/m_c so 300 g of clay and 150 ml of water). The water and the clay have been well mixed in a bowl by hand and then the mixture has been put into a film and let for two days in order to permit to the clay to well absorber the water.

FIGURE 34 MIX OF CLAY AND WATER USED TO MAKE THE INCLUSIONS

After two days the spheres have been made: a little bit of the mixture has been rolled by hand trying to make a little round ball. After this, the size of each sphere has been checked. If the sphere was too big, a bit of the mixture was taken off whereas if it was too little some mixture was added till a diameter of about 1.5 cm was obtained.

FIGURE 35 DIAMETER OF A CLAY INCLUSION 1,5 CM

The limit of the 50% has been chosen because we don't want the spheres to release their water in the mixture of cement but we also don't want them to absorber the water from the cement mixture.
After making the samples, these have been put in plastic bags and stored in a controlled environment at a constant humidity and temperature of 19°. After 7 days the samples have been demolted and wrapped in wet cloths then put again in the controlled environmental till the test.

4.2.4 UCS

Unconfined Compressive Strength is the capacity of a material to support loads, by tending to reduce its size. It is a destructive test that was performed after a curing time of 28 days.
The Unconfined Compressive Strength describes the material behavior in terms of peak resistance and in terms of deformation modulus.
The press used for performing the unconfined compressive strength tests was the INSTRON electro-mechanic control press.
In order to determine the unconfined compressive strength, the cylindrical samples were prepared by cutting and levelling the top and the bottom surfaces using sand paper, as to have even surfaces.
After this step, each sample was measured, weighed and the dynamic elasticity modulus was determined by ultrasound device. Afterwards, the sample was installed into the press, between the plates.

A speed of charge of 0.04 MPa/s was chosen, a speed lower than the one provided by the concrete norm, of 0.50 MPa/s, as it was adjusted to the particles size and the expected low strength of the studied material.

FIGURE 36 INSTRON ELECTRO- MECHANIC CONTROL PRESS AND COMPUTER UNIT

4.2.5 P-WAVE VELOCITY AND DYNAMIC YOUNG MODULUS

The dynamic modulus of elasticity (Young modulus), was determined in order to characterize the behavior of the soil-mixing materials. The European norm (EN 12504-4, 2004) was used as reference.

This is a non-destructive test that provides data about the evenness of the soilcrete, the presence of voids, change in properties with time and in the determination of dynamic properties. The test is based on longitudinal vibrations pulse produces by an electro-acoustical transducer held in contact with the surface of the soilcrete. After passing the length of the sample, the pulse of vibrations is captured and converted into an electrical signal by a second transducer. (EN 12504-4, 2004).

Dynamic Young modulus was determined on each sample before the Unconfined Compressive Strength test.

In order to determine the longitudinal waves (P-waves) velocity, therefore the dynamic modulus, the transducers were placed at the opposite sides of the sample, after being cut and surfaced. For coupling, silicon grease was used between the plates and the sample surface.

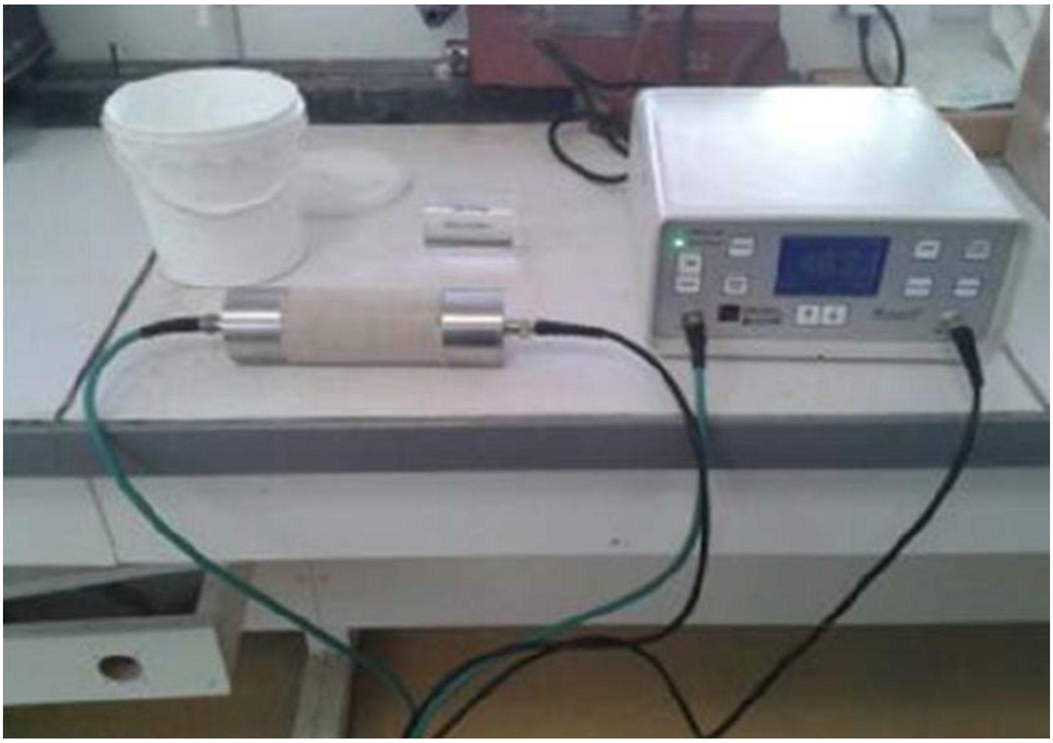

FIGURE 37 PONDIT 7- ULTRASONIC PULSE GENERATOR AND THE TESTED SAMPLE

4.2.6 UCS IN SAMPLES WITH INCLUSIONS (GAUGES)

The first aim of the gauge is to calculate the deformation on an object. The strain gauge consists in a flexible backing which supports a metallic foil pattern. The gauge is attached to the sample with a resin. As the sample is deformed, the foil is deformed, causing its electrical resistance to change. This resistance change is related to the strain by the quantity known as the gauge factor. The gauges used in this research are the Kyowa Gages type KFG-20-120-C1-11 with a length of 20 mm and the gauge factor k= 2.12 ± 1.0%.

$$\frac{\Delta l}{l} = k\,\frac{\Delta r}{r}$$

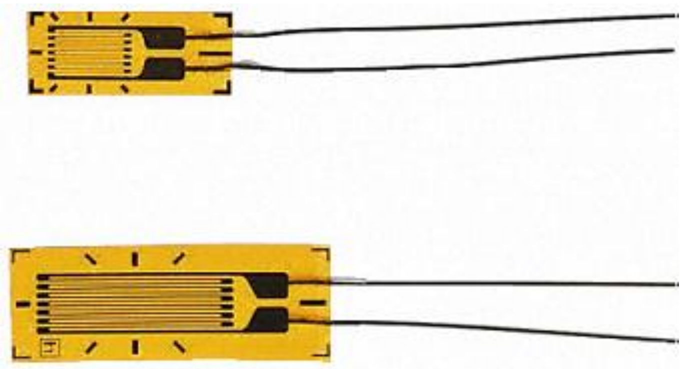

FIGURE 38 GAUGES KYOWA

The test done permits to apply cycles of charge and discharge to the sample until its crash.
The test starts with a phase of charge until 1.5 MPa then it descends at 1 MPa, then a new phase of charge till 2 MPa then again discharge till 1 MPa and so on till a maximum charge of 7.7 MPa. The press used for performing the test is the INSTRON electro-mechanic control press (the same used for the UCS).

FIGURE 39 INSTRON USED FOR THE CYCLIC TEST

Before the test, the samples are surfaced on both the faces, then on both the top and the bottom of the sample is put tape and in the middle part (were the gauges will be placed) it’s put the resin and let it dry for one night.

FIGURE 40 RESIN AND SAMPLES 7X14 WITH TAPE

The next step is to get rid of the excess resin with a sand paper and then mark on the lateral surface of the samples the lines on which the gauges will be glued. The gauge will be placed at half of the height of the sample two in horizontal position (at opposite sides) and two in vertical (again in opposite sides). To find the exact position is necessary to overlap the little black lines on the yellow backing on the lines traced before on the sample.

FIGURE 41 SAMPLE 7X14 WITH VERTICAL AND HORIZONTAL GAUGES GLUED

After that the electric cables are weld to the gauges and the sample is placed between the plates of the press.

4.3 RESULTS AND ANALYSIS

In the following part the results of the tests are showed and analyzed. They include the evaluation of the physic-mechanical behavior of the soils in a hard state, which were presented in the chapter before.

4.3.1 DENSITY

The addition of cement or lime to a soil has as a consequence an increase in density. This is confirmed in the graph below.

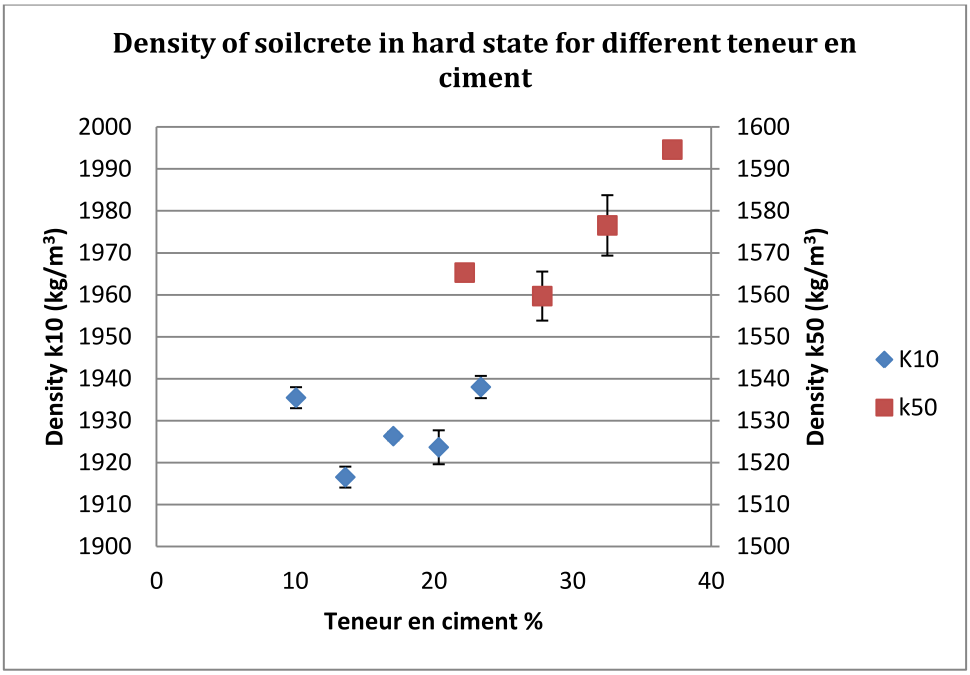

FIGURE 42 DENSITY MEASURED FOR DIFFERENT CEMENT QUANTITIES

The change in density is influenced by the type and amount of binder. Comparing the two soil mixes, we note that the density of the mix with higher percentage of kaolinite is lower than the other one. This can be explained by the fact that a high percentage of kaolinite needs more water to have the same workability of 32 cm. The density seems to augment with the quantity of cement for the formulation with k50 but for the k10 this is not so clear. It seems in fact that the density doesn't change too much when the quantity of cement augments.

4.3.2 UNCONFINED COMPRESSIVE STRENGTH

The best value for the Unconfined Compressive Strength has been obtained for the formulation K10C350. The graph below shows the different values of the UCS in function of the increase of cement quantity.

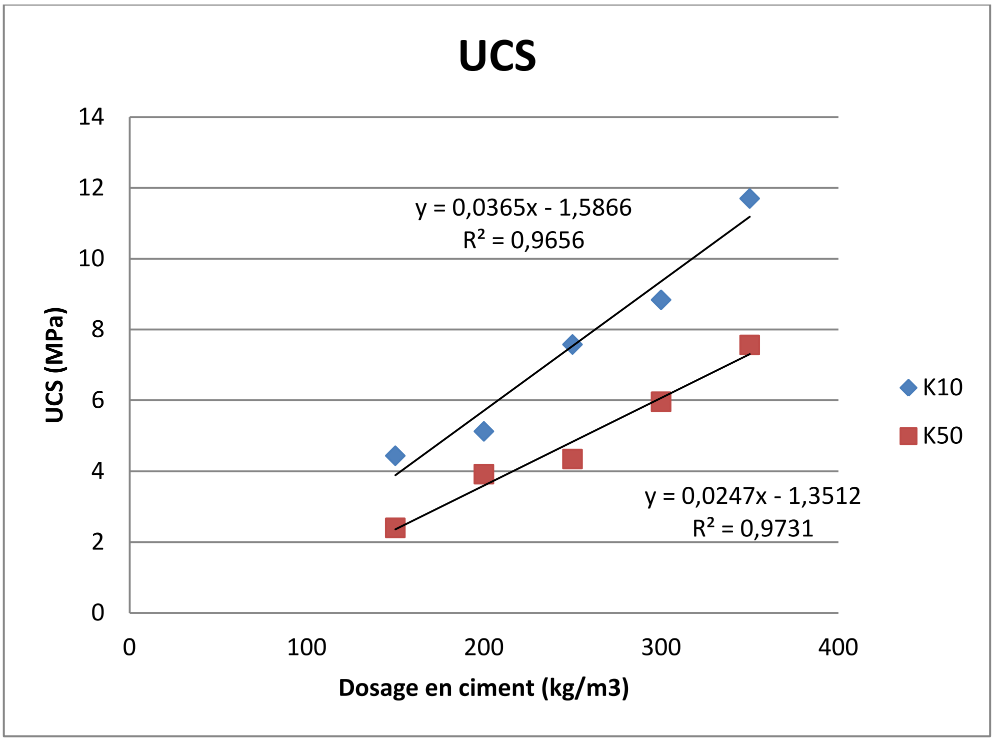

FIGURE 43 UNCONFINED COMPRESSIVE STRENGTH MEASURED AT 28 DAYS

Thus we can say that the best value for the UCS is about 11 MPa and it has been obtained with a formulation of K10C350 so once related this study with (Helson,2014) we can say that the best kaolinite dosage is about 10%.

Here is showed the increase of UCS in function of the cement dosage in percentage

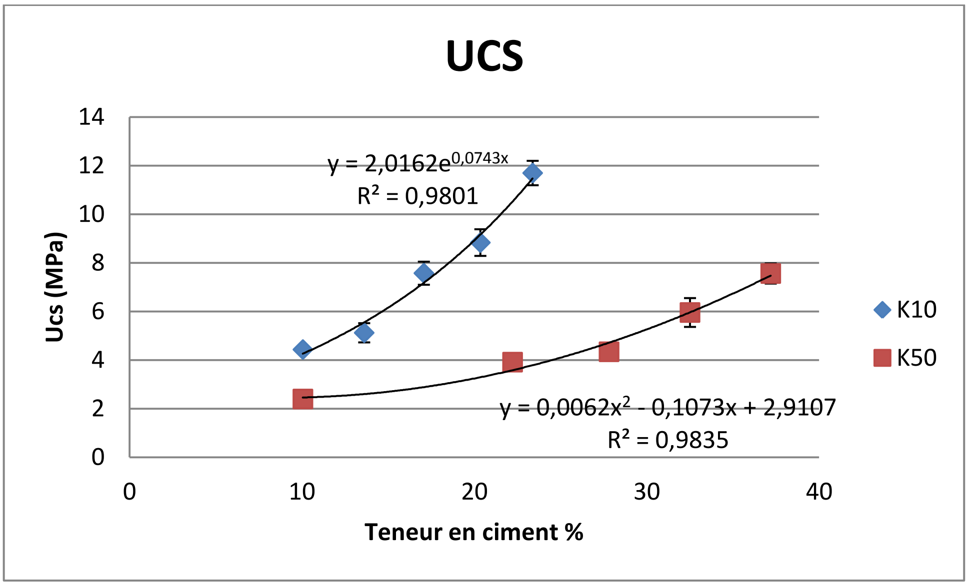

FIGURE 44 UNCONFINED COMPRESSIVE STRENGTH FOR DIFFERENT PERCENTAGE OF CEMENT

The growth of the resistance for the formulation with K10 is higher than the one with K50.

In the following graph is shown the linear relationship between the compressive strength at 28 days of the different kaolinite quantities.

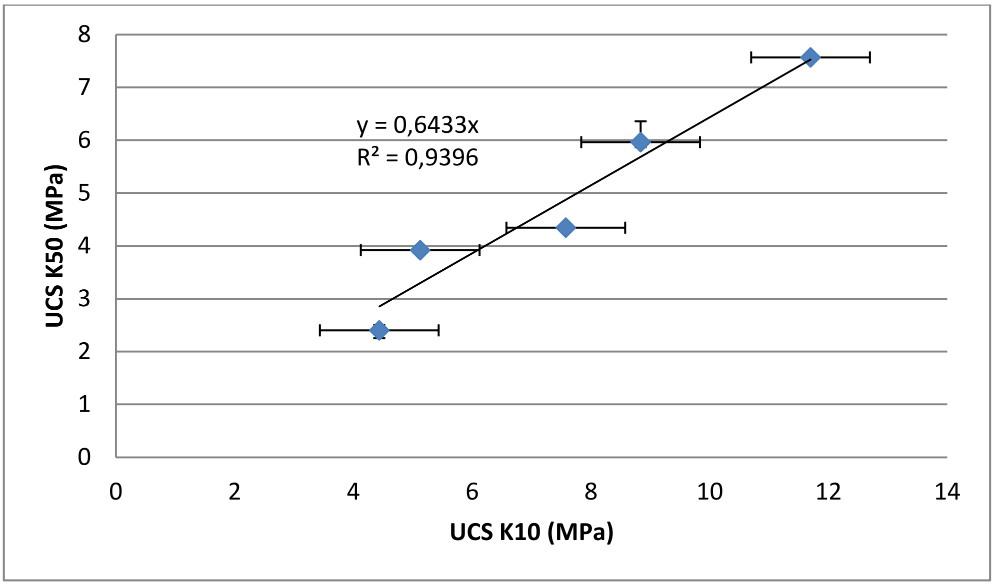

FIGURE 45 RELATION BETWEEN UCS OF K10 AND K50

4.3.3 P-WAVES AND DYNAMIC ELASTIC YOUNG MODULUS

The dynamic Young modulus or elasticity modulus was determined using the ultrasonic wave velocity device, as described in the previous chapter. The equation from which the dynamic modulus can be determined is the following:

$$E_0 = \rho \times V_p^{\ 2}$$

Where :

- E_0 = dynamic modulus in MPa;
- $\rho = kg/m^3$
- V_p = ultrasonic P wave velocity in m/s

However previous researchers carried out by (Ahnberg and Holmen, 2011) recommend a value of Poisson ratio of 0.30. Other studies have shown a value of dynamic Poisson ratio of in-situ cement treated soils of 0.25 to 0.45. Therefore for a known Poisson coefficient, the following formula may be used:

$$E_0 = \rho \times \frac{(1+\nu)*(1-2\nu)}{1-\nu} \times V_p^{\ 2}$$

Where :

- E_0 = dynamic modulus in MPa
- ρ – kg/m^3
- ν – dynamic Poisson ratio;
- V_p – ultrasonic P wave velocity in m/s

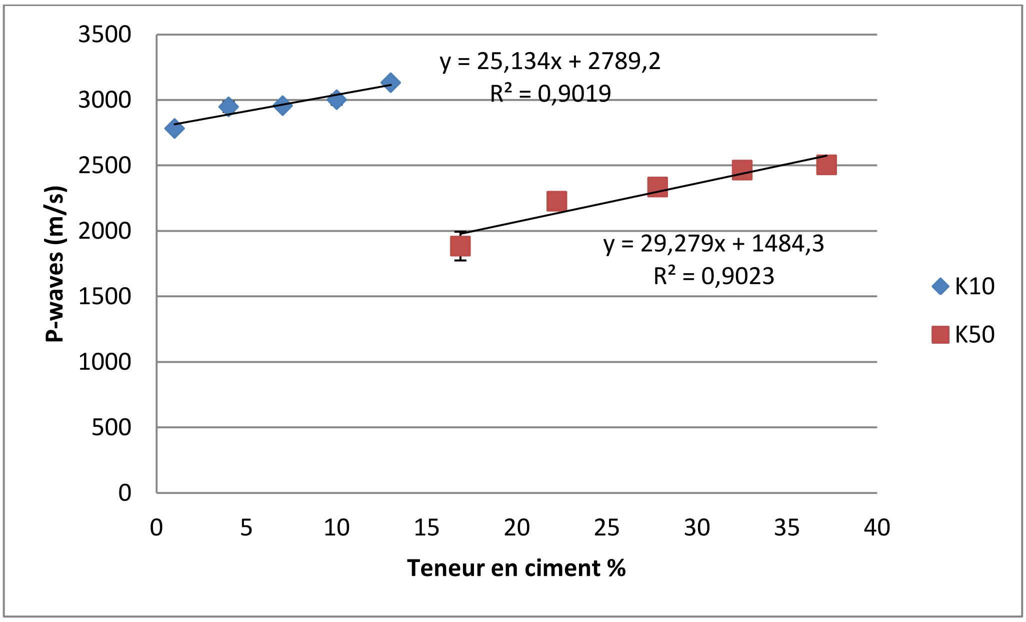

FIGURE 46 P-WAVES DETERMINED AT 28 DAYS

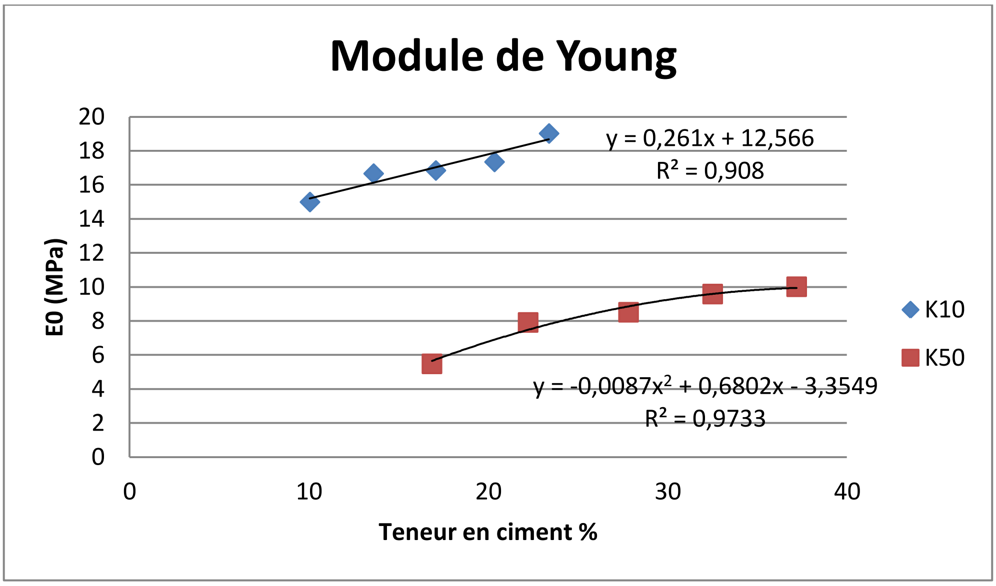

FIGURE 47 DYNAMIC YOUNG MODULUS DETERMINED AT 28 DAYS

It may be observed that the two graphs have different behavior: the P-waves have a linear growth whereas the graph of the Dynamic modulus shows different behaviors: the K10 mix has a positive growth while the behavior of the K50 formulation shows a negative growth. For the P-wave graph the K50 formulation has lower values than the K10 whereas the higher values of E0 are reached by K50.

4.3.4 TEMPERATURE

The temperature influenced the hydration process of the cement so a higher cured temperature it augments the compressive strength.

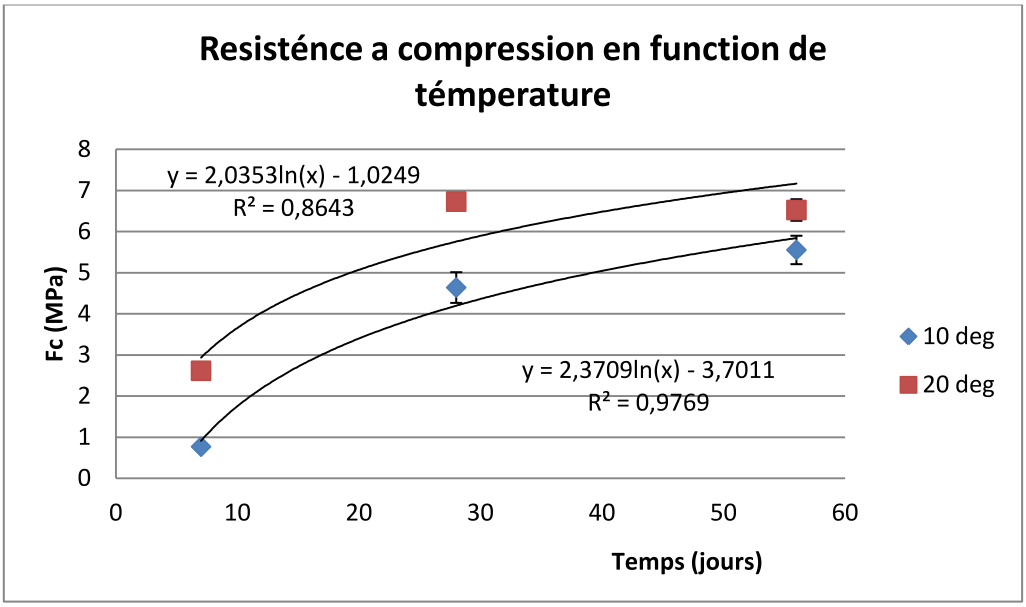

FIGURE 48 UCS TESTED AFTER 7/14/28 DAYS FOR DIFFERENT STORAGE TEMPERATURES

The two curves have a logarithmic growth. From the graph we notice a lower resistance for the samples stored at 10 degrees. In particular the difference between the two curves lies between about 1.8 MPa after 7 days and it gets till 1 MPa after 28 days. We can say so that a higher cured temperature gives a higher compressive strength but with the time, it seems that the difference between the two curves tends to reduce.

4.3.5 INCLUSIONS

The samples with inclusions have been tested at two different essays: Unconfined Compressive Strength and the cycles of charge and discharge to calculate the deformation of the sample.

The UCS test gave the following result:

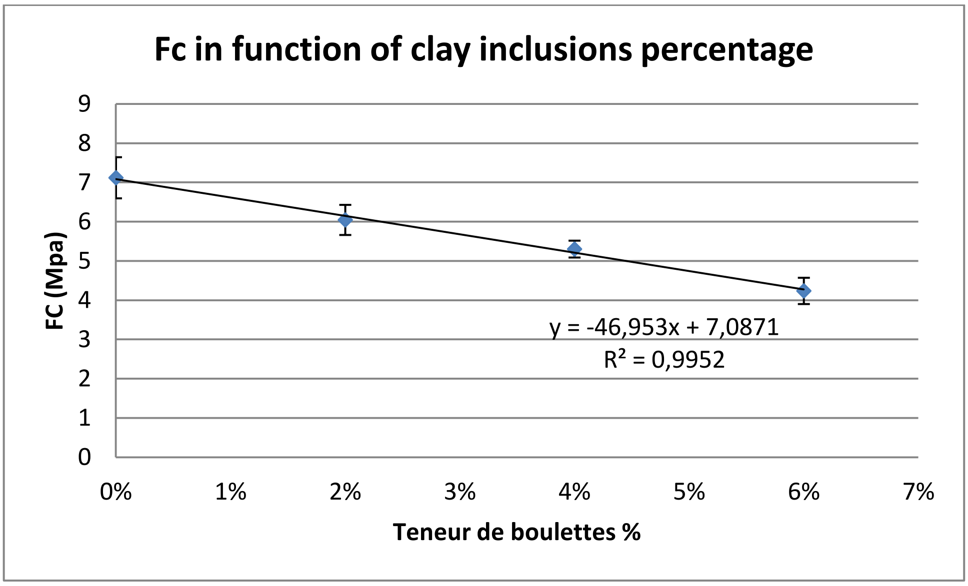

FIGURE 49 UCS TESTED AFTER 56 DAYS FOR DIFFERENT INCLUSIONS CONTENT

As we can see from the graph, the quantity of spheres changes the compressive strength of the samples. In fact, as the percentage of spheres augments, the Fc descends with a linear tendency: an increase of 2% it leads to a decrease of about 1 MPa on the resistance. The difference between the maximum Fc of the samples without inclusions and the samples with inclusions is about 3 MPa. From the graph below we can see the difference between the elastic modules (axial and lateral) of the samples with different content of inclusions. It seems that the axial module it does not follow a linear decrease. There is a difference of about 17% among the module elastic of the sample with no inclusions and the samples with inclusions.

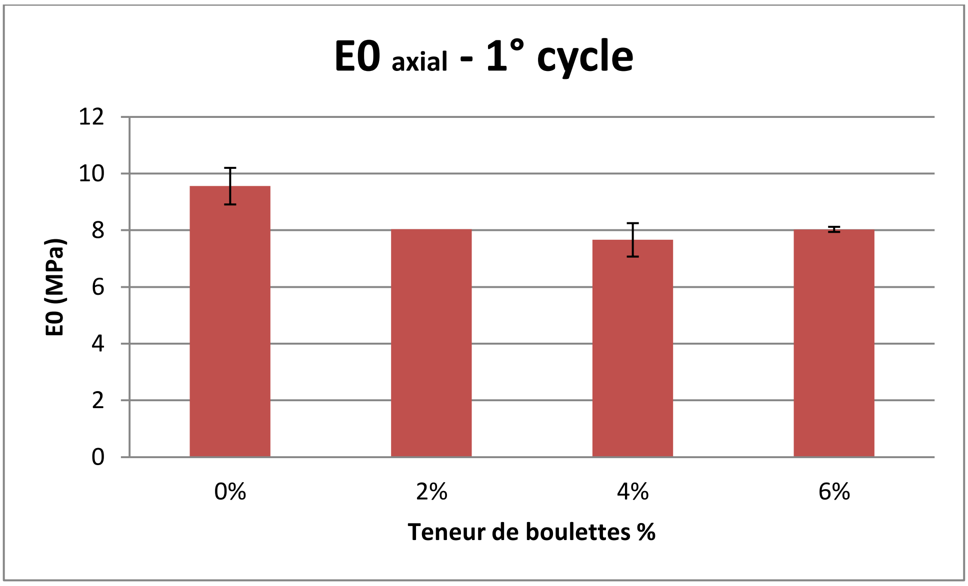

FIGURE 50 AXIAL YOUNG MODULE MEASURED FOR THE FIRST CHARGE AND DISCHARGE CYCLE

The lateral module elastic instead seems to follow a linear decrease and the difference of the module elastic among the samples with and without inclusions is about 12%.

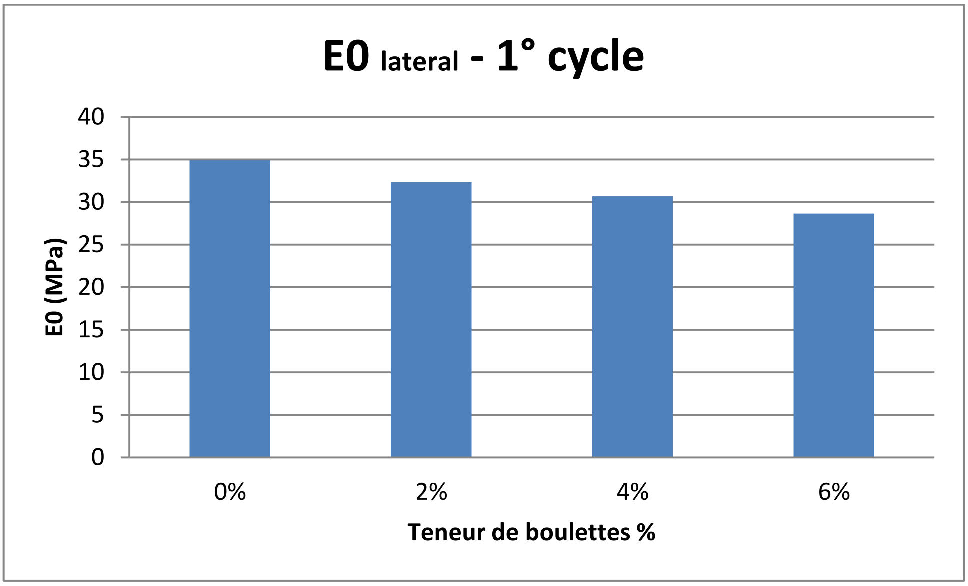

FIGURE 51 LATERAL YOUNG MODULE MEASURED FOR THE FIRST CHARGE AND DISCHARGE CYCLE

Comparing and standardizing the behavior of all the axial modules of the samples it has been obtained this graph:

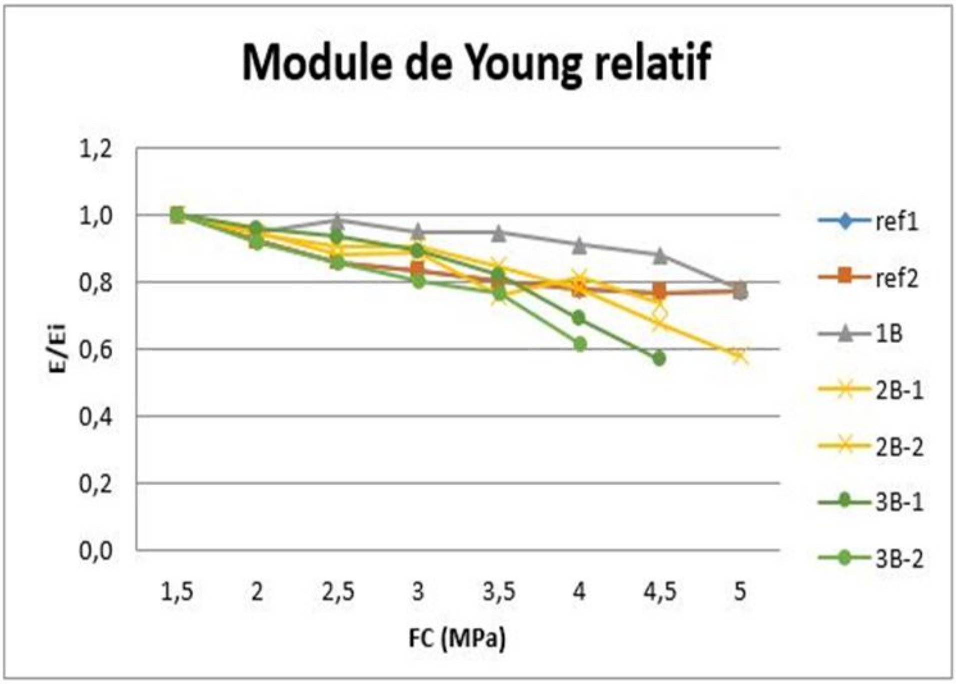

FIGURE 52 STANDARDIZING YOUNG MODULE FOR DIFFERENT INCLUSIONS CONTENT

It shows a decreasing behavior as the stress applied augments. First of all we can see the particular behavior of one of the curve with 2 spheres: the curve presents continuous decreases and increases as the stress augments so we can imagine that there must have been some problems with the gauge. As we can see, till 3 MPa the behavior of the curves it doesn't present big change but we notice that the decrease of the module of the samples without inclusions is as similar as the one with the sample with 3 inclusions. After 3.5 MPa the module of the samples with 3 spheres has a fast decrease. We can also notice that the presence of one inclusion per layer doesn't influence too much the decreasing of the module elastic.
The Poisson coefficient is as follows

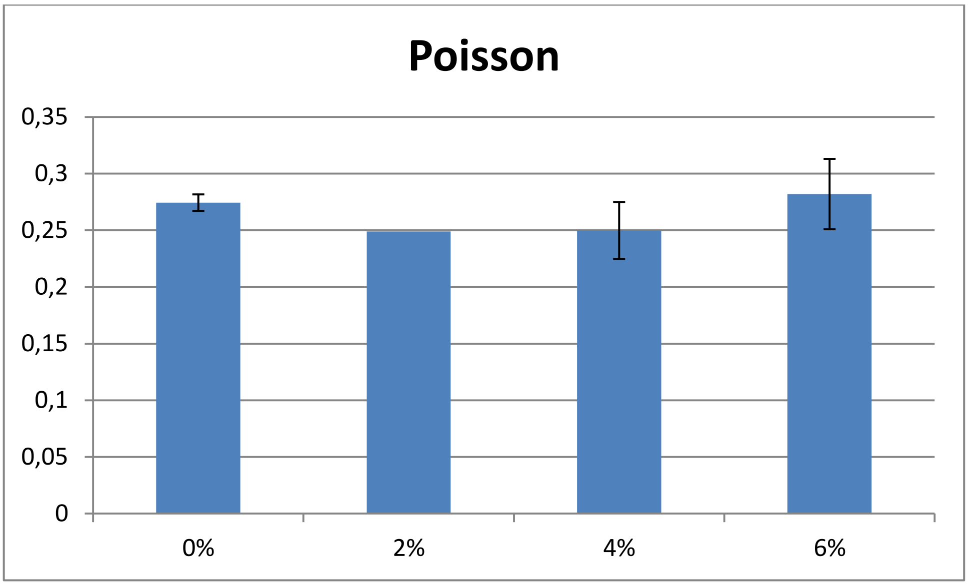

FIGURE 53 POISSON MODULE MEASURED FOR THE FIRST CHARGE AND DISCHARGE CYCLE FOR DIFFERENT INCLUSIONS CONTENT

As we can see from the graph, the use of clay spheres does not affect that much the coefficient of Poisson. In fact it's included between 0.25 and 0.3.

The last graph analyzed is the Stress-Strain curve:

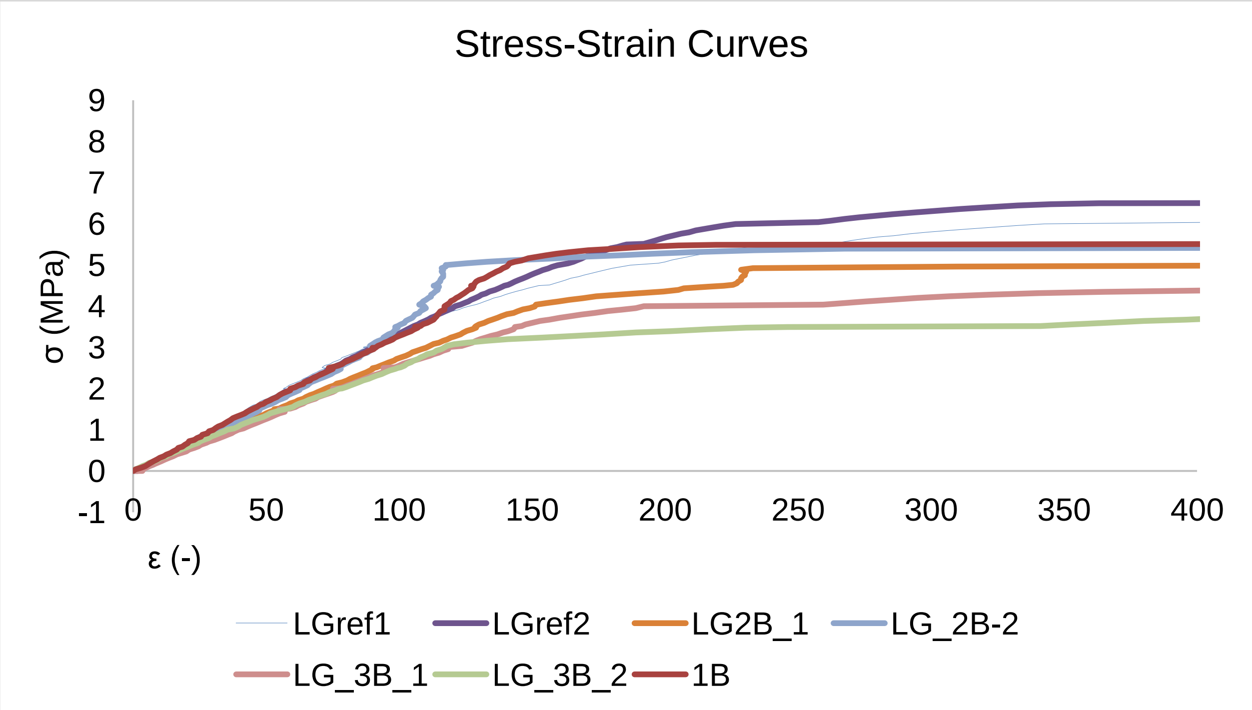

FIGURE 54 STRESS-STRAIN CURVES OF MANY CHARGE AND DISCHARGE CYCLES FOR SAMPLE WITH DIFFERENT INCLUSIONS CONTENT

The graph shows the behavior of the samples exposed to cycles of charge and discharge. As first impression we can confirm the fact that the gauge on the sample with two inclusions has been unglued after a strain of about 100 µm. From the other curves we can confirm that the presence of the spheres influences the resistance of the samples. The strength increases when it decreases the presence of the inclusions.

We can affirm otherwise that the presence of the inclusions do not affect sensibly the module elastic of the material as the slope of the curves is approximately the same for all the cases until a stress of about 3MPa.

CHAPTER 5_ CONCLUSIONS

The main objective of this research, conducted at Cergy- Pontoise University, was to study the behavior of the soil- mixing and in particular the influence of different quantity of cement on the mechanical and physical characteristics of the mix. It has been study also the influence that clay inclusions and temperature, together with curing time, have on the strength of the soil- mixing. To do this, artificial soils with controlled cement quantity were made.

Different essays have been done: P-waves measurements, UCS (on samples with different dosages of cement: 150; 200; 250; 300; 350 kg/m³) and again UCS on samples stored at different temperatures and test with gauges with whose samples were exposed at charge and discharge cycles.

The density is influenced by the amount of binder put into the mix, when it augments the quantity of cement in the mix, the density of the mix K10 seems to remain about the same whereas the density for the K50 seems to augment. We can also say that the density of the formulation with 10% has higher values than the values for the formulation with 50% of kaolinite. This might be explained by the fact that a higher quantity of kaolinite needs more water to obtain the same workability of 32 cm.

The UCS is shown to be higher for the formulation with 10% of kaolinite and in particular the highest value reached is about 11 MPa with a cement quantity of 350 kg/m³. The ideal clay quantity is then 10% as it has been proved by other studies (Helson, 2014). We can also say that the increase of cement percentage leads to an increase of strength that is faster for the formulation with 10% of kaolinite.

The P-waves of both the mixes have a linear growth with higher values for the mix with 10% of kaolinite but this tendency is not reflexed on the behavior of the Module Elastic. While the K10 seems to follow a linear growth, the K50 shows a negative growth.

The cured temperature and the time of curing of the soil-mix influence the strength. In fact the samples stored at 20 degrees show higher values of strength compared to the values of the samples stored at 10 degrees. The difference between UCS values after 7 days is about 1.8 Mpa and after 56 days is about 1.2 MPa. We can also remark that the resistance of the samples stored at 10 degrees it augments with the cured days so we can imagine that with time the difference between the two curves tends to reduce.

In the end the characteristics of soil-mix with clay inclusions have been studied. The results of the UCS test show that the inclusions have an influence on reducing the strength of the samples. We saw that the decrease on resistance is linear and an increase of about 2% of inclusions in the sample leads to a reduction of about 1MPa of resistance.

The lateral module elastic has shown a linear decrease as the quantity of clay inclusions increased whereas the axial module elastic didn’t show a constant behavior. The average reduction of the axial module elastic among the samples with inclusions and the sample without inclusions is about 17%.

Standardizing the axial module elastic in function of Fc we noticed that the presence of the inclusions leads to a decreasing behavior of the resistance. The higher is the percentage of the inclusions, the higher is the decrease.

Eventually the stress-strain curves confirms that a higher percentage of clay spheres involved a decrease of the resistance but that until a certain stress value (about 3 MPa) the module elastic doesn’t show sensible change.

Bibliography

1. ASTM D 2216. 2008. Standard Test Methods for Laboratory Determination of Water
(Moisture) Content of Soil and Rock by Mass.
2. ASTM D 5058. 1997. Standard Practices for Compatibility of Screening Analysis of Waste .
3. BS 1377: Part 2. 1990. Methods of test for soils for civil engineering purposes. Classification tests.
4. BS 1377: Part 8. 1990. Methods of test for soils for civil engineering purposes. Shear strength tests (effective stress) .
5. Darcy. 1856. Les Fontaines Publiques de la Ville de Dijon. Dalmont, Paris. 647 p. & atlas. ("The Public Fountains of the City of Dijon" is a lengthy work.
6. Denies, N. 2012a. Soil Mix walls as retaining structures - Belgian practice. Proceedings of the International symposium of ISSMGE - TC211. Recent research, advances & execution aspects of ground improvement works. 31 May - 1 June 2012, Brussels,Belgium, Vol. 3,
7. EN 12390. 2004. Testing hardened concrete. Shape, dimensions and other requirements for specimens and molds .
8. EN 12504-4. 2004. Testing concrete. Determination of ultrasonic pulse velocity.
9. Helson, O. 2014. Influence de l'argilosité du sol sur les propriétés physico-mécaniques des bétons de sol.
10. K.H. Head. 1998. Manual of Soil Laboratory Testing - K.H. Head - Volume 3 - Effective Stress Tests.
11. Kitazume et al. 2012. An application of wet grab sampling to quality assurance of wet type cement stabilized soil, Proc. of the 4th International Conference of Grouting and Deep Mixing.
12. NF P 94-050. 1996. Sols : reconnaissance et essais - Détermination de la teneur en eau pondérale des matériaux - Partie 1 : méthode de la dessiccation au four à micro-ondes.
13. Richardson, S. C. 1991. Soil Use and Management.
14. Poenaru, A., 2014. Physico-mechanical characterization of stabilized soils by Deep Mixing – The influence of kaolinite content. Stage report, Universite de Cergy-Pontoise,
15. Helson, O., 2013. Etude des performances des betons de sol : formulation, proprieties mecaniques et durabilite. Stage report, Universite de Cergy-Pontoise, 74 pages
16. Ahnberg and Holmen. 2011. Assesment of stabilied soil strength with geophysical methods. Ground Improvement, vol. 164, no. 3
17. Van Lysebetten, Vervoort, Maertens, Huybrechts. Discrete element modeling for the study of the effect of soft inclusions on the behavior of soil mix material

18. O. Carasca. The physical and mechanical characteristics of soilcrete determined by laboratory test