UNIVERSITY OF SAAD DAHLAB – BLIDA 1

Faculty of Technology

Department of civil engineering

THESIS OF MASTER'S

Faculty : Civil Engineering

Speciality : Geotechnical Engineering

Title :

INFLUENCE OF DIFFERENT TYPES OF FINES ON MECHANICAL BEHAVIOR OF ZEMMOURI SAND -LABORATORY STUDY

Presented by ;

ADAN Ikram Hassan

In front of the Jury :

D.AMAR BOUZID	Professor U. Saad Dahleb-Blida 1	President
Y.ABED	Lecturer U. Saad Dahleb-Blida 1	Examiner
LEILA HAZOUT	Lecturer U. Saad Dahleb-Blida	Supervisor

Blida, 2021/2022.

ACKNOWLEDGEMENT

All praise and thanks belongs to Allah subhana wataala, Lord of majestic throne for enabling me to be able to accomplish this work and for His many bounties in my life which is uncountable الحمدلله كثيرا

To Dr .Hazout Leila whom I can’t express my full gratitude to her and it is next to impossible to pay her for her dedication ,suggestions, time, effort, continuous support, encouragement for research, correction and most importantly accepting to supervise this thesis .Her competence and experience in the field of engineering was of great help in accomplishing this work and helped me solve all the problem that I encountered and answering diverse question during my studies of this thesis, May Allah subhana wataala reward her immensely in this life and next life.

I thank the members of the jury for accepting to judge this thesis, I appreciate.

To Mr.OUIR Youcef I return my gratitude for receiving me well at their laboratory to do my practical .I owe my deepest gratitude to the practical supervisor, Mr.Bouziane ,Engineer in the laboratory of mechanical of soil at national higher school of hydraulics in Blida, Algeria ,for technical assistance in lab ,management of testing materials of my thesis and taking an extra time in his schedules for us to accomplish the work ;he gave me each and every opportunity to learn .To Mr. HADJ Sadok Ahmed and Eng .Mohamed Ali Mohamed I appreciate their support while doing my research in hydraulics schools.

To the entire fraternity of the faculty of engineering at university of Saad Dahlab Blida -1,my deepest appreciation for helping me acquire knowledge in civil engineering,to promotion 2021/2022 geotechnicians,the class representative Flitta Yusra,to Medjoudbi Mounira ,I appreciate for always being there and helping me in my studies whenever I needed help.

To my family in Algeria, Kenyan students in Blida ,the Girls from Mali(hostel 5),the Chaddians ,Aziizi Baguma Ugandan(hostel 6), to the one who became my mother in Algeria madam Amal Meguetounif,together with her family, and all those who supported me in one way or the other I appreciate everything.

Last but not least ,I would like to thank my dear mum ,Lula Mohamed for her support in my journey of studies , encouragement and long distance love ,also appreciation goes to my biological dad, Hassan Adan for financial intervention where necessary in my studies, to Adan Muminna also ,May ALLAH subhana wataala reward them.

Dedication

*To my dearest mother ,Lula mohamed who believed in me ,supported, encouraged and always showed me love and care,*حفظها الله

To my siblings ,Samira Hassan ,Khadija Abdikheir and Siraju Rahman Abdikheir may Allah protect them

To my grandfather may jannatul firdows be his final abord,my grandmother and my aunt Halima Abdi may Allah grant them long life.

To the whole Abdi and Adan family may Allah preserve them

To Abdulrazak Abdullah may Allah protect and preserve him for the encouragement.

To Eng. Shuaib Abdurahman Ahmed and Eng.Alfred Mwambingu for there support from the beginning of my university journey till the end.

Abstract

The shear strength of soils is one of the most important parameters in the study and design of structures. Several researchers have studied the effects of different types of fines on the mechanical and physical behavior of soils. In the literature there are many controversies in the results interpretation concerning the resistance, the deformations, mechanical characteristics...

The objective of this research work is to study the effect of different types of fines on the behavior of Zemmouri sand mixed with three types of fines, such as (sand-fly ash mixtures, sand-Kaolin mixtures and sand-bentonite mixtures), for a range of fines content varying from 0% to 30%, using the Casagrand direct shear box, considering the influence of the plasticity index parameter on the mechanical response of the mixtures for the different types of fines tested. All sand samples were reconstituted by the dry pluviation method at an initial relative density (Dr=55%). The obtained results indicate clearly that the fine content has a significant influence on the mechanical behavior of the studied soils. Moreover, the outcome of this research work show that the sand –fly ash mixtures indicate a higher shear strength at the elastic phase, up to the steady state in comparison to sand-bentonite and sand-kaolin mixtures for the three normal stresses. However, sand –fly ash mixtures exhibit a remarkable phase of dilation compared to sand kaolin and sand bentonite mixtures, in which they reach the contract (cotractance) phase quickly. When comparing the three groups of sand mixtures, we notice that adding fines decreases relatively the shear resistance with the increase of fine content percentages for the three types of fines, as well as, the three normal stresses. Furthermore, the trend cited above is well pronounced and is clearly noticed in the case of sand kaolin-mixtures, where the shear strength falls sharply with the increase of the fine percentage, at the highest normal stress. The results found indicate that adding fine content induces a small variation in the mechanical responses for the three types of fines considered, therefore we concluded that for Zemmouri Sand there is no improvement in terms of mechanical response.

Key words: Sand, fly ashes, bentonite, kaolin, shear strength, mechanical characteristics, fine content.

Résumé

La résistance au cisaillement des sols est l'un des paramètres les plus importants dans l'étude et la conception des ouvrages. Plusieurs chercheurs ont étudié les effets de différents types de fines sur le comportement mécanique et physique des sols. Dans la littérature il existe de nombreuses controverses dans l'interprétation des résultats concernant la résistance, les déformations, les caractéristiques mécaniques...

L'objectif de ce travail de recherche est d'étudier l'effet de différents types de fines sur le comportement du sable de Zemmouri mélangé à trois types de fines, telles que (mélanges sable-cendres volantes, mélanges sable-Kaolin et mélanges sable-bentonite), pour un interval de teneur en fines variant de 0% à 30%, utilisant la boîte de cisaillement direct, en considérant l'influence de l'indice de plasticité sur la réponse mécanique des mélanges pour les différents types de fines utilisés. Tous les échantillons de sable ont été reconstitués par la méthode de la pluviation a sec à une densité relative initiale (Dr=55%). Les résultats obtenus indiquent clairement que la teneur en fines à une influence significative sur le comportement mécanique des sols étudiés. De plus, les résultats de ce travail de recherche montrent que les mélanges sable-cendres volantes indiquent une résistance au cisaillement plus élevée à la phase élastique, jusqu'au régime permanent par rapport aux mélanges sable-bentonite et sable-kaolin pour les trois contraintes normales. Cependant, les mélanges sable-cendres volantes présentent une phase de dilatation remarquable par rapport aux mélanges sable kaolin et sable bentonite, dans laquelle ils atteignent rapidement la phase de contratance. En comparant les trois groupes de mélanges de sable, on remarque que l'ajout de fines diminue relativement la résistance au cisaillement avec l'augmentation des pourcentages de teneur en fines pour les trois types de fines, ainsi que les trois contraintes normales. De plus, la tendance citée ci-dessus est bien prononcée et se remarque clairement dans le cas des mélanges sable-kaolin, où la résistance au cisaillement chute fortement avec l'augmentation du pourcentage des fines, sous la contrainte normale la plus élevée. Les résultats trouvés indiquent que l'ajout des fines fin une faible variation des réponses mécaniques pour les trois types considérés. Nous avons donc conclu que pour le sable de Zemmouri, il n'y a pas d'amélioration en termes de réponse mécanique.

Mots clés : Sable, cendres volantes, bentonite, kaolin, résistance au cisaillement, réponse mécanique, fines

ملخص

تعتبر قوة القص للتربة من أهم العوامل في دراسة وتصميم الهياكل، قام العديد من الباحثين آثار أنواع مختلفة من المواد الدقيقة (من تربة دقيقة ومواد اخرى) على السلوك الميكانيكي والفيزيائي للتربة، يوجد في الأدبيات العديد من الخلافات في تفسير النتائج فيما يتعلق بالمقاومة والتشوهات والخصائص الميكانيكية.

الهدف من هذا البحث هو دراسة تاثير أنواع مختلفة من المواد الدقيقة مثل (مخاليط الرمل- الرماد المتطاير- مخاليط الرمل +الكاولين، مخاليط الرمل + البنتونيت)، مجال نسبة هذه المواد تتراوح من 0% إلى30 % باستخدام آلة القص المباشر(casagrand)ثم تكوين جميع عينات الخلائط بطريقة المطر بكثافة نسبية أولية تقدر بـ 55 % .

تشير النتائج المتحصل عليها بوضوح كبير على السلوك الميكانيكي للتربة المدروسة، علاوة على ذلك تظهر نتائج هذا البحث أن مخاليط الرمل مع الرماد المتطاير تشير إلى قوة قص الأعلى من الطور المرن إلى الحالة المستقرة مقارنة بمخاليط البنتونيت والكاولين مع الرمل ، كما أن مخاليط الرماد المتطاير تظهر مرحلة ملحوظة وواضحة من التمدد مقارنة بالمخاليط الأخرى التي تصل إلى المرحلة المستقرة بسرعة.

عند مقارنة المجموعات الثلاثة من الخلائط نلاحظ أن إضافة المواد الناعمة تقلل نسبيا من مقاومة القص مع زيادة نسب المحتوى الناعم بالنسبة للأنواع الثلاثة، وكذا تحت الضغوط الثلاثة، علاوة على ذلك فإن الاتجاه المذكور أعلاه واضح بشكل جيد في حالة مخاليط الرمل بالكاولين، حيث تنخفض مقاومة القص بشكل حاد مع زيادة النسبة المئوية عنه على الضغط.

تشير النتائج إلى أن إضافة محتوى المواد الناعمة بالنسبة إلى جميع النسب يؤدي إلى تباين بسيط في الاستجابات الميكانيكية للأنواع الثلاثة من المواد الناعمة، لذلك خلصنا إلى أنه لا يوجد تحسن فيما يخص الاستجابة الميكانيكية لرمال زموري.

الكلمات المفتاحية:

قوة القص، الرماد المتطاير، بنتونيت، الكاولين، الرمل، الخصائص الميكانيكية، المواد الناعمة.

Table of Contents

CHAPTER 3: Effect Of Fines Content On The Mechanical Behavior Of Zemmouri Sand

CHAPTER 4: Effect Of The Nature Of The Fines On The Shear Strength Of The Sandy Soils

LIST OF FIGURES

LIST OF TABLES

SYMBOLES AND ABBREVIATIONS

$A_{corrected}$	Corrected surface
AASHTO	American association of state highway and transportation officiel
ASTM	American society for testing and materials
Cc	Coefficient of curvature
Cu	Coefficient of uniformity
C	Cohesion
Dmax	Maximum diameter
Dmin	Minimum diameter
D_{10}	Effective diameter or diameter corresponding to 10% of the sieve
D_{30}	Diameter corresponding to 30% of the sieve
D_{50}	Average diameter or diameter corresponding to 50% of the sieve
D_{60}	Diameter corresponding to 60% 0f the sieve
Dr	Relative density
e	Void ratio
e_{max}	Void maximum ratio
e_{min}	Void minimum ratio
FA	Fly ash content
FB	Bentonite fine content
FC	Fraction of fines
FK	Kaolin fine content
FCth	Threshold content of fines
Gs	Specific gravity
IP	Index of plasticity
ISO	International Organization for Standardization
LCPC	Central Laboratory for Roads and Bridges
Ms	Mass of the soil
Np	Non-plastic
Pc	Pressure of confinement
P'c	Initial pressure confinement
PS	Dry pluviation method
USCS	Unified Soil Classification System

σn	Initial normal stress
τ	Shear strength
τmax	Maximum Shear strength
φ	Internal friction angle
Δh	Horizontal displacement
Δv	Vertical displacement

General introduction

General introduction

In the field of civil engineering, the construction of large structures requires a perfect understanding and identification of soils, based on observations and measurements in situ or in the laboratory. Soil is a mixture of different materials, where structures are erected, which why engineers must strive to understand its behavior and know its properties. The mechanical characterization and the stability of granular soils in particular, has always been one of the most important problems in the field of geotechnics. Despite previous studies, the published literature encompasses a great deal of experimental research that has been conducted to analyze and understand the fundamental phenomena that govern soil response. The study of the mechanical and physical characterization of granular soils treated and improved or found mixed in the nature by other materials, necessarily involves knowledge of the fundamental concepts controlling their behavior under the impact of various factors.

Fly ash, kaolin, bentonite are materials that have been introduced in the field of geotechnics in recent years, are among the parameters that play very important roles in understanding the mechanical response of soils.

Several search works were based on the impact of fines fraction and type of fines on the sand shear strength. Most search reports have shown the sand shear strength increases with the increase of non-plastic fines contents. On the other hand, other researches have shown opposite results, noting a decrease of shear strength with the increase of fine content in the mixture tested. In this case we conclude that the **difference in types of fines** is among the parameters that must be correctly identified in the control of mechanical response of granular soils.

The main objective of this experimental study is to perform direct shear tests, in order to study the effect of different types of fines such as: bentonite, kaolin, and fly ash on the behavior of Zemmouri sand from (Boumerdes). The choice of this material was due to the particular violent earthquake that shook this area, on May 21, 2003. whose magnitude was 6.7 on the Richter scale. This earthquake was the deadliest in Algeria since the 1980 El Asnam (currently chlef). has caused enormous deformations to the soil such as: landslides and liquefaction of sandy soils.

The material used, is a natural marine sandy soil, which was collected along the beach of Zemmouri el Bahri from liquefied soil deposit areas. And was mixed with three types of fines “Zemmouri sand- fly ash mixtures, Zemmouri sand-bentonite mixtures and

Zemmouri sand-kaolin mixtures" considering five fines content (Fly ash fines" FA", bentonite fines "FB", kaolin fines "FK" = 0%, 5%, 10%, 20%, 30%). All samples are reconstituted by the dry funnel pluviation method with an initial constant relative density (Dr = 55 %). and subjected to normal stress (σn=100,200 and 300kPa).

- The first chapter presents a bibliographic research, which is a synthesis of the work carried out on the influence of different types of fine and their nature on the mechanical response of soils, as well as, the influence of other parameters on the behavior of granular soils such as : effect of initial density, grain size, grain shape, etc…

The second chapter includes the presentation of the device used for the realization of this study, as well as, the direct shear box test procedure. Then, we discussed the methods adopted for the Zemmouri sand samples preparation and the mixtures components description (sand-bentonite, sand –kaolin, and sand-fly ash), showing some test carried out, and finally the presentation physical characteristics of the tested material.

The third chapter presents a deep analysis of the experimental results, the purpose is to study the influence of different fines percentages: such as, bentonite as high plastic fine, kaolin as low plastic fine, and fly ash as non-plastic on Zemmouri sand, from liquefied soil deposit area, forming three groups of samples: each group is subdivided to give five samples according to the percentages set for the related fine at 0%, 5%, 10%, 20%, 30%. The specimens were reconstituted at the lab by dry pluviation method with a medium dense initial relative density (Dr=55%) and which were subjected to three normal stress of 100,200 and 300kPa.

The fourth chapter presents a deep analysis of experimental results, the purpose is to study the effect of the nature of fines on the shear strength of sandy soil: such as, bentonite as high plastic fine, kaolin as low plastic fine, and fly ash as non-plastic on Zemmouri sand, from liquefied soil deposit area, forming three groups of samples: each group is subdivided to give five samples according to the percentages set for the related fine at 0%, 5%, 10%, 20%, 30%. The specimens were reconstituted at the lab by dry pluviation method with a medium dense initial relative density (Dr=55%) and which were subjected to three normal stress of 100,200 and 300kPa.

All the tests were made at the laboratory of Blida National Higher School of Hydraulics, thanks should be given to the staff who supported us and went out of their way to help us.

1.1 Introduction

Soils commonly found in nature are consisting of different mixtures and minerals. Soil mixture such as silty clays, clayey sands, silty sands, silts and clays, clean sand,… are most commonly found in nature. The realization of large structures requires a thorough understanding of the soil characteristics (physical, mechanical etc.) which is always based on observations and measurements in situ, or in the laboratory.

The mechanical behavior and stability of the granular soils has always been one of the most important problem that requires a detailed study analysis. When it comes to fines, their fraction in the sand has a great influence on the shear resistance and must be correctly identified in the control of the mechanical response of granular materials.

Fly ash, kaolin, bentonite are materials that have been introduced in the field of geotechnics in recent years, are among the parameters that play very important roles in understanding the mechanical response of soils. several researchers have studied the impact of fines content on the behavior of granular soils and they found different results regarding the effect of these parameters.

In this chapter, we begin a synthesis of research work in the field of granular soils and their behavior, emphasizing the influence of fines in general on their mechanical response, Then, we discuss the effect of some other parameters on the shear strength such as: relative density, grain size, fines content and deposition method.

1.2 General information on fines content and their effects on the soils mechanical response:

1.2.1 Effect of plastic and non-plastic fines presence

The effect of fine particles on the soils shear strength is not fully understood until today.

Troncoso (1990) studied the resistance to cyclic shearing of a mixed sand with different contents of fines (silts) from Fc =0% to Fc=30% with constant initial void ratio (e=0.85). He found that the cyclic shear strength decreases with the fines fraction increase. On the other hand, Koester (1994) showed from the results obtained on reconstituted samples with a variation of the fines fraction (Fc=0 to Fc =60%) and with an initial void index (e=0.48), that the cyclic strength decreases with the fines fraction increase. The results found by these two researchers confirm that the percentage of fines plays a very important role in the reduction of the inter-particle forces between the grains of sand and consequently the reduction in the resistance to cyclic shearing of the sand–silt mixtures as indicated by the **(Figure1.1**) (MERNI and ELEZAAR).

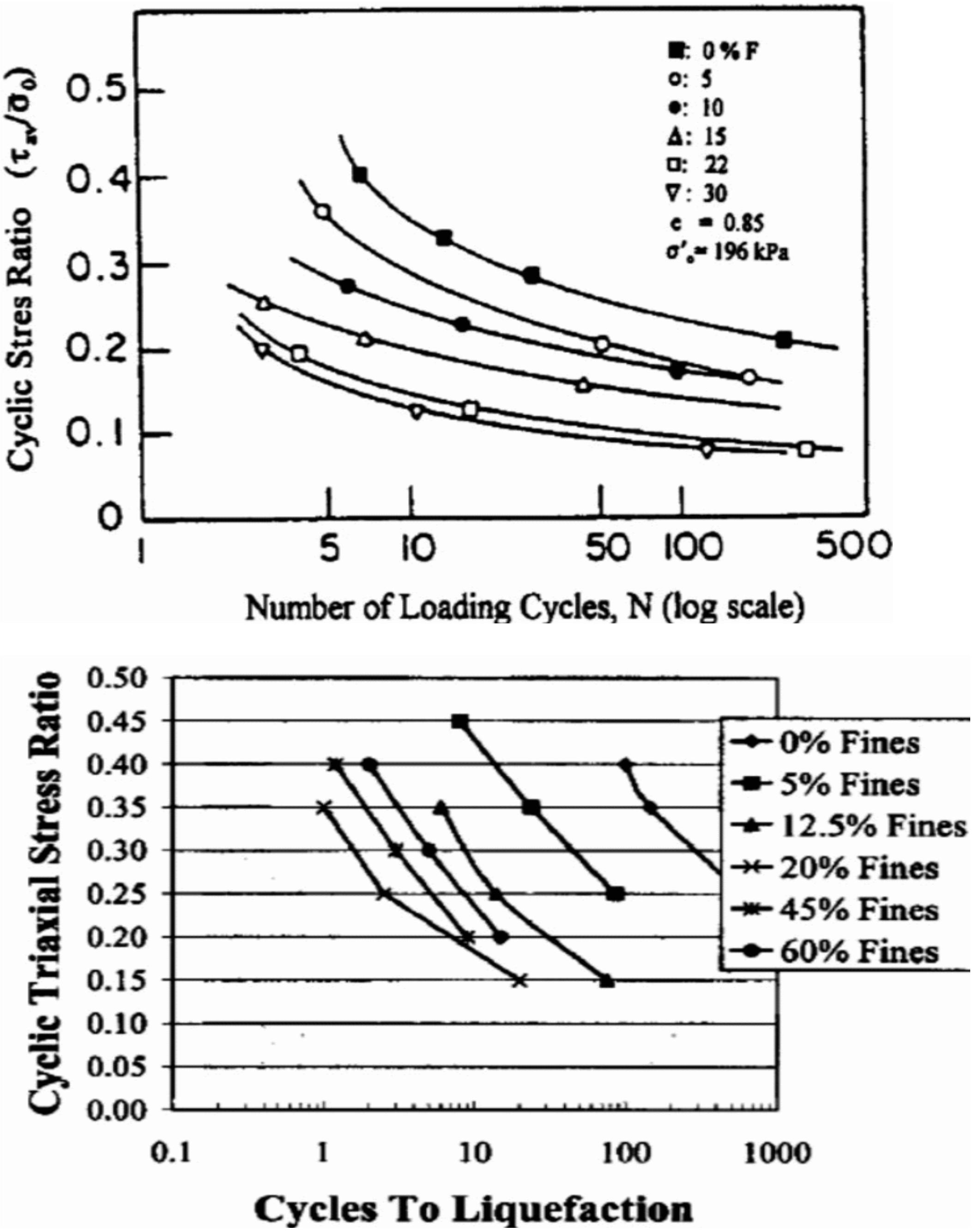


Figure 1.1 : Effect of fines content on shear strength non-drained from soil (a)Troncoso (1990) (b) Koester (1994).

Bengalia and al.(2014)carried out cyclic tests on two different sands, Chlef sand and Oued

Rass sand, with the aim of studying the influence of low plastic fines on the cyclic behavior of silty sand. They found that the cyclic resistance of the sand decreases with the increase in fines up to a limiting value Fc_{thre}=5% then it increases with the increase of fines for the two mixtures (Chlef sand mixed with Chlef silt) and (Oued Rass sand mixed with Chlef silt) as shown in **(Figure 1.2).**

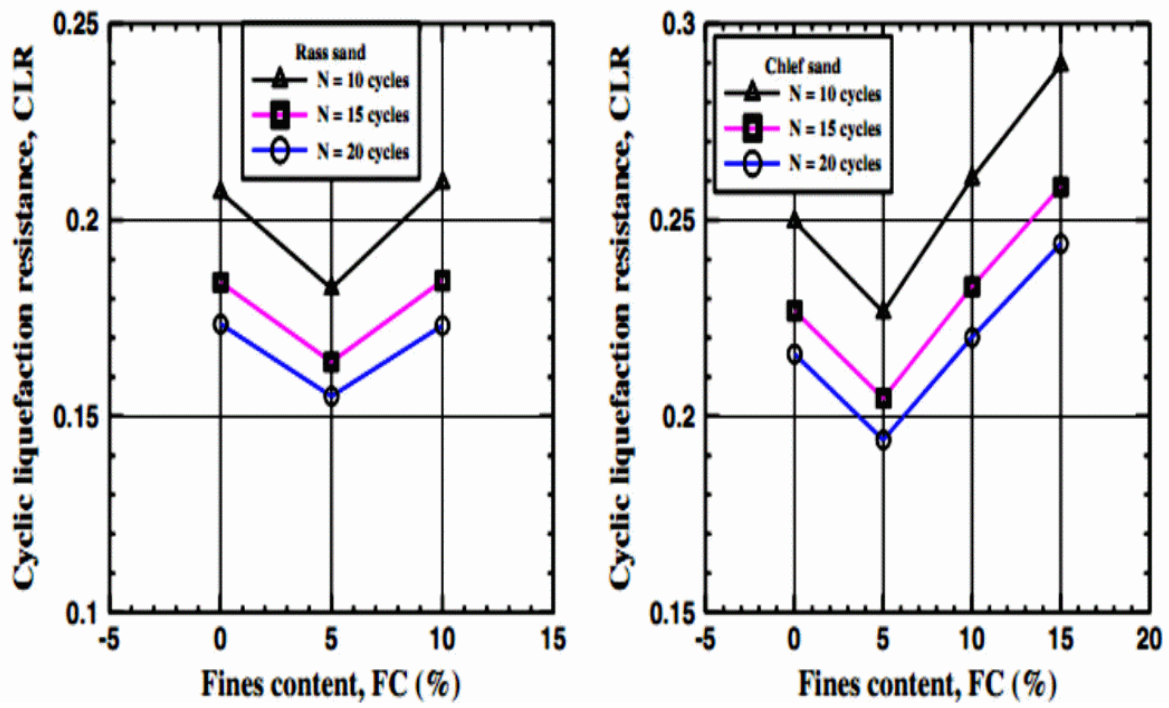
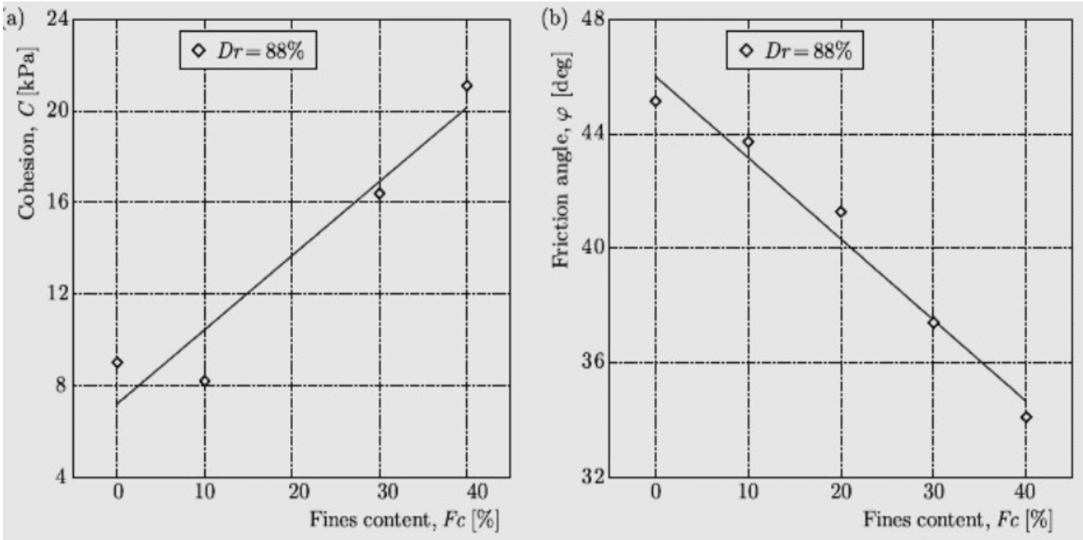


Figure 1.2: Effects of non-plastic fines on the cyclic behavior of sands Bengalia et al. (2014).

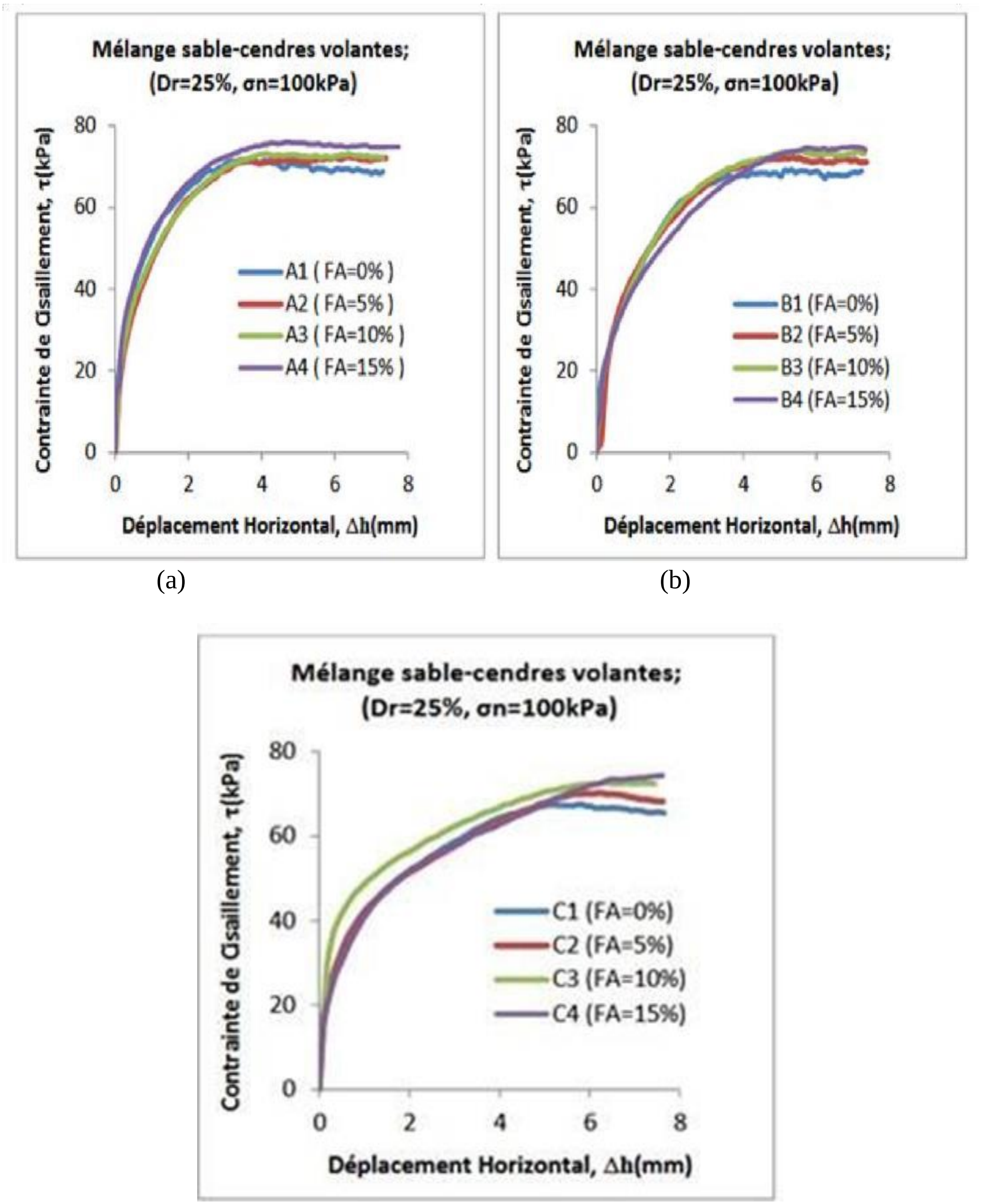
Flitti et al.(2016) carried out direct shear tests using the Casagrande apparatus, with the aim of identifying the influence of low plastic fines on the mechanical characteristics, such as the cohesion and the internal friction angle of the reconstituted sand-silt mixtures at the lab, with a relative density of 88%. They observed that the cohesion increases with the increase in fines content **(Figure 1.3a).** On the other hand, for the friction angle, they found that it decreases linearly with the increase in the low plastic fines **(Figure 1.3b).** This decrease in resistance is due to the presence of fine particles between the grains of sand which promote the reduction of contact between the large sand particles.



(a) (b)

Figure 1.3 : Variation of mechanical characteristics with fines content (a)cohesion as a function of fines content, (b)Friction angle as a function of fines content, Flitti et al.(2016).

Merni et Elezaar (2019) studied the influence of fly ash content on Chlef sand having different maximum diameters (0.63mm≤Dmax≥4.0mm) and minimum diameter (Dmin =0.08mm). Their samples were reconstituted with a loose sand with an initial relative density of 25% and subjected to a normal stress (σn=100kPa). They clearly showed that the proportion of fly ash has a remarkable effect on the mechanical characterization of the different granular classes of Chlef sand. They also found that the shear strength increases with increasing fly ash percentages from FA=0% to FA=15%. They also noticed that the samples having a maximum diameter (Dmax=4.00 mm) presents higher resistances compared to those having the maximum diameters (Dmax=2.00 mm and Dmax =0.63 mm) as shown in **(Figure 1.4).**



(a) (b)

(c)

Figure 1.4 : Effect of fly ash on mechanical behavior of sand -fly ash mixture (σn=100 kPa ,Dr=25%) (a)-Dmax =4 mm (b)-Dmax =2 mm (c) –Dmax =0.63 mm,Merni and Elezaar (2019).

Kermatikerman et al.(2018) carried out undrained triaxial compression tests on sand samples, reconstituted in the laboratory with fly ash contents (FA=0%,2%,4% and 6%) at a very loose initial relative density (Dr=20%) and subjected to an initial confining pressure (Pc=50kPa). According to their results, they showed that the addition of fly ash in the sand samples changed the behavior in terms of stress strain. They found that fly ash plays a very important role in amplifying the undrained shear strength of sands. They found that the undrained shear strength increases with increasing fly ash. This increase in resistance due to the fact that the fly ash contributed to the strengthening and augmentation of sand intergranular forces, as shown in **(Figure 1.5)**.

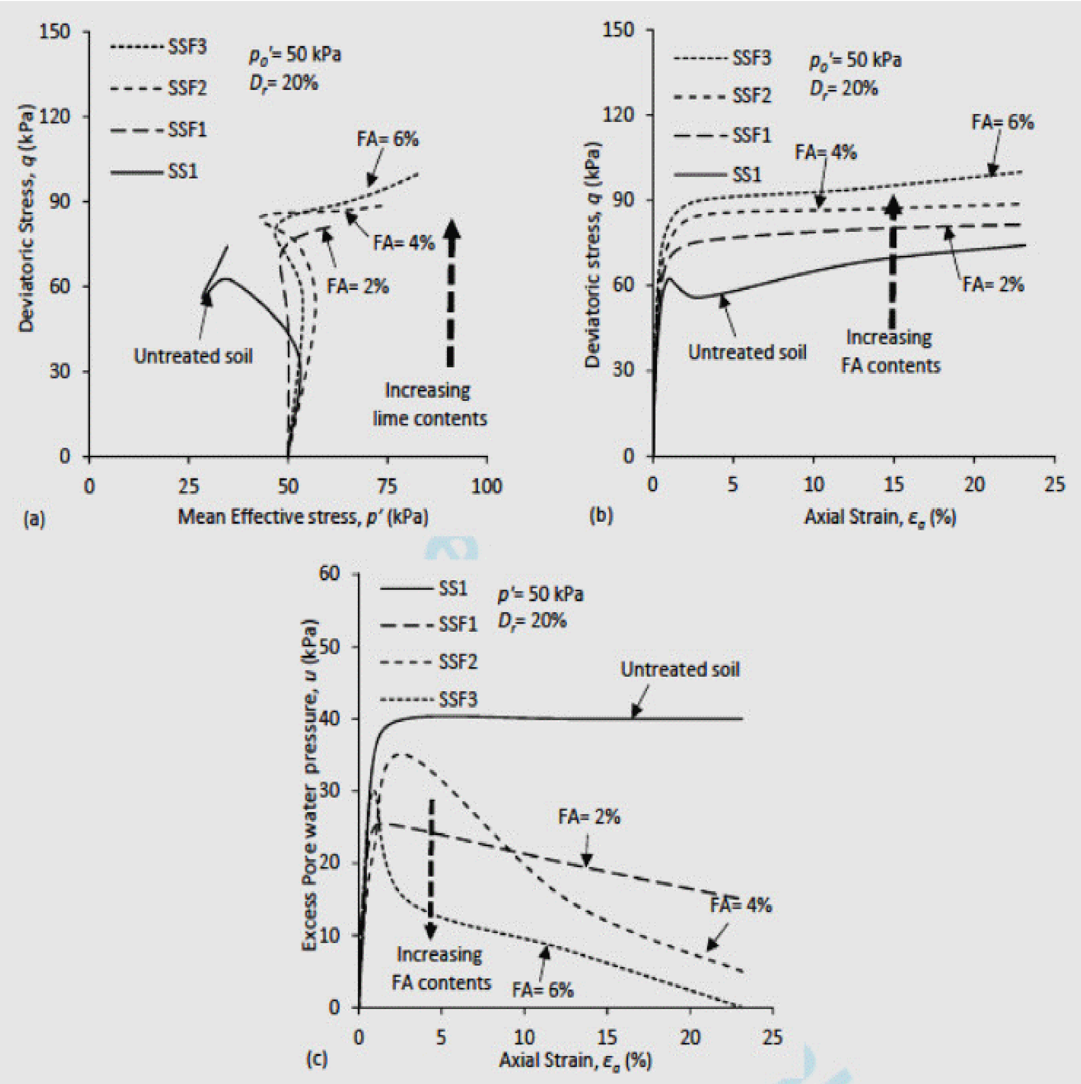


Figure 1.5 : Influence of fly ash content on undrained shear strength of granular soils. Kermatikerman et al. (2018).

Arab 2009, studied in the laboratory the influence of non-plastic fines on the behavior of silty sand. The study was based on monotonic drained and undrained triaxial tests, which were carried out on fines fractions varying from 0 to 50%; and cyclic tests carried out on fines fractions varying from 0 to 25%. The tests show that the increase in the fines content from 0 to 50%, induces a reduction of the shear strength, but affects slightly the characteristic angle. Residual strength decreases linearly and has a significant effect on the volumetric behavior which is manifested by an amplification of contractance phase when the fine fractions increase, especially for mixtures containing 25 to 50% of fines,as shown in (**Figure 1.6 ,1.7 and 1.8).**

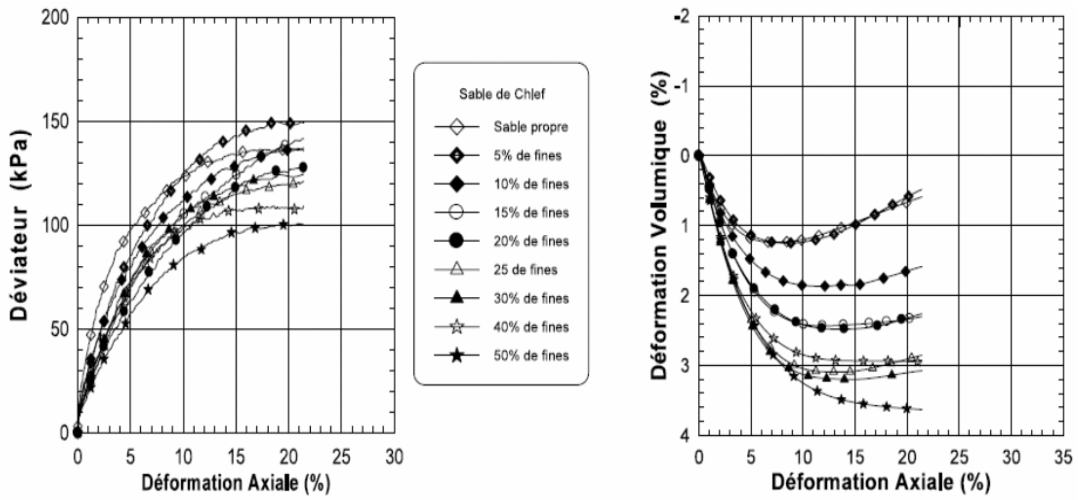


Figure 1.6 : Influence of the fines content on the drained response of the sand-silt mixture (Arab., 2009).

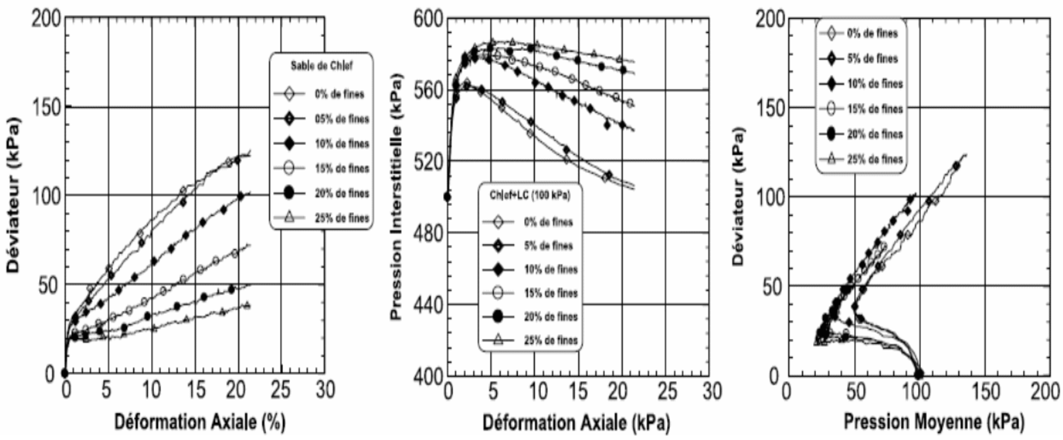


Figure 1.7 : Influence of the fines content on the undrained behavior of a sand-silt mixture (p´c = 100 kPa) (Arab., 2009).

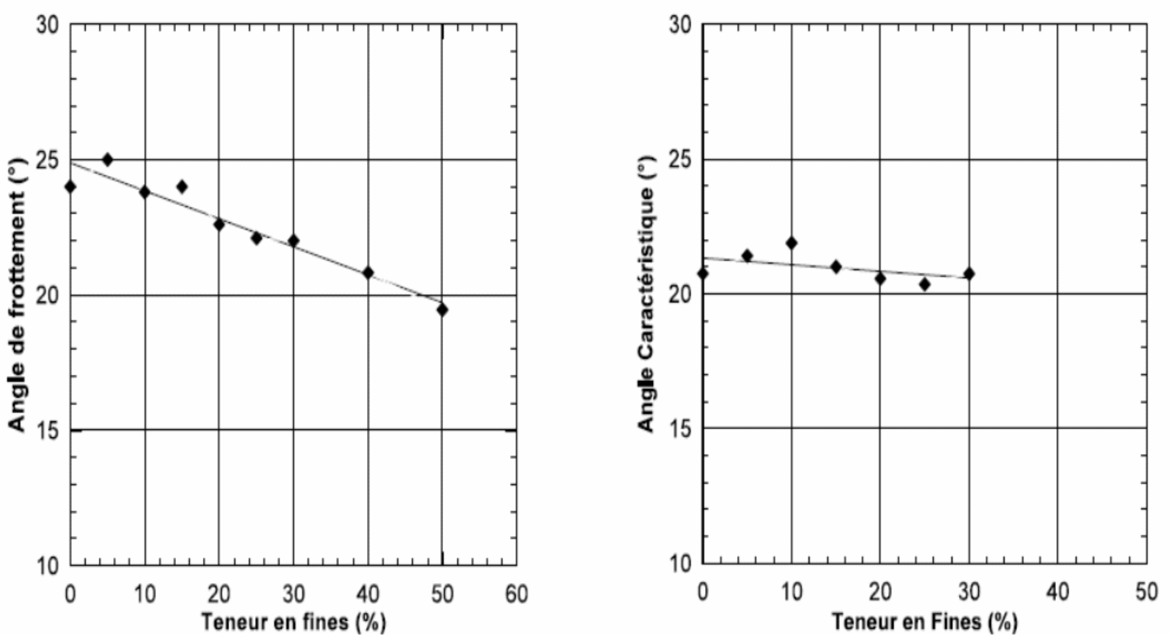


Figure 1.8 : Influence of fines fraction on internal friction angle and characteristic angle (Arab., 2009).

Rojimul and al.(2020) performed shear test on the sand–biochar mixture, with the aim of studying the effect of biochar on the shear strength parameters (C and Ø) of clayey sand .The samples were mixed with biochar fractions of (Fbio=0%, 5%, 10% and 15%) and subjected to three normal stresses (50kPa, 100 kPa and 150 kPa). They found that biochar content has noticeable effect on the shear strength of sand–biochar mixtures. They showed that increasing the percentage of biochar from Fbio =0% to Fbio=15% induces a remarkable increase in the shear strength of the soils studied. Moreover, they proved that biochar has a significant influence on the mechanical characteristics in terms of internal friction angle and cohesion of sand–biochar mixtures. The cohesion increases by 12.52kPa, 18.2kPa, 22.75kPa and 25.76 kPa with an increase of biochar fraction by 0%, 5%, 10% and 15% respectively. Furthermore, the addition of biochar (Fbio =0% to 10%) induces an increase in the internal friction angle of ϴ= 31.1 ± 0.5°,33.09°, 37.95° respectively. Beyond this value, the friction angle decreases (ϴ=37.53°) with an increase of biochar fraction for the tested soils as illustrated in (**Figure 1.9**).

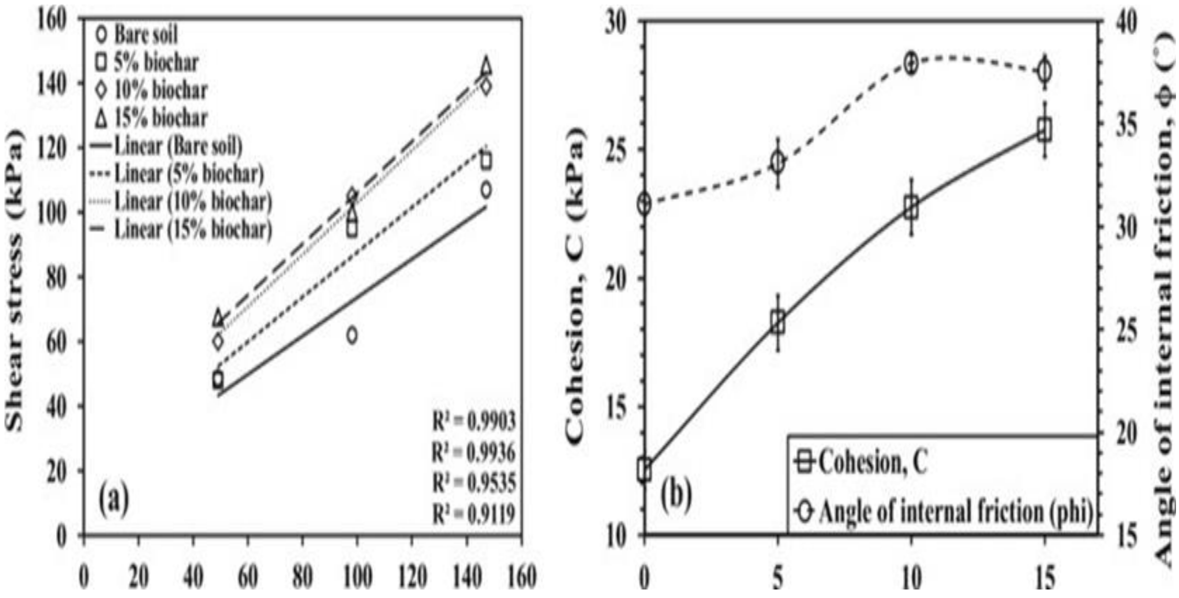


Figure 1.9 : Effect of biochar content on shear strength and mechanical characteristics of sand. Rojimul et al.(2020).

Derakhshandi et al.(2008) performed cyclic tests on mixtures of Monterey sand with a bentonite fraction, varying from (Fb=0%,10%,20% and 30%). Their samples were reconstituted in the laboratory with an initial relative density Dr=50%. They noticed that the excess pore water pressure increases significantly with an increase of bentonite fraction up to 10%. Beyond this value, it decreases for the percentage of 10% and 20%. On the other hand, beyond Fb=20%, they noticed a drop of the excess pore water pressure for soils tested as indicated in **(Figure 1.10).**

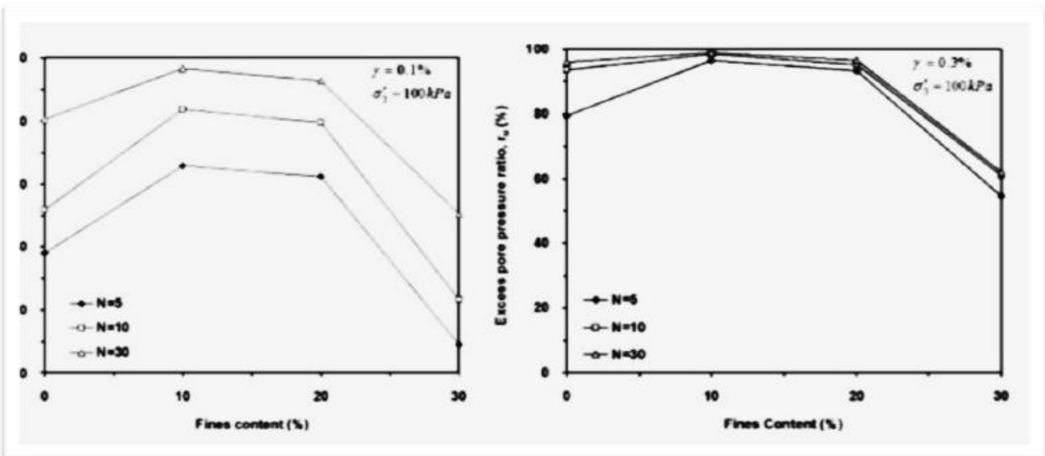


Figure 1.10 : Influence of the content of fine plastics on the over generation of pore pressure Derakhshandi et al.(2008).

Bouchibane et Ben Abdel –Mouttaleb (2020) examined the impact of bentonite content on the mechanical characterization of Chlef sand. The tests were carried out using a direct box shear device on specimens of Chlef sand mixed with bentonite contents (Fb=0%, 5%, 10%, 20% and 30%). The sand-bentonite mixtures were prepared using the dry pluviation method with an initial relative density (Dr=55%), and subjected to normal stress (σn = 100 kPa). They found that the percentage of bentonite has an impact on the mechanical characterization of the mixture of sand-bentonite; they showed that the shear strength decreases with the increase in the proportion of bentonite from (Fb=10%). Beyond this value, the increase in bentonite content induces an increase in the dilatancy phase as shown in**(Figure1.11).**

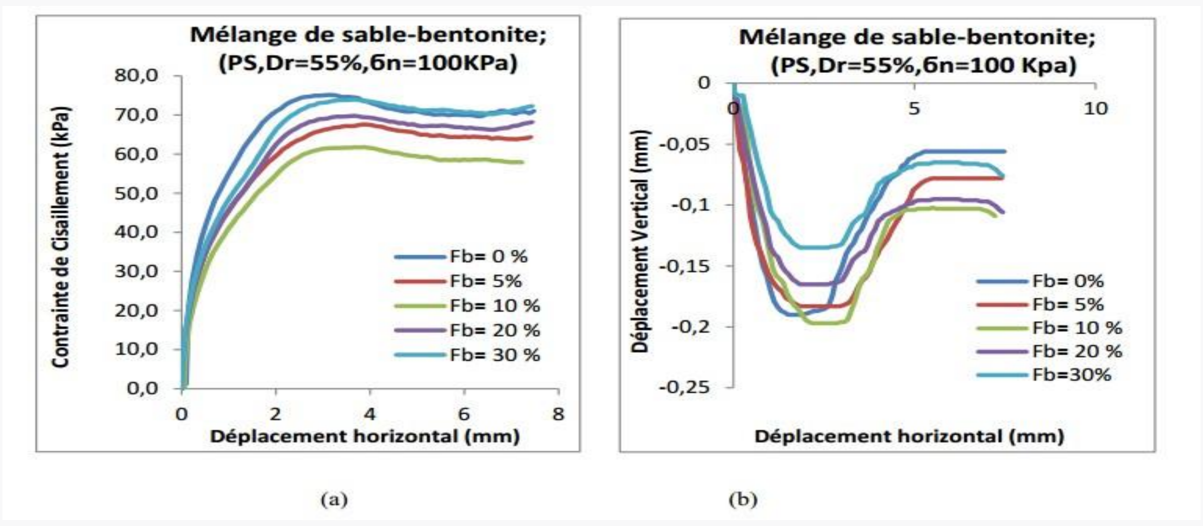


Figure 1.11 : Effect of bentonite fraction on mechanical behavior Bouchibane and Ben Abdel–Moutaleb (2020).

Mochamad Arief et al.(2015) carried out direct shear tests on sand-biochar (biological coal) mixtures with carbon contexts (Fbio =0%, 1%, 2% and 3%), under three normal stresses (σn=50, 150 and 250 kPa). They found that biochar has a very significant influence on the shear strength of a sand–biochar mixture. They also found, for a normal stress of 250 kPa and for a carbon content of 1%, the shear strength decreases by 15.3% compared to that of clean sand, while for mixtures with carbon fractions of 2% and 3%, the percentage of shear strength decreases by 18.6% and 22.5% respectively compared to the shear strength of clean sand. They concluded that the percentage of biochar plays a very important role in decreasing the shear strength of sand-biochar mixtures as illustrated in **(Figure 1.12**).

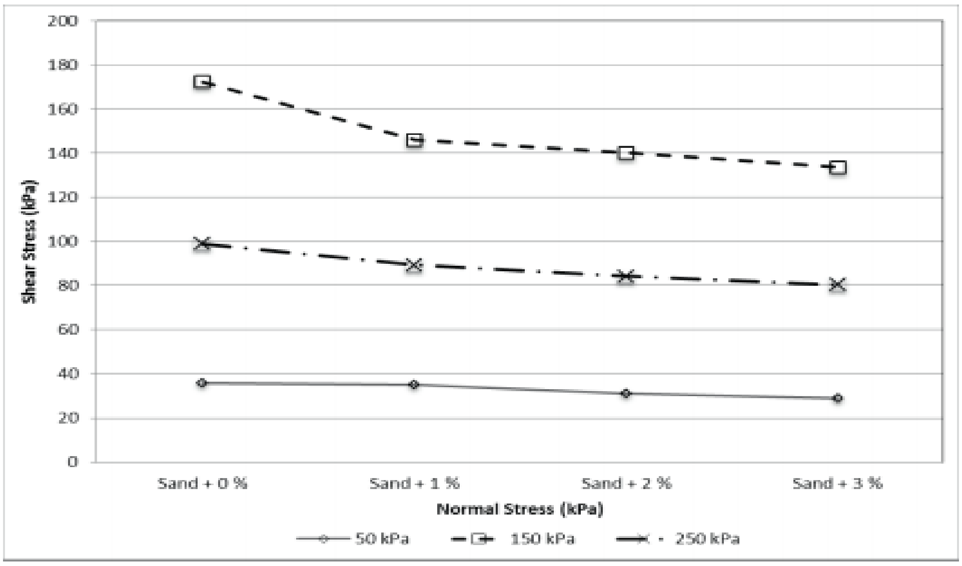


Figure 1.12: Comparison of shear strength of sand containing 0%,1% and 3% biochar. Mochamad Arief and al.(2015).

Pardo and al.(2018) carried out cyclic triaxial tests on sand mixed with biochar fractions varying from (Fbio=0% 3% and 5%). The mixtures were subjected to a confinement stress of 100kPa. They showed that biochar impacts the cyclic shear strength of sand-biochar mixtures. They found that increasing the biochar content induces a very significant increase in the cyclic shear strength of the tested soils. The cyclic shear strength of a sand-biochar mixture for the 5% Fbio fraction is six times greater than the cyclic shear strength of clean sand as shown in **(Figure 1.13).**

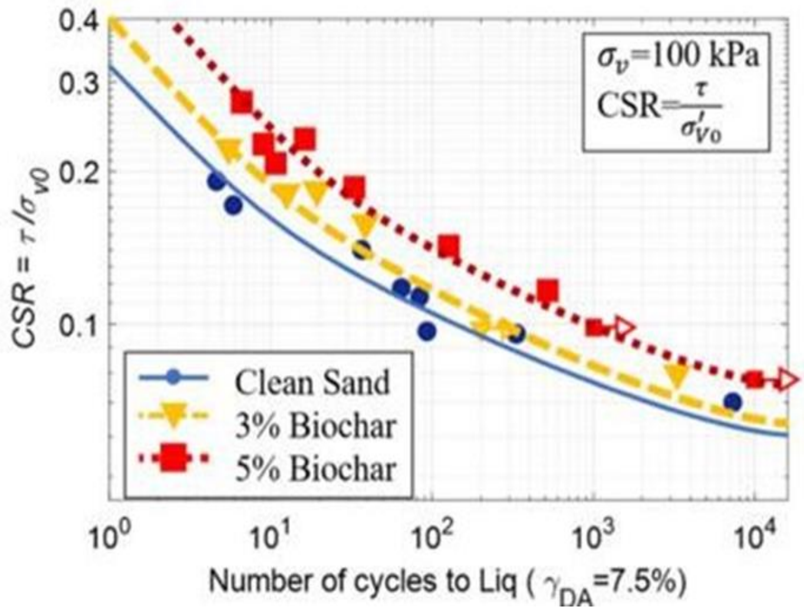


Figure 1.13 : Results of cyclic shear tests on samples of sand-biochar mixtures Pardo et al.(2018).

Bayat et al, 2012 carried out monotonic triaxial tests on sand specimens with the same relative densities and variation in the plastic fines (kaolinite or bentonite) contents ranging from 0 to 30 % and consolidated at mean confining pressure of 100, 200 and 300 kPa, in order to study the influence of fine content and other parameters on the undrained shear strength and liquefaction potential of clayey sand specimens; Results show that the peak strength decreases as the fines (kaolinite or bentonite) content increases up to a threshold content of fines (FCth) after which, increases in plastic fine content lead to improve the peak shear strength of specimens, and also the ultimate steady-state strength has been improved due to the increased in plastic fines content.shown in **Figure 1.14 and Figure 1.15.**

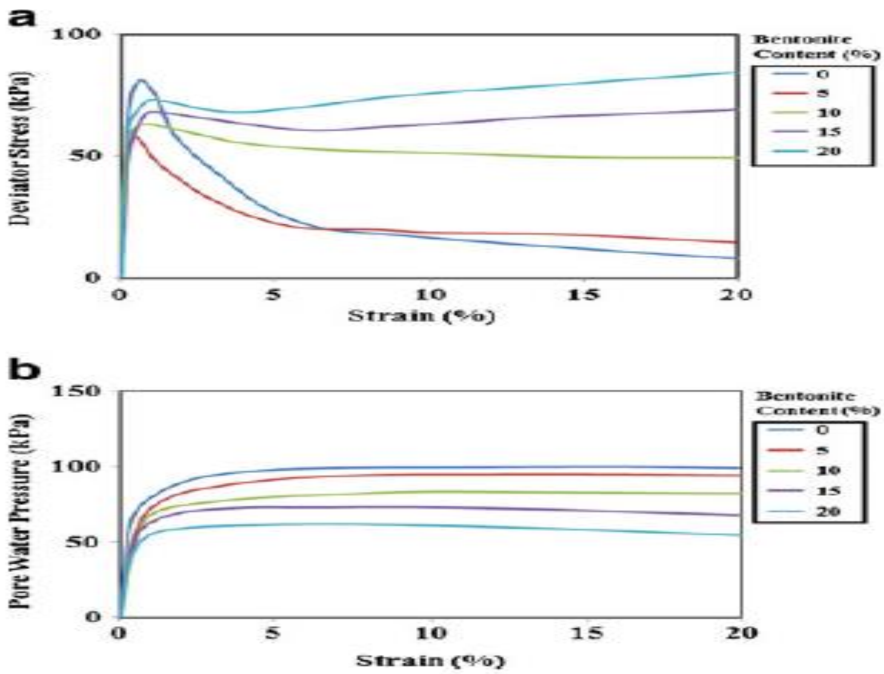


Figure 1.14 : Mechanical behaviour of specimens of sand–bentonite mixture at 100kPa confining pressure. a) Stress–strain curves. b) Pore-water. b Pore-water pressure–strain curves (Bayat et al.2012).

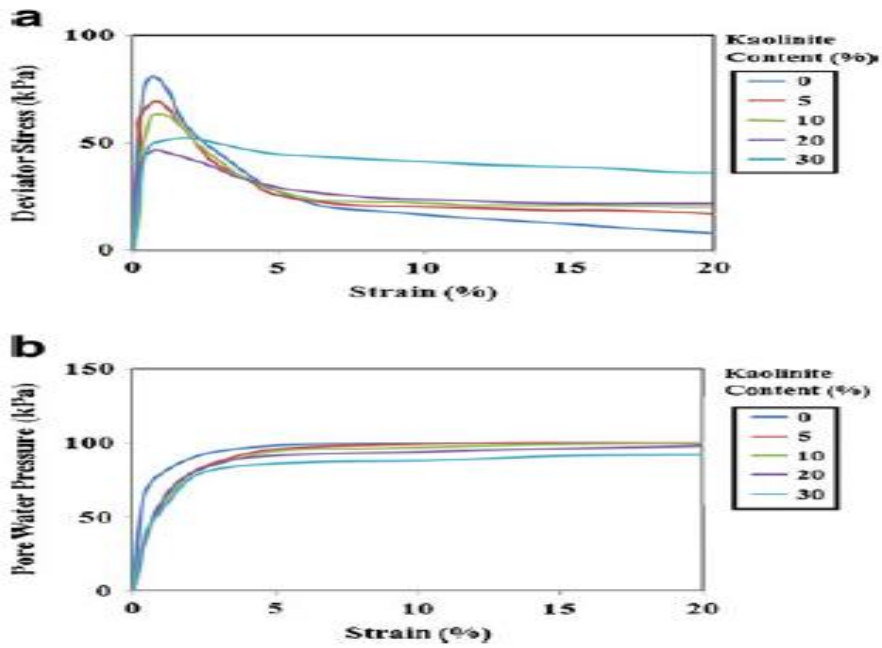


Figure 1.15 : Mechanical behavior of specimens of sand-kaolinite mixture at 100 kPa confining pressure. a) Stress–strain curves. b) Pore-water pressure–strain curves (Bayat et al.2012).

1.3 Effect of some parameters on the mechanical response of soils:

Several parameters can have a considerable influence on the mechanical behavior of soils, among them: relative density, confining pressure, particle shape, grain size, degree of saturation, etc...

1.3.1 Influence of grain size

Particle size is one of the parameters that has a significant effect on the shear strength of a soil. (Tsuchida 1970) identified a range of grain–size curves that represent the zones separating liquefiable and non-liquefiable soils **(Figure 1.16**). The area over the two inner curves exhibits the sands and silty sands having lower undrained shear strengths. The space between the two curves located on the left corresponds to the contribution of the fines in the reduction of the densification of these sands and that during the shearing. He also proved that the addition of less plastic fines in the sand matrix generally creates sufficient adhesion and stiking between the sand grains and the silts which limits the ability of larger particles to pass into a denser arrangement. (SERAY and Taleb 2020).

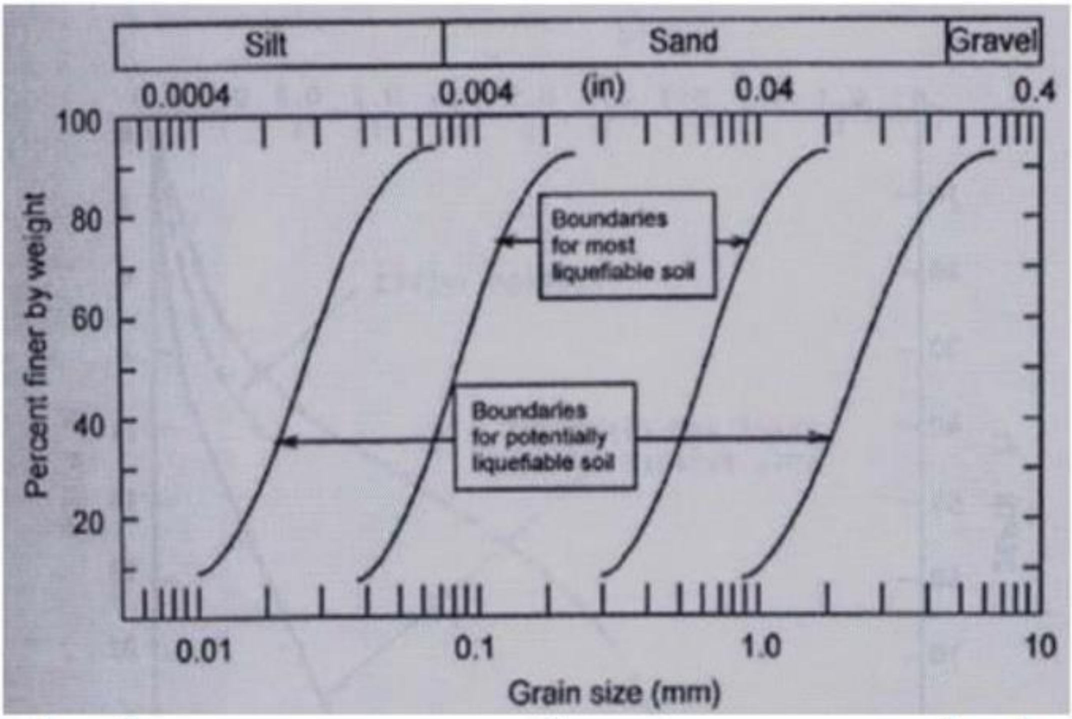


Figure 1.16 : Particle size curves of liquefiable and non-liquefiable soils (Tsuchida1970).

Hazout et al. (2022) performed a series of undrained shear tests on 9 samples with different maximum diameters (Dmax=4mm, 2.5mm and 1.6mm) and mean grain size (D50=1mm, 0.63mm and 0.25mm) to analyze their influences on the maximum undrained shear strength. They noticed that the grain size has a significant influence in terms of maximum diameter (Dmax) and mean grain diameter (D50) on the undrained shear resistance. Moreover, they interpreted the combined influence of these parameter “Dmax” and “D50” in the increase of the undrained shear strength due to the amplification of the entanglement between the coarse sand of the fine sand, which induces an increase in the dilatancy phase and consequently a more stable structure as shown in following figure **(Figure 1.17).**

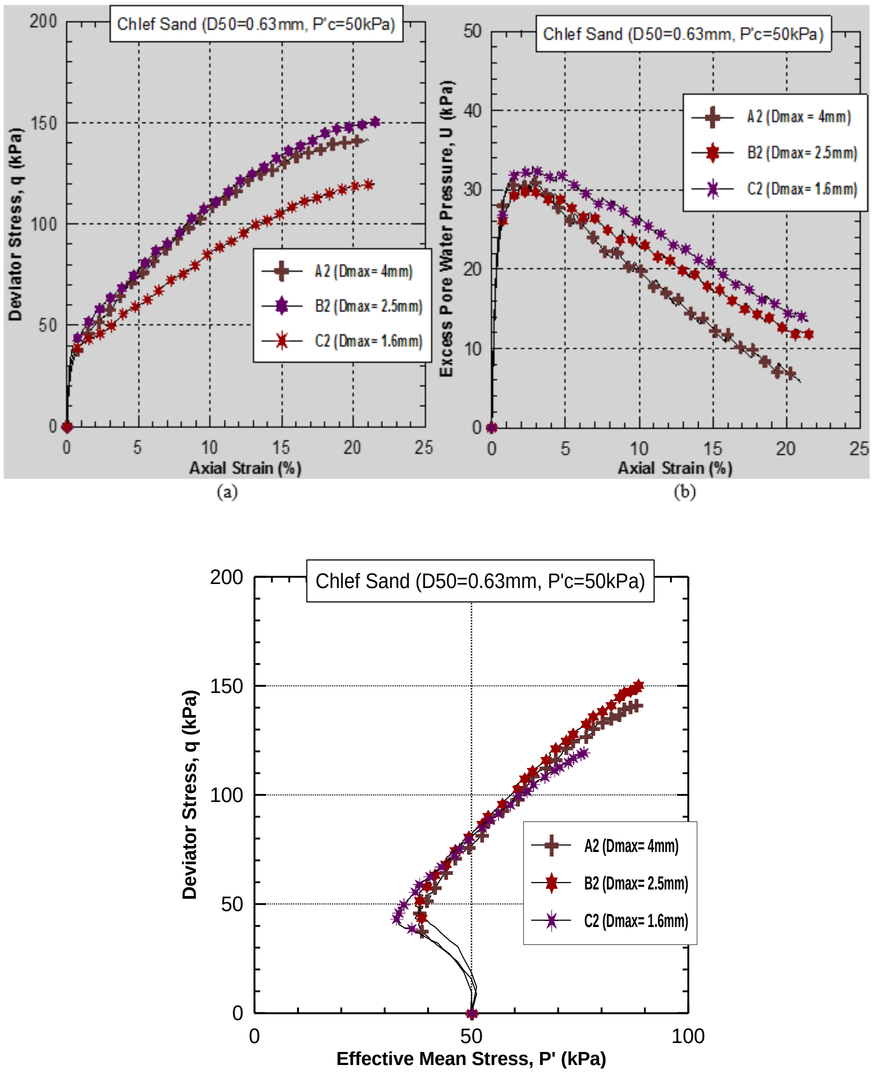


Figure 1.17 : Undrained mechanical response of Chlef river sand (Samples: A_2, B_2, C_2)(D_{50} = 0.63mm, Dmax= 4mm, 2,5mm, 1,6mm, Dr = 25%, P‘c =50 kPa, PS) Hazout et al.(2022).

<u>1.3.2 Influence of relative density and grain shape</u>

Relative density has a very remarkable influence on the undrained shear strength of granular soil. Tatsuoka and al. (1986) obtained results on Toyoura sand. They found that the undrained shear strength increases in a linear manner with increasing relative density. This increase means that relative density plays a primary role in increasing grain entanglement of granular soils and hence increasing undrained shear strength of soils as shown in **(Figure 1.18)**. (TERBAG 2019)

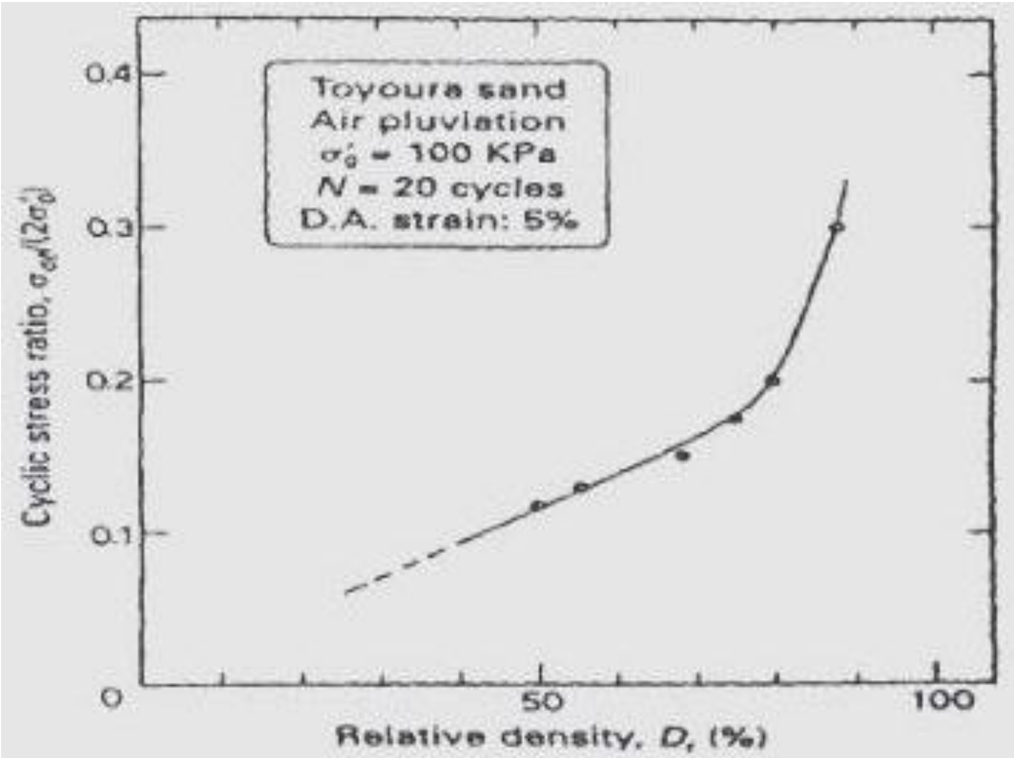


Figure 1.18 : Effect of relative density on shear strength Tatsuoka et al., (1986).

Other experimental studies initiated by Verdugo and al.(1992), they carried out triaxial tests in order to study the influence of the initial relative density on the mechanical response of the Toyoura sand. Their results were discussed by Yoshimine and Ishihara (1998). They indicated that the tendency to dilatancy is with the increase of the initial relative density as shown in **(Figure1.19).** They found that dense to very dense samples exhibit high values of the undrained shear strength of sand compared to samples reconstituted by loose and moderately dense.

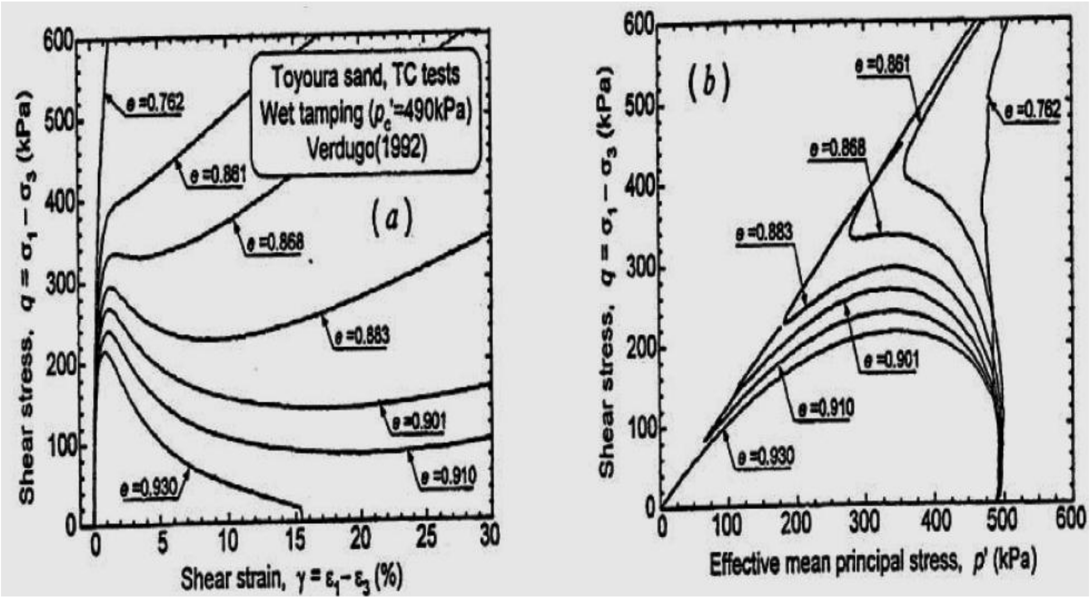


Figure 1.19 : Evolution of shear strength with relative density,Yoshimine and Ishihara.(1998).

Arab et al. (2010) studied the influence of relative density on the mechanical behavior of granular soils. They carried out cyclic tests on two different sands: Hostun sand and Chlef sand. Their samples were prepared with three initial relative densities (Dr=15%, 50% and 65%) and subjected to an initial confinement pressure (P'c =100kPa). Their results show clearly that the increase in the relative density leads to a very significant improvement in the undrained shear strength of Hostun sand, and is superior compared to Chlef sand. This can be explained by the fact that the semi-angular grain shape of Hostun sand has a significant effect on the undrained shear strength compared to the rounded shape of Chlef sand as shown in **(Figure 1.20).**

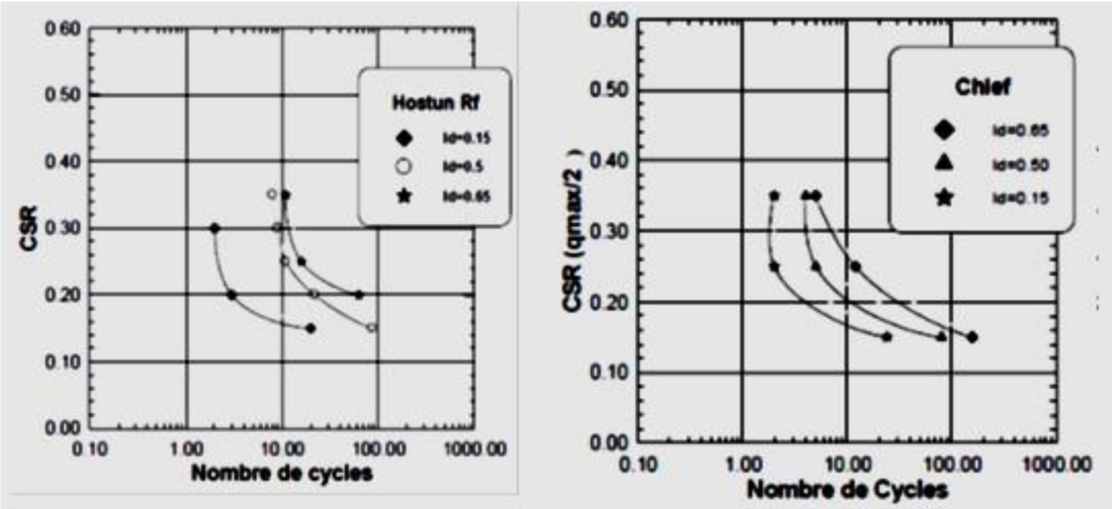


Figure 1.20 : Influence of shape and the initial relative density on the mechanical behavior of (a) - Hostun sand, (b)-Chlef sand, Arab et al.,(2010).

Conclusion

In this chapter, we have presented a bibliographical synthesis of various research works published in the literature, in particular the study of the mechanical behavior of granular soils, focusing on the types of fines and their effects on the instability, the failure and the resistance of the of granular soils in one hand. On the other hand it represents also the impact of several other parameters on the mechanical behavior of granular materials which are: influence of grain size, grain shape, initial relative density, confining pressure.

To reach a clear and a better understanding on how fines and sand mixtures behave mechanically, we took a further step and carry out detailed experimental study, that aims to investigate the factors affecting the mechanical response of sand mixtures, with emphasis on the parameters related to the nature of fines which is among the most important topics in soil mechanics.

2.1 Introduction

The study of the mechanical behavior of soils, in general, requires the performance of laboratory and in-situ tests, using special equipment. In our study, we used the direct shear box device, through which we seek to obtain the rupture of the sample according to an imposed plane Figure (2.1) and to subsequently deduce the soil mechanical characteristics. Shear strength depends on the type of soil, on whether it is cohesive, granular or a mixture of the two soils, on the state of density, the particle size, the grain shape, etc...

2.2 Experimental program

In chapter two, we present the materials used in this study, the different specimens reconstitution procedure as well as their physical characterization, and the experimental devices showing different tests carried out.

The material chosen for this research is a natural marine sandy soil from North Algeria, which was collected along the beach of Zemmouri el Bahri from liquefied soil deposit areas, close to Zemmouri strong earthquake epicenter (on May 21, 2003). this later is mixed with three types of fines "Zemmouri sand- fly ash mixtures, Zemmouri sand-bentonite mixtures and Zemmouri sand-kaolin mixtures" considering five fines content (Fly ash fines" FA", bentonite fines "FB", kaolin fines "FK" = 0%, 5%, 10%, 20%, 30%). All samples are reconstituted by the dry funnel pluviation method with an initial constant relative density (Dr = 55 %).

2.3 Experimental apparatus:

2.3.1 The purpose of the test

Published literature showed that the shear strength of sands depended on the presence of fines particles and also the type of fines in terms of the plasticity index parameter. In this context, this study aims to evaluate the effect of different types of fines on the mechanical response of Zemmouri sand as (sand-fly ash mixtures, sand-Kaolin mixtures and sand-bentonite mixtures) for a range of fines content varying from FA=0% to FA=30%, using the Casagrande direct shear box considering the influence of the plasticity index parameter on the mechanical response of the mixtures for the different types of fines tested.

The direct shear box tests were carried out on Zemmouri clean sand having a maximum diameter of 2,5 mm and minimum diameter of 0,008mm (Dmax = 2.5 mm and Dmin = 0.08 mm), mixed with three types of fines, cited above, and subjected under a constant normal stress of 100, 200, and 300 kPa.

Figure 2.1: Direct Shear box device.

2.3.2 Components of the direct shear box

Shearing box **(Figure 2.2)** has a dimension of 60*60 mm^2. It includes:

- Two porous stones: they are used to facilitate drainage and ensure good adhesion and attachment between the sample and the half-boxes;

- Upper half –box :consists of a base allowing to receive the loading head in order to apply the vertical load N on the sample ;

- Lower half –box

The shearing machine essentially consists of;

- A carriage moving at constant horizontal speed and driving the lower half –box.
- A ring attached to the upper half –box indicating the shearing force T developed in the specimen.
- A lever-caliper system applying a vertical load, through the loading head, to the upper box using plates of known weights.

Figure 2.2 : Components of direct shear box.

2.3.3. Determination of mechanical responses of soils (according to NF P94-071-1)

The soil sample has the following dimensions (6cm*6cm*2.5cm) ,is placed between two half-boxes (the upper and lower) which can slide horizontally on top of each other.

Attach the horizontal and vertical dial gauges (small div) to the shear box measure the vertical and the horizontal displacement during the test.

apply to the sample a normal compressive force N. The normal stress are generally fixed at σn=100kpa, 200kpa and 300kpa means (1bar, 2bars and 3bars)

Apply horizontal load, to the top half of the shear box. The rate of shear displacement should be 1mm/min. For every tenth small division displacement in the horizontal dial gauge, record the readings of the vertical dial gauge and the proving ring gauge (which measures horizontal load,). Continue this until after:

a. the proving ring dial gauge reading reaches a maximum and then falls, or
b. the proving ring dial gauge reading reaches a maximum and then remains constant.

The tangential stresses are calculated by the following procedure:

a. Calculate the initial surface area of the box which has a length of 6 cm and width of 6 cm, giving 36 cm^2.

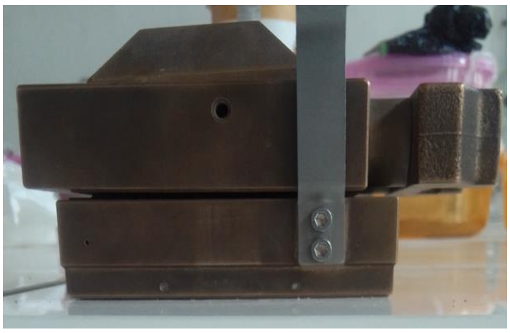
b. Calculate the corrected area: $(L- \Delta L)*L= A_{corrected}$;

ΔL is the horizontal displacement

c. The strain rate applied is fixed throughout the test for the granular soil at 1mm/min ;

d. T= dial gauge reading which is converted to force using a shear device data sheet;

e. The shear stress $\tau = T/A_{corrected}$.



Before shearing **After shearing**

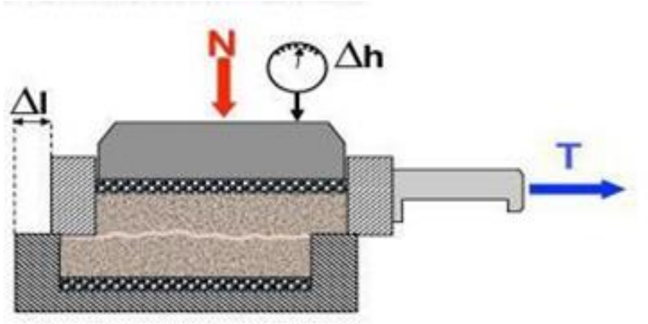


Figure 2.3: Normal stress plane (σ) and shear stress plane (τ).

We plot in a diagram **τmax versus f(σ).** in order to determine the mechanical characterstics of the tested specimens, known by the internal friction angles φ and the cohesion C. These laters allow us to estimate, for example, the breaking stress under a foundation, the active earth pressure behind a retaining wall, the bearing capacity of soils etc...

Rupture states and Mohr-Coulomb criterion represented in the following **Figure (2.4):**

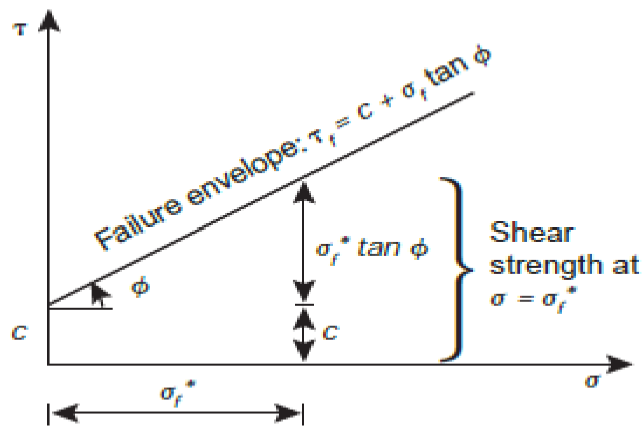


Figure 2.4 : Failure criterion: Mohr's Coulomb's (N. Sivakugan | Braja M. Das

2.4. Tested material

Natural Zemmouri (Algeria) sandy soil material was collected at a shallow depth, along the beach of Zemmouri el Bahri from liquified soil deposit areas.

Having a maximum diameter "Dmax" of 2.5 mm and minimum diameter of 0.008 mm, mixed separately with three different types of fines: fly ash fines "FA", bentonite fines "FB" and kaolin fines "FK". To form three groups of samples:

- -Zemmouri sand- fly ash mixtures,
- -Zemmouri sand-bentonite mixtures,
- Zemmouri sand-kaolin mixtures”

Each group is subdivided to give five samples according to the percentages set for the related fine at 0%, 5%, 10%, 20%, 30%. Totaling 15 samples altogether for the three groups.

All samples are reconstituted by the dry funnel pluviation method with an initial constant relative density (Dr = 55 %).

The sand mixtures used in this experimental study are shown in **(Figure 2.5). Tables 2.1** shows all the test done with their function**,Table (2.2,2.3 and 2.4) present** the chemical composition bentonite, kaolin and fly Ash respectively.

The physical properties of the studied materials are presented in **the (Tables 2.4 ; 2.5 and 2.6).**The maximum void ratio (emax) corresponding to the loosest state of the soil sample (minimum index density) and minimum void ratio (emin) corresponding to the densest state of the soil sample (maximum index density) .The particle size curves distribution of the examined samples are shown in the **(Figures 2.6 ; 2.7 ; 2.8 and 2.9).** The variations of the void ratios of the mixtures of Zemmouri sand with the three types of fines are shown in **Figure (2.10 ; 2.11 and 2.12).**

(a) Zemmouri sand.

(b) Fly ash.

(c) Kaolin (d) Bentonite

Figure 2.5 : Tested materials.

For the accomplishment of our work, we managed to do different test that enabled us to get results for each test.**Table 2.1** show the test carried out with their functions.

Table 2.1 : Test carried out with there functions.

Test	Function/role of the test
Pycnometer test	For determining specific gravity of soils (granular or cohesive).
Grain size analysis (sieving) for grain diameter ≥0.08mm), (grain size ≥80µm)	To classify a granular soil by using the curve size distribution.
Grain size analysis by hydrometer test is for particle size <0.08mm, (grain size<80µm)	the hydrometer method is used to determine the particle size distribution of the fine soils.
Sand equivalent test	This test method provides the procedure for measuring the relative proportions of detrimental fine dust or clay-like material in soil or fine aggregates.
Determination of minimum and maximum relative density of sands.	-Define maximum and minimum void ratios of sands.
Atterberg limits	To classify a fine soil by using the Casagrand diagram.
Direct shear box (Casagrand shear apparatus).	Determine the soil mechanical response such as shearing stress, vertical and horizontal displacement, the friction angle (φ) and the cohesion (C)

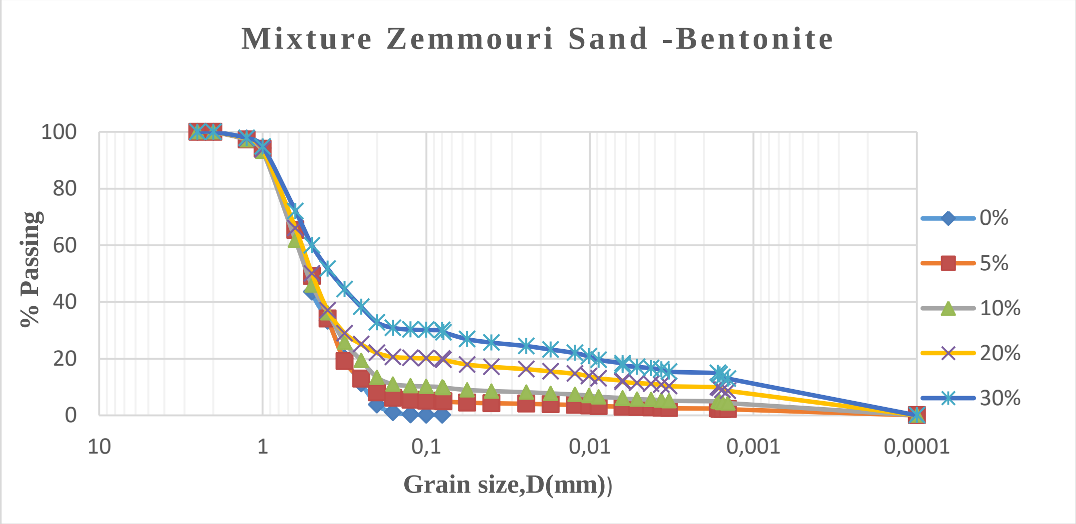


Figure 2.6 : A grain-size distribution plot-combined results from sieve analysis and hydrometer analysis ,Sand-bentonite.

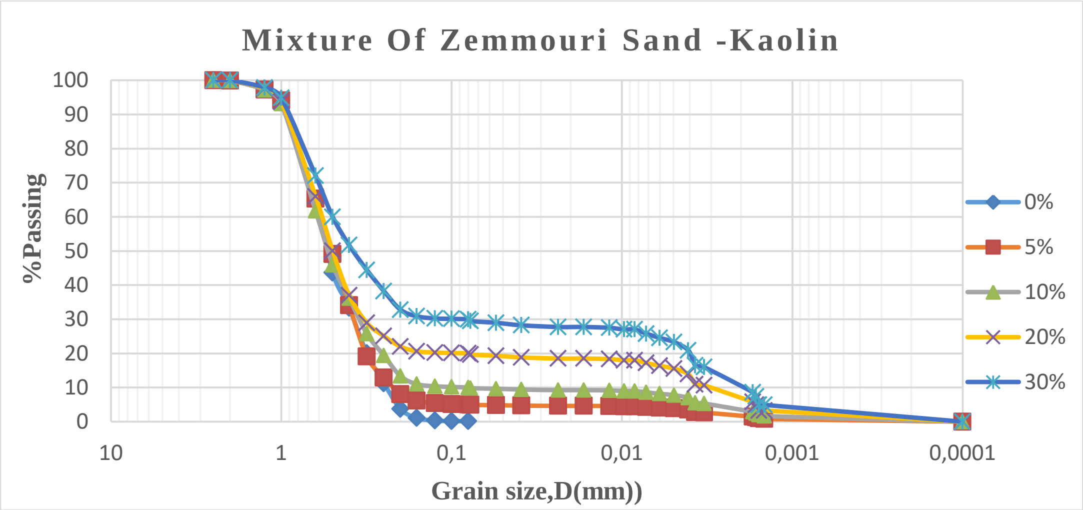


Figure 2.7 : A grain-size distribution plot-combined results from sieve analysis and hydrometer analysis ,Sand-kaolin.

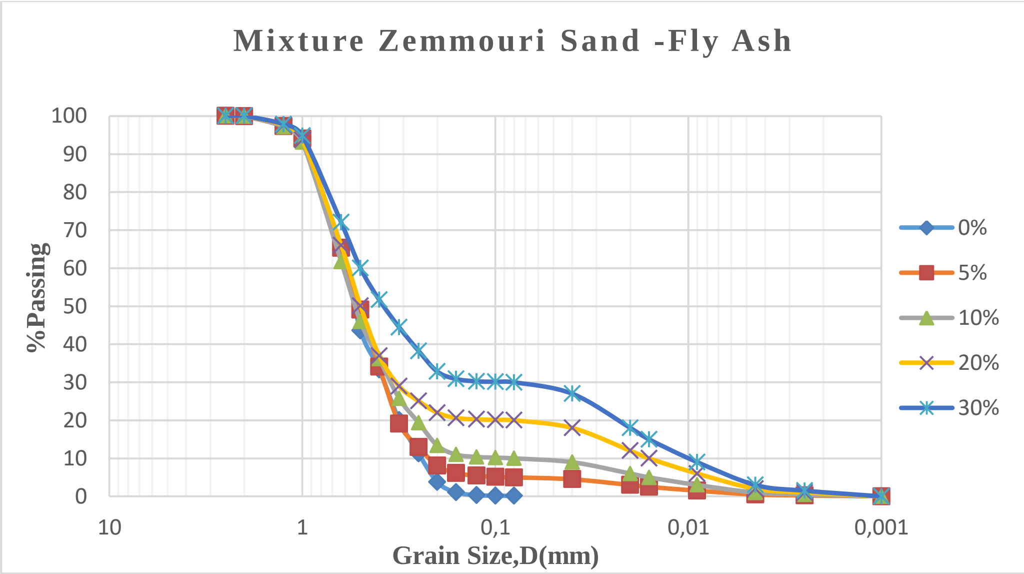


Figure 2.8 : A grain-size distribution plot-combined results from sieve analysis and hydrometer analysis ,Sand-fly ash.

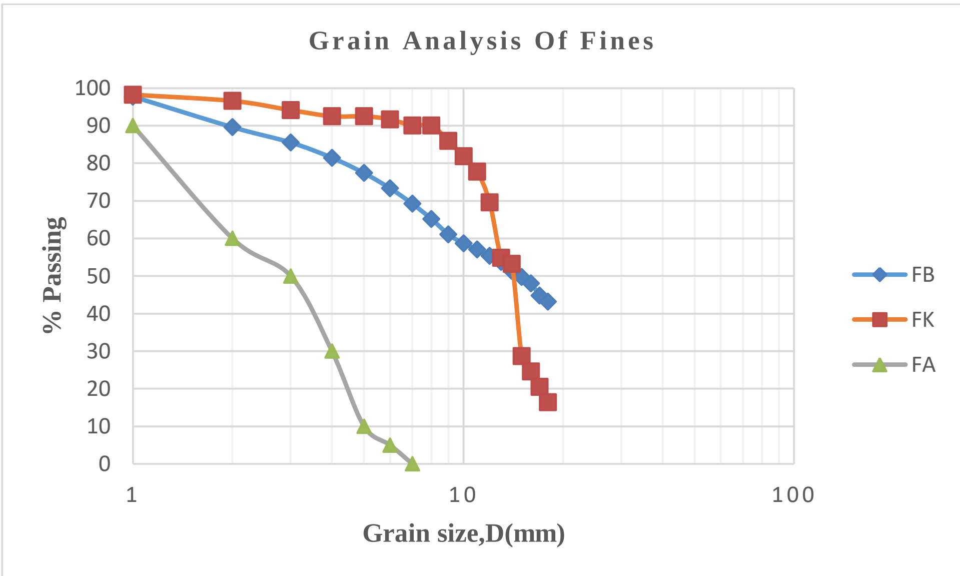


Figure 2.9 : A grain-size distribution plot results from hydrometer analysis (FB,FK,FA=100%).

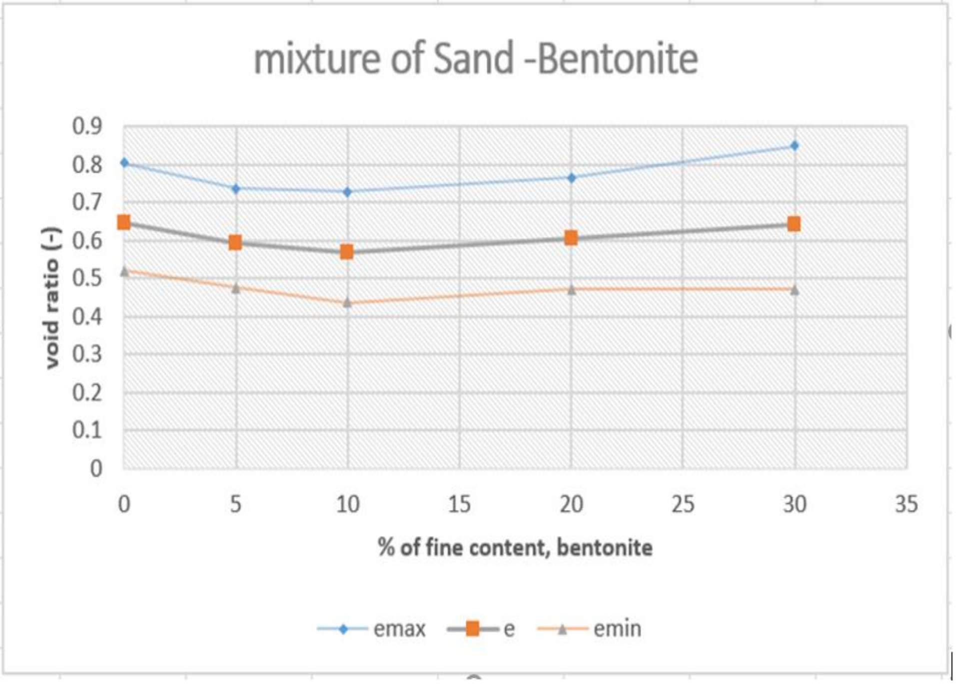


Figure 2.10 : Void ratios index of Zemmouri sand-bentonite mixtures versus bentonite content (%).

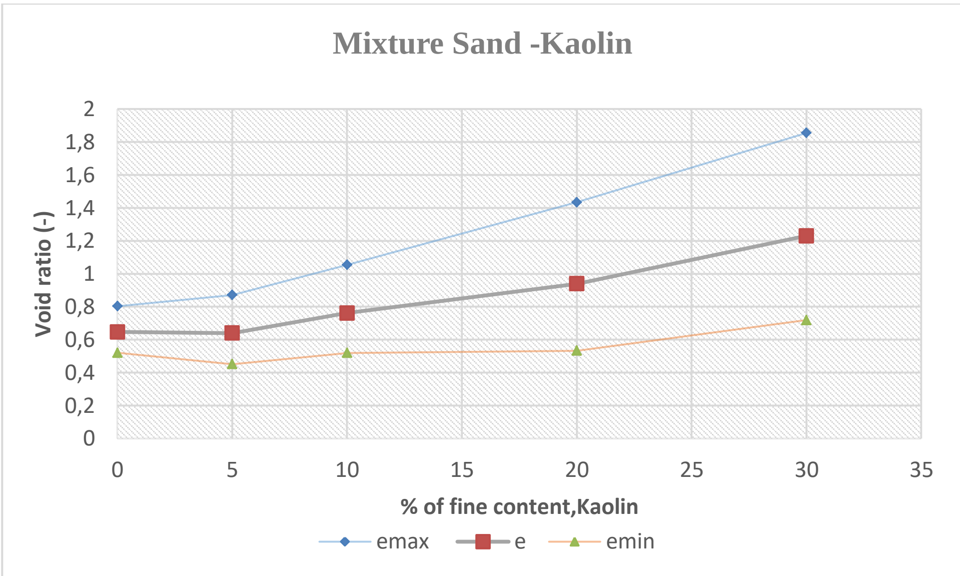


Figure 2.11: Void ratios index of Zemmouri sand-kaolin mixtures versus kaolin content (%).

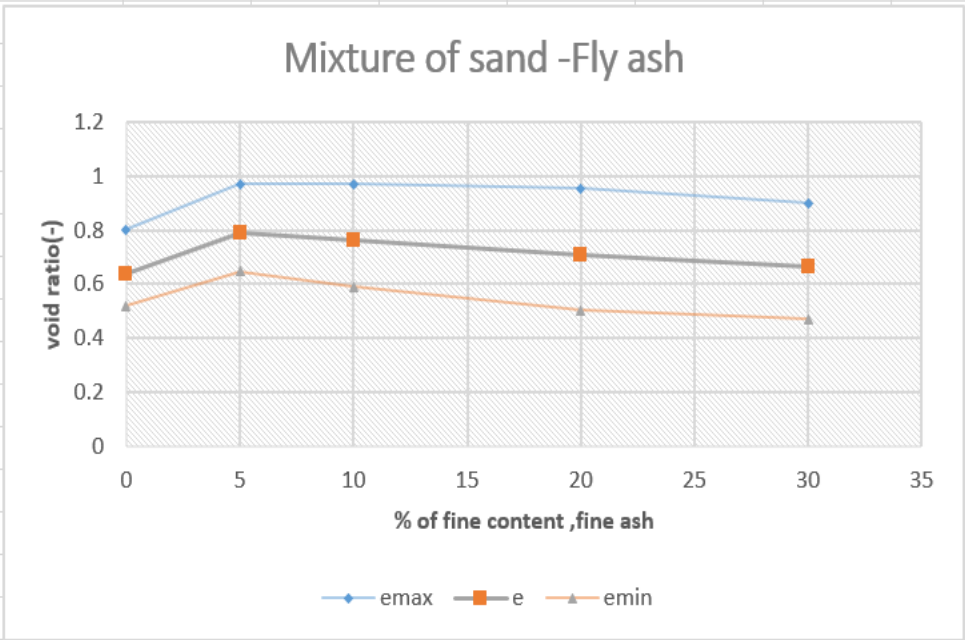


Figure 2.12 : Void ratios index of Zemmouri sand-fly ash mixtures versus fly ash content (%).

Table 2.2: Chemical composition of bentonite.

Constitution	**Percentage (%)**
Alumina (Al2O3)	16,39
Silica (SiO2)	60,61
Titanium Oxide (TiO2)	0,69
Iron Oxide (Fe2O3)	5,00
Potassium Oxide K2O	2,70
Calcium Oxide (CaO)	1,96
MagnesiumOxide (MgO)	1,72
SO3 Sulfates	0,04
Mn2O3 Manganese oxide	0,06
Mn304 Manganese tetroxide	0,09
P2O5 Phosphorus oxide	0,017
Na2O Sodium oxide	0,014

Table 2.3 : Chemical composition for kaolin.

Composition	**Percentage (%)**
Alumina (Al_2O_3)	39,5
Silica (SiO_2)	46,5
Water (H_2O)	Up to 14

Table 2.4 : Chemical composition of fly-Ash.

Composition	**Percentage (%)**
Silica (SiO_2)	22,30
Alumina (Al_2O_3)	5,13
Iron Oxide (Fe_2O_3)	3,78
Calcium Oxide (CaO)	66,67
Magnesium Oxide (MgO)	0,47
Titanium Oxide (TiO_2)	0,5
ignition loss	0,5-3

Table 2.5 : Physical properties of the mixture Sand-bentonite.

Physical property	**Material tested**					**Bentonite**
FB(%)	0	5	10	20	30	100
Dmax (mm)	2.5	2.5	2.5	2.5	2.5	0.08
Gs	2.65	2.647	2.644	2.638	2.626	2.59
D10 (mm)	0.27	0.23	0.2	0.005	0.0009	/
D30 (mm)	0.4	0.39	0.29	0.0055	0.001	/
D60 (mm)	0.6	0.6	0.6	0.6	0.5	/
Cu (-)	2.22	2.61	3	/	/	/
Cc (-)	0.988	1.102	0.701	/	/	/
emax (-)	0.803	0.736	0.729	0.765	0.847	/
emin (-)	0.520	0.474	0.437	0.472	0.471	/
e (-)	0.647	0.592	0.568	0.604	0.641	/

Table 2.6 : Physical characteristic of mixture sand-kaolin.

Physical properties	**Material used**					**Kaolin**
FK (%)	0	5	10	20	30	100
Dmax (mm)	2.5	2.5	2.5	2.5	2.5	0.08
Gs	2.65	2.647	2.644	2.638	2.632	2.57
D10 (mm)	0.28	0.21	0.18	0.003	0.0019	/
D30 (mm)	0.4	0.4	0.38	0.38	0.018	/
D60 (mm)	0.06	0.06	0.06	0.06	0.49	/
Cu (-)	2.143	2.857	3.33	/	/	/
Cc (-)	0.952	1.269	1.337	/	/	/
emax (-)	0.803	0.871	1.054	1.435	1.856	/
emin (-)	0.520	0.451	0.519	0.533	0.719	/
e (-)	0.647	0.640	0.762	0.939	1.230	/

Table 2.7 : Physical characteristic of mixture sand -fly ash.

Physical properties	**Materials used**					**Fly ash**
FA(%)	0	5	10	20	30	100
Dmax (mm)	2.5	2.5	2.5	2.5	2.5	0.08
Gs	2.65	2.615	2.693	2.736	2.779	3.08
D10 (mm)	0.25	0.22	0.27	0.08	0.009	/
D30 (mm)	0.39	0.39	0.35	0.33	0.18	/
D60 (mm)	0.62	0.62	0.62	0.60	0.60	/
Cu (-)	2.48	2.82	2.30	/	/	/
Cc (-)	0.981	1.115	0.732	/	/	/
emax (-)	0.803	0.9705	0.9695	0.9531	0.8988	/
emin (-)	0.520	0.6466	0.5906	0.5047	0.4696	/
e (-)	0.647	0.7923	0.7611	0.7065	0.6627	/

- **Pycnometer test.**

The mass of the solid particles is obtained by weighting. The soil sample is oven dried and then weighted. The volume of the particles is deduced by weighting using pycnometer by substituting water of known density to solid particles.

(a) Pcynometer

(b) Scale

Figure 2.13 : Pcynometer test (a) Pycnometer, (b) Accurate scale.

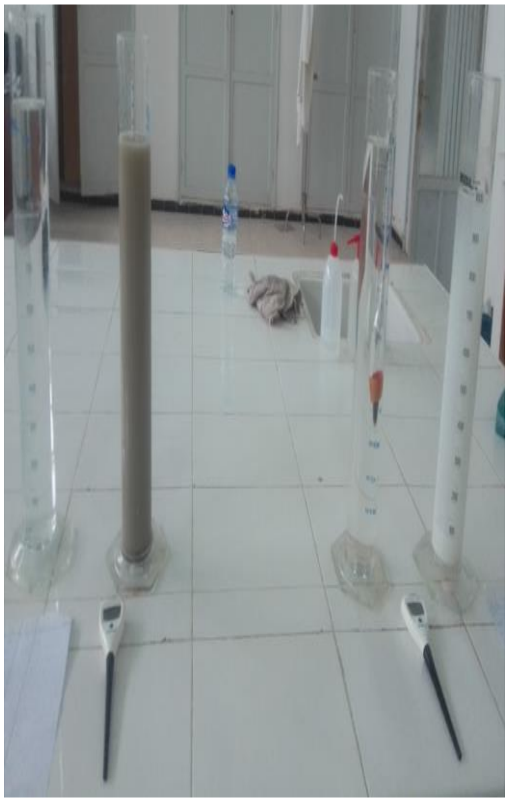
Table 2.8 : Density of solid grains.

Materials	**Bentonite**	**Kaolin**	**Fly-ash**	**Sand**
Density of solid grains	2.59	2.57	3.08	2.65

- **Grain size analysis (sieve analysis and hydrometer analysis).**

The deposits are made up of mixtures of types of soil and therefore of particles of different sizes. To properly describe a soil, it is necessary to know its grain size ,i.e the distribution of its particle according to their dimensions. The grain size is always carried out on a fraction 0/50mm according to LCPC and USCS.

(a) Sieving



(b) Hydrometer test

Figure 2.14: Grain size analysis.

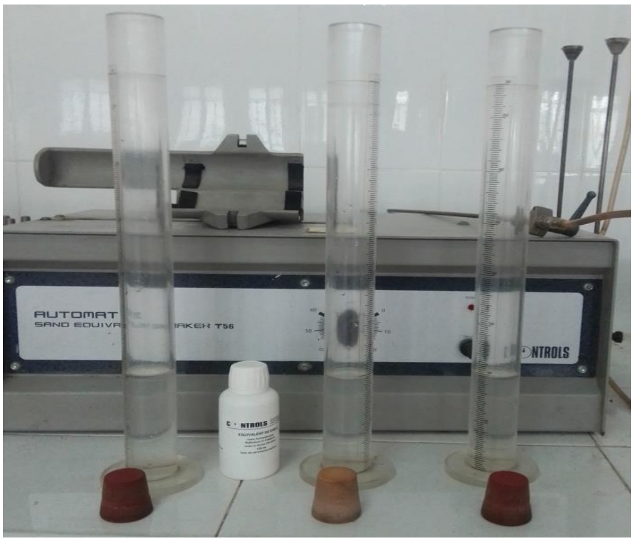
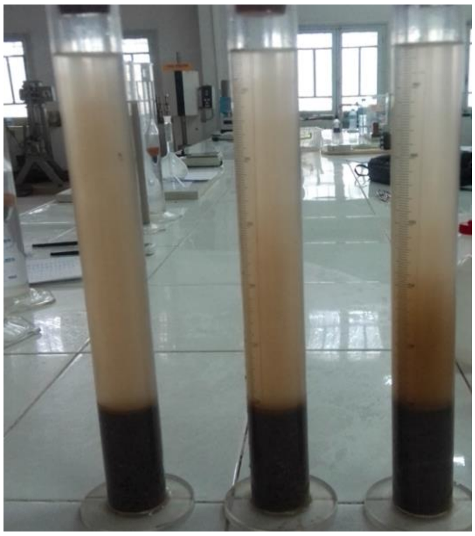
- **Sand equivalent test.**

Table 2.9 : Results for sand equivalent test.

Cylinder	**Sand reading visual(cm) (H2)**	**Clay reading(cm) (H1)**	**Sand reading with pistol(cm) (H3)**	**Visual sand equivalent %**	**Piston sand equivalent %**
1	9.6	9.8	9.1	97.9590	92.8571
2	9.2	9.5	8.3	96.8420	87.3684
3	9.4	9.7	9.0	96.9072	92.7835
Total	291.7082	273.009			
Average value	97.236	91.003			

Conclusion

Our sand is a clean sand.

(a)Before (b) After

Figure 2.15 :.Sand Equivalent test.

- **Determination of minimum and maximum dry density of sand (φ<5mm).**

The determination of void ratio is an essential step before determining the mass of the material to be tested in the direct shear box.

The maximum void ratio (emax) corresponding to the loosest state of the soil sample (minimum index density) and minimum void ratio (emin) corresponding to the densest state of the soil sample (maximum index density were determined according to ASTM D4253 and ASTM D4254 standards respectively, for 0–100% range. The void ratio to be calculated for a medium initial relative density should not be a value that is above the maximum void ratio and it should not be below the minimum void ratio, that means it should be between the two values.


(a) (b)

Figure 2.16: Determination of minimum and maximum dry density of sand (φ<5mm) according to ASTM D4253 and ASTM D4254 standards.

- **Determination of liquid and plastic limits.**

The liquid limit and the plasticity index of cohesive soils are important parameters for classification purposes,**Figure 2.17** present the test done on liquidity limit and plasticity limit,**Table 2.10** shows the results with bentonite having the highest plasticity index,kaolin medium plasticity and fly ash lowest plasticity index, this was determined by the new norme ISO 17892-12 -2018(F).

(a) soil pat in the cup of the liquid limit device

(b)plastic limit

Figure 2.17 : Atterberg limit.

Table 2.10 : Results of atterberg limit test.

Type of fine	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)
Bentonite	301,8	37	264,8
Kaolin	46	28	18
Fly ash	24,7	20,5	4,2

2.5 Test procedure

2.5.1 Introduction

In experimental work the choice of the shear device depends on its availability at the laboratory. It would have been preferable to carry out triaxial tests, but the unavailability of this device led us to carry out these tests at the direct shear box.

2.5.2 Reconstitution of the samples

The sand-mixtures were reconstituted at the lab with fine fractions content (FA, FB and FK of 0%, 5%, 10%, 20% and 30%. Thus each group is subdivided to give five samples according to the percentages set for the related fine . totaling 15 samples for the three groups.

All samples are reconstituted by dry funnel pluviation method with an initial relative density (Dr = 55 %), and subjected to normal stress of 100kPa, 200 kPa and 300kPa (σn1 =100kPa, σn2 =200kPa and σn3 =300kPa) respectively.

The pluviation technique is quite well standardized (Rad and Tumay, 1987). We selected the funnel pluviation method, in our case, because it is appropriate for our sand sands . Several researchers (Belkhatir et al. 2012, 2014; Sze et al. 2014; Cherif Taiba et al. 2016) used dry funnel pluviation technique to study the liquefaction resistance susceptibility of sand–silt mixture samples. Dry pluviation has been shown to create a grain structure similar to that of naturally deposited river sands (Oda et al. 1978; Ishihara 1993). Therefore, the dry funnel pluviation method was selected as a suitable depositional technique for the present experimental program.

The sample preparation method is illustrated in **(Figure 2.18)**

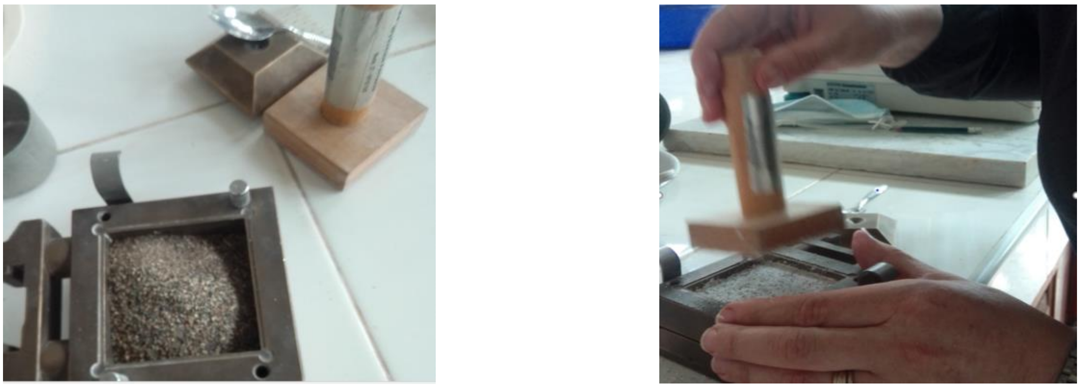


Figure 2.18 : Dry Pluviation method.

The determination of the quantity of material corresponds to the different soil states such as:loose state, medium dense state and dense state.

A relative density of the sample is proposed, then the void index corresponding to it is calculated and then the soil mass is determined.

In our research we proposed a medium initial relative density of 55%, this is due to economy reason, at the end we conclude if under this state the soil strength is improving or no.

The mass of the material studied in this experimental work is shown in **(Table 2. 11)**

Table 2.11 : Mass calculated for the mixtures (sand-fines).

Fines (%)	**mass (g) (mixture of sand + Bentonite)**	**mass (g) (mixture of sand + kaolin)**	**Mass (g) (mixture of sand + fly ash)**	**Relative density**
0%	144.7731	144.7731	144.7731	55%
5%	149.6232	145.2555	134.1486	
10%	151.737	135.1899	137.6244	
20%	148.0093	122.4612	144.2952	
30%	144.0396	106.207	150.4242	

Conclusion

➓ In this chapter we presented the apparatus used in mechanical response of Zemmouri sand mixed with three different types of fines namely bentonite, kaolin and fly ash. Also, we introduced the apparatus and procedures to determine physical characterizations, and not forgetting to mention various tests carried out.

➓ Natural Zemmouri sand was collected at a shallow depth along the beach of Zemmouri el Bahri from liquified soil deposit areas.and mixed separately with three different types of fines: fly ash fines “FA”, bentonite fines “FB” and kaolin fines “FK”. To form three groups of samples:Zemmouri sand- fly ash mixtures, Zemmouri sand-bentonite mixturesand Zemmouri sand-kaolin mixtures”. Each group was subdivided to give five samples according to the percentages set for the related fine at 0%, 5%, 10%, 20%, 30%. Totaling 15 samples altogether for the three groups.

➓ All samples are reconstituted by the dry funnel pluviation method with an initial constant relative density of 55% (Dr = 55 %), and subjected to the three normal stresses (σn =100 kPa, 200 kPa et 300 kPa).

➓ We did not stop here but rather took a further step where this chapter lead us to the next chapter in which we will study the mechanical response of sand mixture with different fines content (bentonite ,kaolin and fly ash) while emphasizing on the influence of fraction of the fines, initial relative density and normal stress on the mechanical behavior of the materials tested while carefully interpreting each and every results in function of various observation.

3.1 Introduction

Characterization of granular soils found in nature as variable mixtures is very complex due to the interaction of their parent constituent matrices and the many parameters that can impact their behavior. When these materials are present in the form of sand-silt or sand-clay mixtures, their behavior becomes completely different from the original materials, (Belkhatir and al. 2014. Andrews and Martin 2000; Bouferra and al. 200; Dash and al.2011; Jakka and al.2010; Mroz and al.2003; et Mahmoudi and al 2020). However, the behavior of soil mixture is not well understood yet.

Several researchers have shown that the content of fines or clay has a very important effect on the shear strength of soils. Troncoso (1990) studied the resistance of cyclic shearing of a mixed sand with different contents of fines (silts) from Fc =0% to Fc=30% with constant initial void ratio (e=0.85) and found that the cyclic shear strength decreases with increase in fines fraction. Undrained triaxial compression tests on sand samples was reported by Kermatikerman et al. (2018), they showed that the addition of fly ash in the sand samples changed the behavior in terms of stress strain. They found that the undrained shear strength increases with increasing fly ash mixtures. This increase in resistance due to the fact that the fly ash contributed to the inter-granular forces of sands .A monotonic drained and undrained triaxial tests was carried out on fractions of fines varying between 0 to 50%; and cyclic tests carried out on fractions of fines varying between 0 to 25%, Arab 2009, The tests show that the increase in the content of fines induces a reduction in the content of fines increases from 0 to 50%,but little affects the characteristic angle.(Bayat and al.2014) found that the maximum shear strength decreased with increase in the content of fine plastics up to thresholds of (FB=5% and FK=20%) considering the two types of fine plastics (bentonite and kaolin) respectively.Beyond this ,it increases with increase of fraction fines. Rojimul and al.(2020)performed shear test on the sand–biochar mixture, with the aim of studying the effect of biochar on the shear strength parameters (C and $\emptyset$)of clayey sand.They showed that increasing the percentage of biochar from Fbio=0% to Fbio=15% induces a remarkable increase in the shear strength of the soils studied.

In that case the main objective of this experimental work is to study the influence of the mixture of Zemmouri sand with three fine content (sand-fly ash mixtures, sand-Kaolin mixtures and sand-bentonite mixtures) for a range of fines content varying from FA=0% to

FA=30% using the Casagrand direct shear box considering the influence of the plasticity index parameter on the mechanical response of the binary mixtures for the different types of fines tested. The specimens were reconstituted at the lab by dry pluviation method with a medium dense initial relative density (Dr=55%) and which were subjected to three normal stress of 100,200 and 300kPa.

3.2 Results of the tests carried out

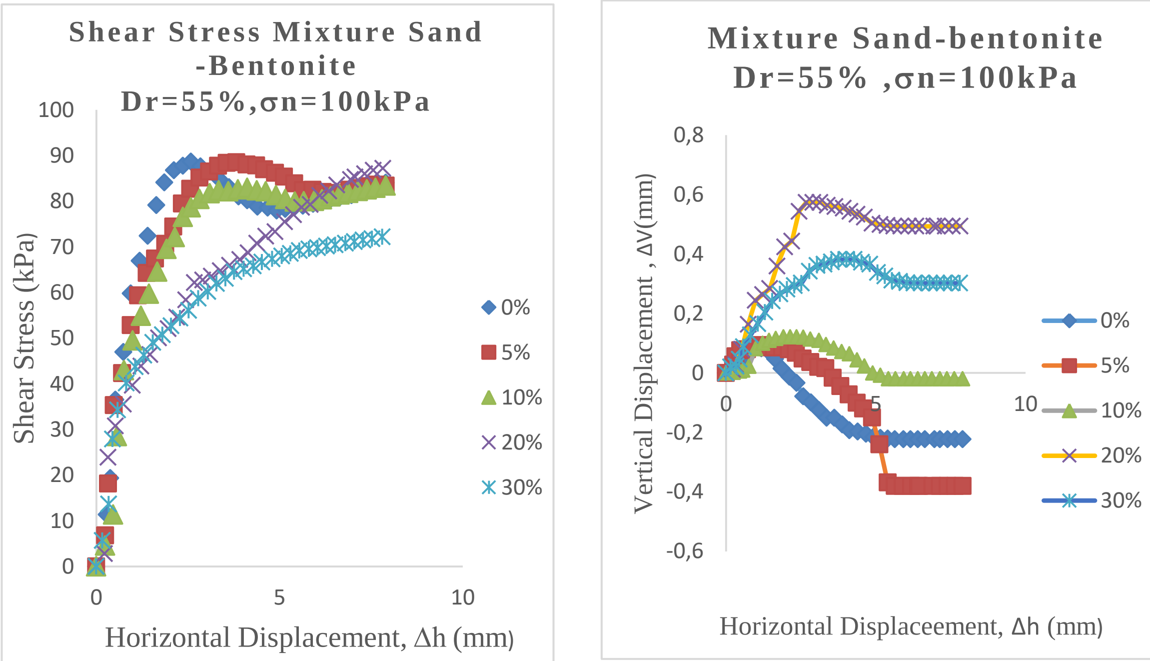
3.2.1 Effects of fines content

3.2.1.1 Zemmouri sand-bentonite Mixtures

The influence of the high plastic bentonite content (FB=0%,5%,10%,20% and 30%) on the shear resistance of Zemmouri sand-bentonite mixture is clearly illustrated in **(Figure 3.1,3.2 and 3.3).**The samples were reconstituted with an initial relative density (Dr =55%) and subjected to three initial normal stresses (σn=100,200 and 300kPa).

The results of various tests indicate that the addition of the bentonite content has an influence on the mechanical behavior of the zemmouri-bentonite mixture. However, the shear strength decreased with increase in bentonite content for the two normal stresses considered; (τpic =88.6886 kPa ,88.531 kPa, 82.39kPa,85.29kPa and 69.8378kPa for σn=100kPa, (τpic=161.552kPa, 156.627kPa, 154.979kPa, 159.339kPa and 109kPa for σn=200 kPa. However for a normal stress of 300kPa we have an increase in the increase of bentonite content until a threshold of (FB=5%);(τpic=247.564kPa and 255.948kPa), FB=0% and FB=5% respectively. In the same normal stress(300kPa) a decrease in the increase of bentonite content was observed, (τpic=246.765kPa, 230.486kPa and 209.852kPa) as presented in **(Figure 3.1a,3.2a and 3.3a).**

The results of this study is in a good agreement with (Bayat and 2012) and (Bayat 2014). **Figures 3.1b, 3.2b and 3.1b** below show the variation of the vertical displacement according to the horizontal displacement considering the impact of a high plastic bentonite content. The results obtained indicate that the phase of dilatancy decreases progressively with the increase in the increase in the bentonite fraction for all the bentonite fraction considered.

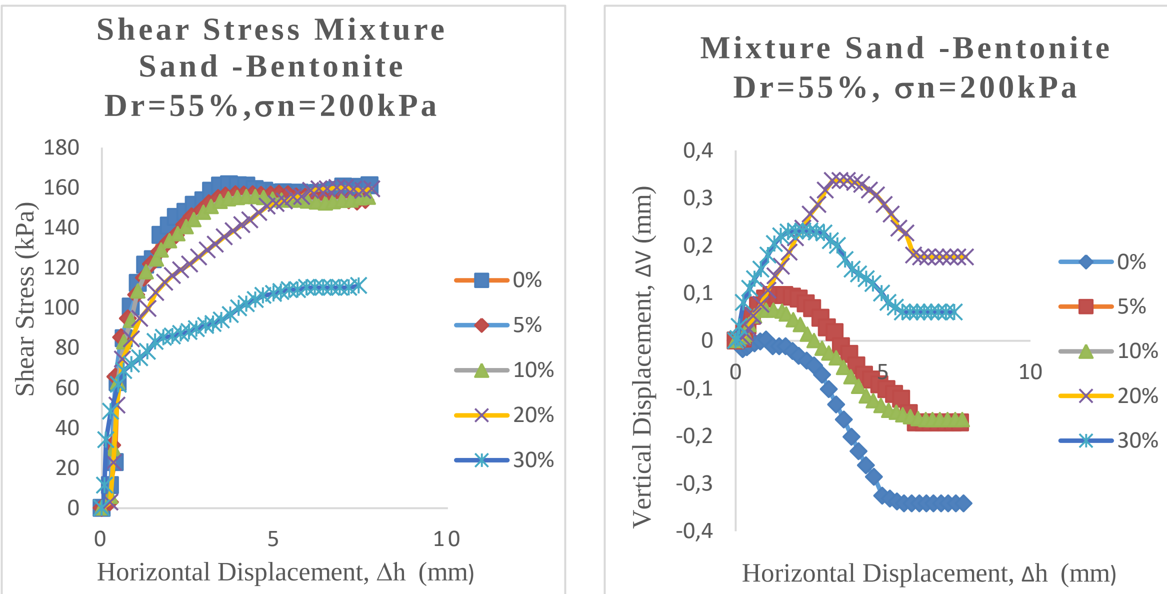


(a) (b)

Figure 3.1 : Effect of bentonite fraction on the mechanical behavior of zemmouri sand (σn=100kPa,Dr=55%).

(a)-Evolution of shear stress,

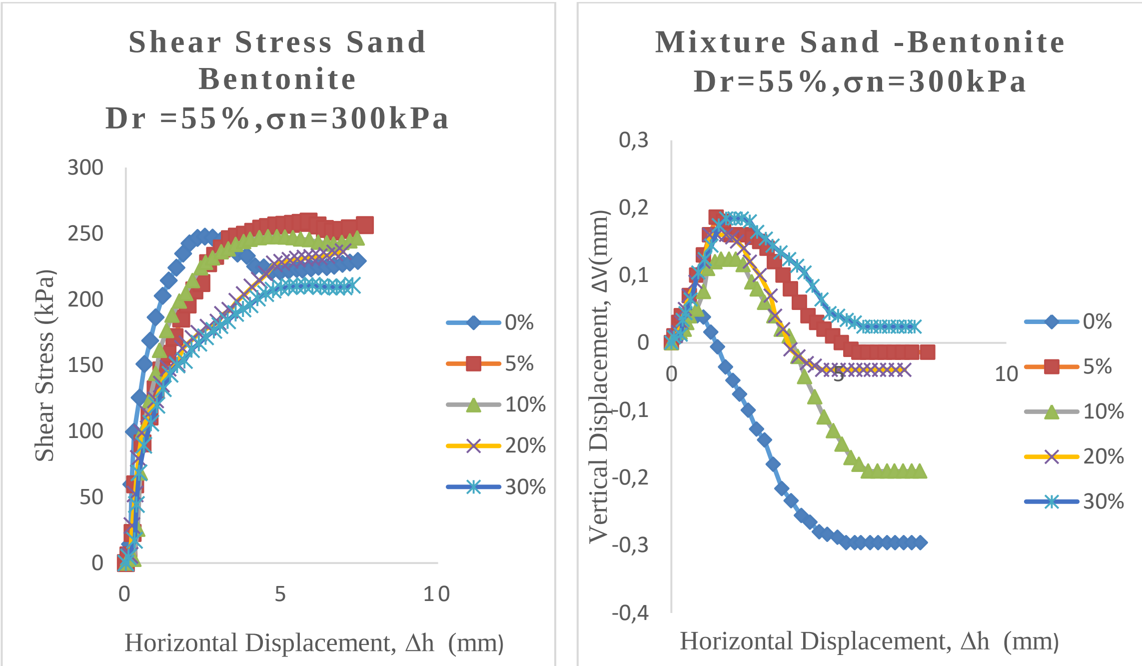
(b)-Evolution of vertical displacement VS horizontal displacement



(a) (b)

Figure 3.2 : Effect of bentonite fraction on the mechanical behavior of zemmouri sand (σn=200kPa,Dr=55%) (a)-Evolution of shear stress,

(b)-Evolution of vertical displacement VS horizontal displacement



(a) (b)

Figure 3.3 : Effect of bentonite fraction on the mechanical behavior of Zemmouri sand

(σn=300kPa, Dr=55%).

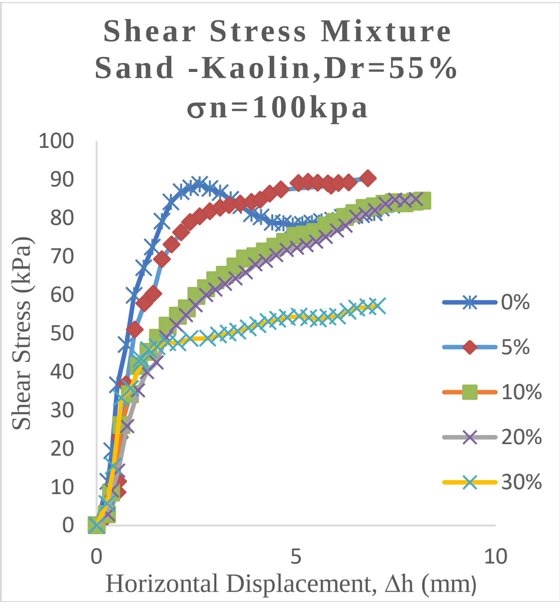
(a)-Evolution of shear stress,

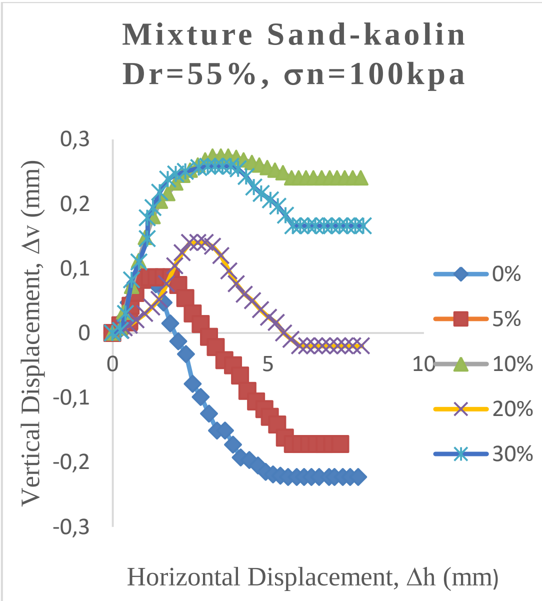
(b)-Evolution of vertical displacement VS horizontal displacement.

3.2.1.2 Zemmouri sand-kaolin mixtures

Figure 3.4-3.6 present the results of direct shear box test for the purpose of analyzing the effect of plastic kaolin content (FK=0%,5%,10%,20% and 30%) on the mechanical behavior of Zemmouri sand-kaolin mixtures samples on which were prepared at the lab with the dry pluviation method, for medium dense initial relative density (Dr=55%), under three initial normal stresses (σn=100,200 and 300 kPa). From these figures below, we notice that the shear strength decreases progressively with the increase in the content of plastic kaolin for two normal stresses 200kPa and 300kPa studied (161.552 kPa; 165.321 kPa; 144.978 kPa; 140.395 kPa; 124.104 kPa for 200kPa) and (247.564 kPa; 230.787 kPa; 207.369kPa; 169.624kPa; 139.914kPa for 300 kPa). while the shear stress variation in normal stress (100kPa), is illustrated in **(Figure 3.4a,3.5a and 3.6a)** as **(**88.6886 kPa ; 89.375 kPa; 82.922 kPa; 84.6811 kPa; 54.399 kPa) means that the shear resistance remains almost the same from 0% to 20% after that it decreases about 36% **.**

(Figure 3.4b,3.5b and 3.6b) illustrate the evolution of the vertical displacement according to the horizontal displacement considering the effect of kaolin content. The obtained results confirm the role of this parameter, that the contractance phase gradually increases with an increase of FK fraction (0%,5%,10% ,20% and 30%) and therefore decreasing the resistance in shear.





(a) (b)

Figure 3.4 : Effect of kaolin fraction on the mechanical behavior of zemmouri sand (σn=100kPa,Dr=55%).

(a)-Evolution of shear stress,

(b)-Evolution of vertical displacement VS horizontal displacement.

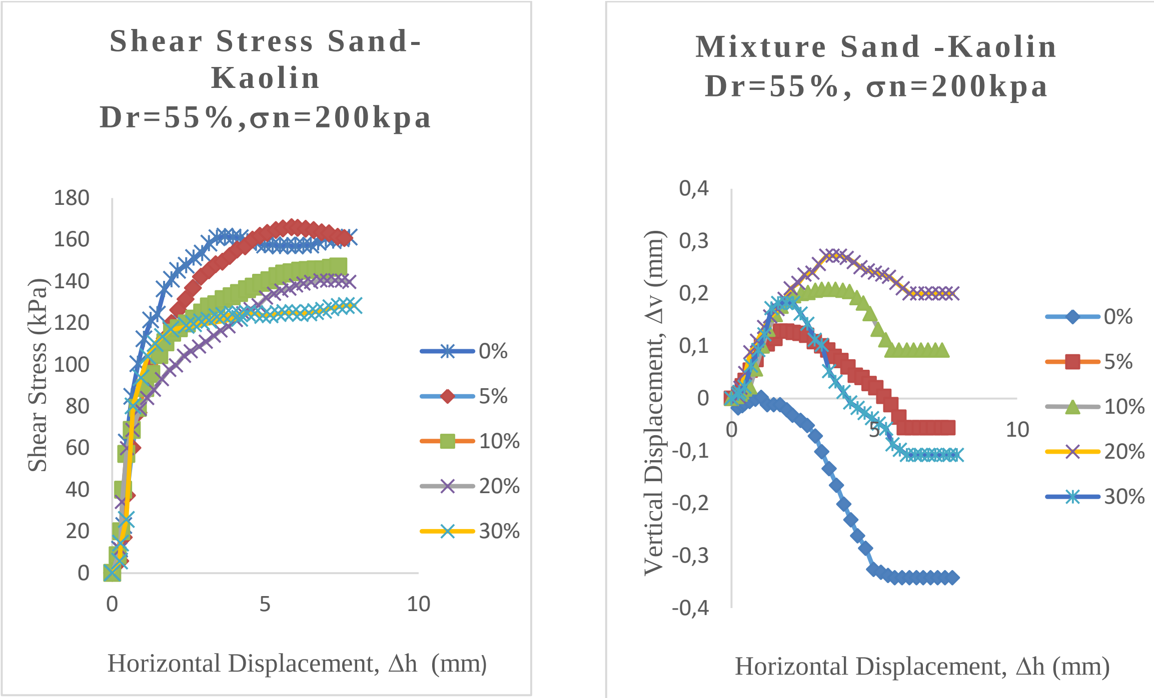


Figure 3.5 : Effect of Kaolin fraction on the mechanical behavior of zemmouri sand (σn=200kPa,Dr=55%).

(a)-Evolution of shear stress,

(b)-Evolution of vertical displacement VS horizontal displacement.

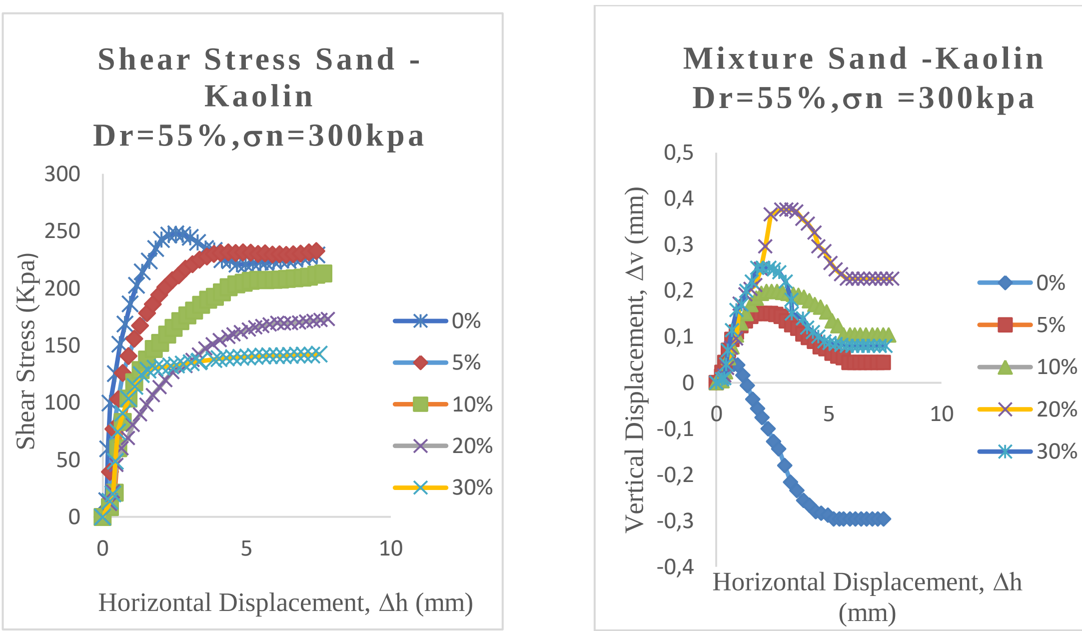


Figure 3.6 : Effect of Kaolin fraction on the mechanical behavior of zemmouri sand (σn=300kPa,Dr=55%).

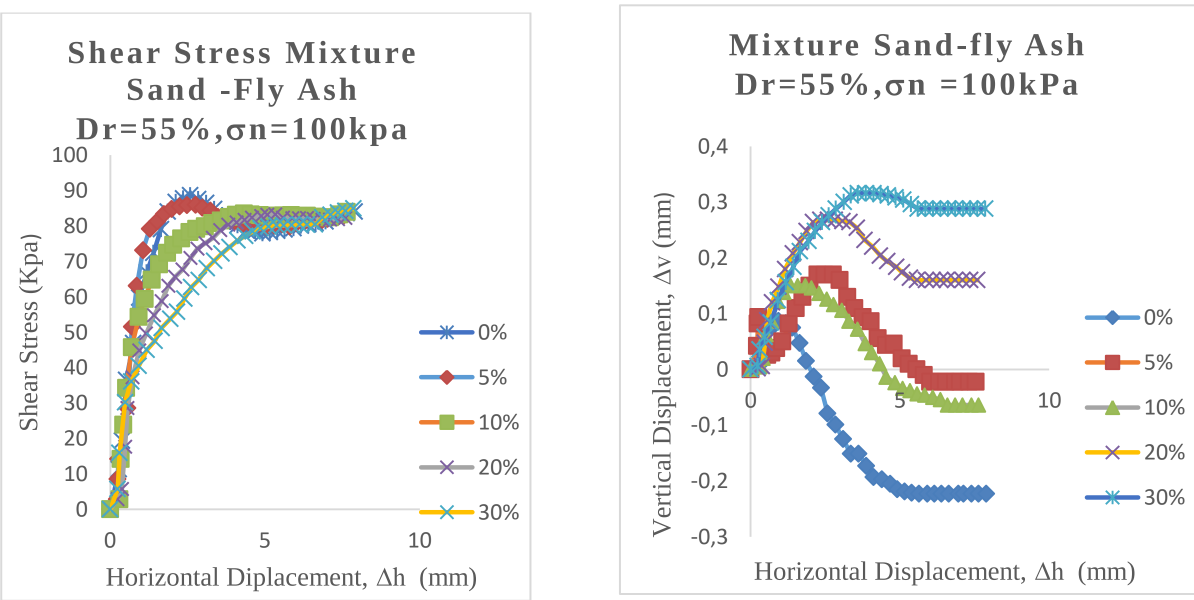
(a)-Evolution of shear stress,

(b)-Evolution of vertical displacement VS horizontal displacement.

3.2.1.3 Zemmouri sand-fly ash mixture

For the purpose of studying the impact of the non-plastic fly ash content (FA=0%,5%,10%,20% and 30%) on the shear strength of Zemmouri sand -fly ash mixtures ,**Figure 3.7-3.9** reproduce the results obtained from this study. The samples of the sand -fly ash mixtures were reconstituted by the of dry pluviation method at an initial relative density (Dr=55%) and subjected to three initial normal stress (σn =100,200 and 300kPa).

(Figure 3.7a,3.8a and 3.9a) shows a decrease of the shear strength in the increase of fly ash content for initial normal stress 100kPa and 300kPa respectively, while in the initial stress of 200kPa we have a decrease in the increase of fly ash until threshold of fine content (FA=10%) ,a slight increase in FA=20% and from that a decrease in the increase of fine content for threshold (FA=30%) was observed. The results obtained indicate that the parameter fly-ash content has a significant influence on mechanical response on Zemmouri sand-fly mixture for the three normal stress considered. The trend of decrease shear strength with the increase in fly ash content can be attributed to the decrease of entanglement between the particles of Zemmouri sand.

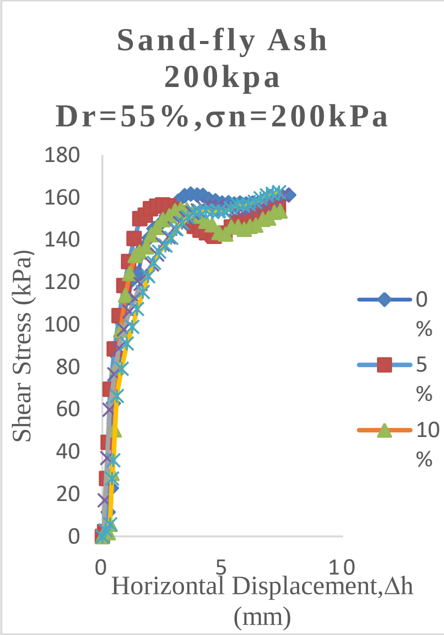


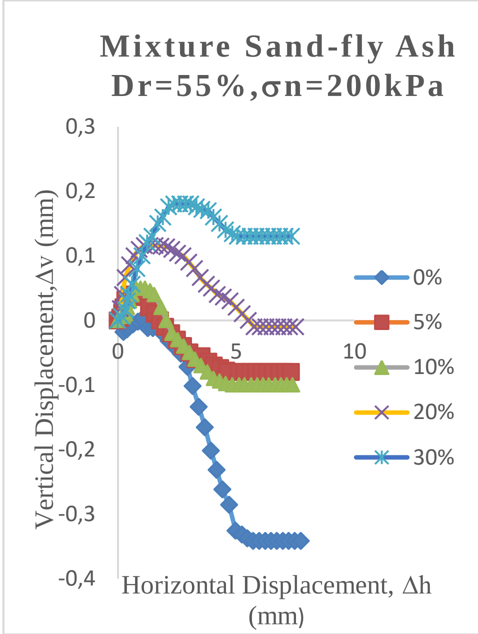
(a) (b)

Figure 3.7: Effect of Fly -ash fraction on the mechanical behavior of zemmouri sand (σn =100kPa,Dr=55%).

(a)-Evolution of shear stress,

(b)-Evolution of vertical displacement vs horizontal displacement

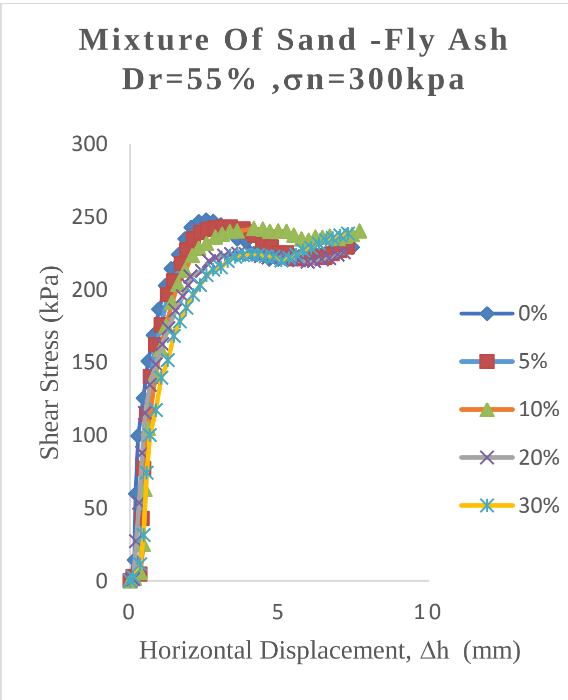


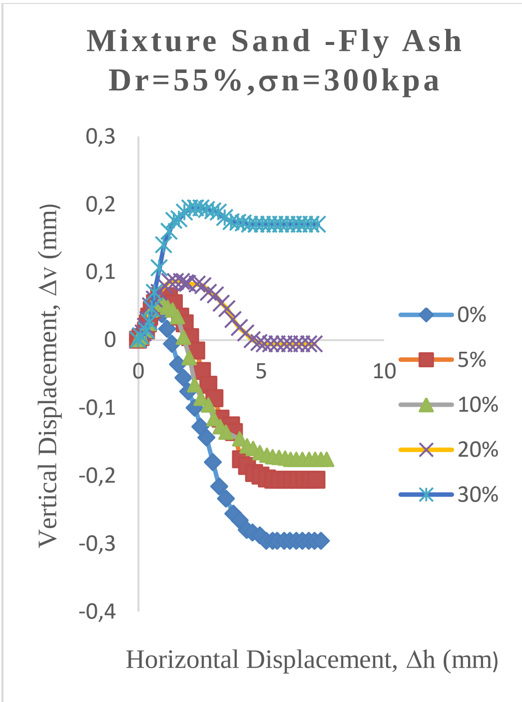


(a) (b)

Figure 3.8 : Effect of Fly-ash fraction on the mechanical behavior of zemmouri sand (σn=200kPa,Dr=55%) (a)-Evolution of shear stress,

(b)-Evolution of vertical displacement vs horizontal displacement





(a) (b)

Figure 3.9: Effect of Fly-ash fraction on the mechanical behavior of Zemmouri sand (σn=300kPa, Dr=55%) (a)-Evolution of shear stress,

(b)-Evolution of vertical displacement vs horizontal displacement

3.3 Effect of the fraction of non-plastic and plastic fines on the shear strength at peak

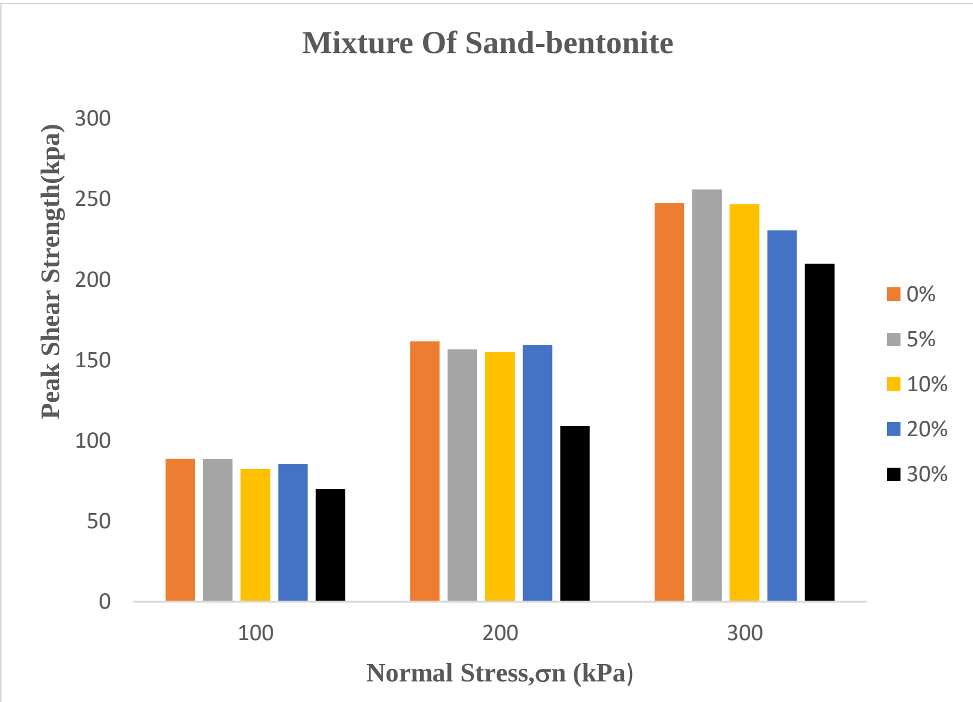
Figure (3.10) illustrates the effect of the content of non –plastic and plastic fines on shear resistance at the peak of Zemmouri sand considering the three types of fines, fly ash (FA), bentonites (FB) and kaolin (FK). The mixtures (FA, FB, FK =0%,5%,10%,20% and 30%) were reconstituted in the laboratory with a constant initial relative density (Dr=55%) and subjected to three initial normal stresses of (σn=100,200 and 300kPa).

When comparing the three groups, we notice that adding fines decreases relatively the shear resistance with the increase of fine content percentage for the three normal stresses, as well as the three types of fines.

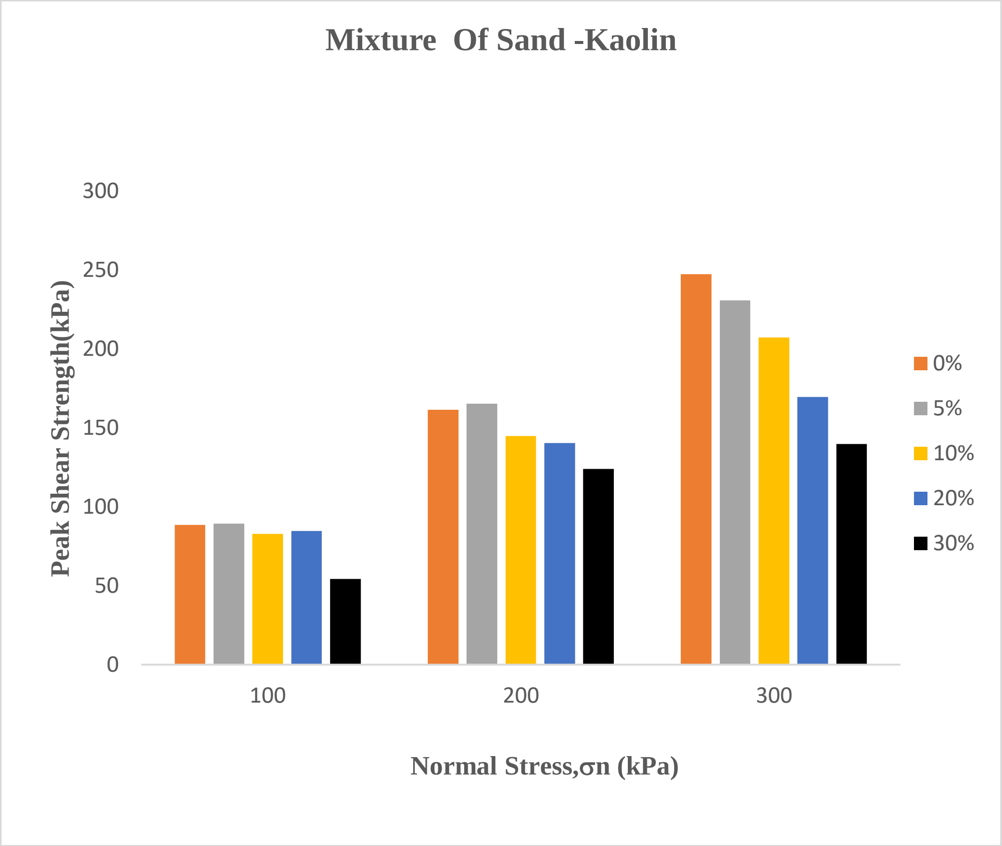
Furthermore, the trend cited above is well pronounce and is clearly noticed in the case of sand kaolin-mixtures, where the shear strength falls sharply with the increase of the fine percentage, at the highest normal stress specially for the.

When it comes to the lowest (100 kPa) and the medium normal stress (200 kPa), the trend is comparable for the three groups (sand-fly ash mix (FA), sand- bentonites mix (FB) and sand-kaolin mix (FK)) .

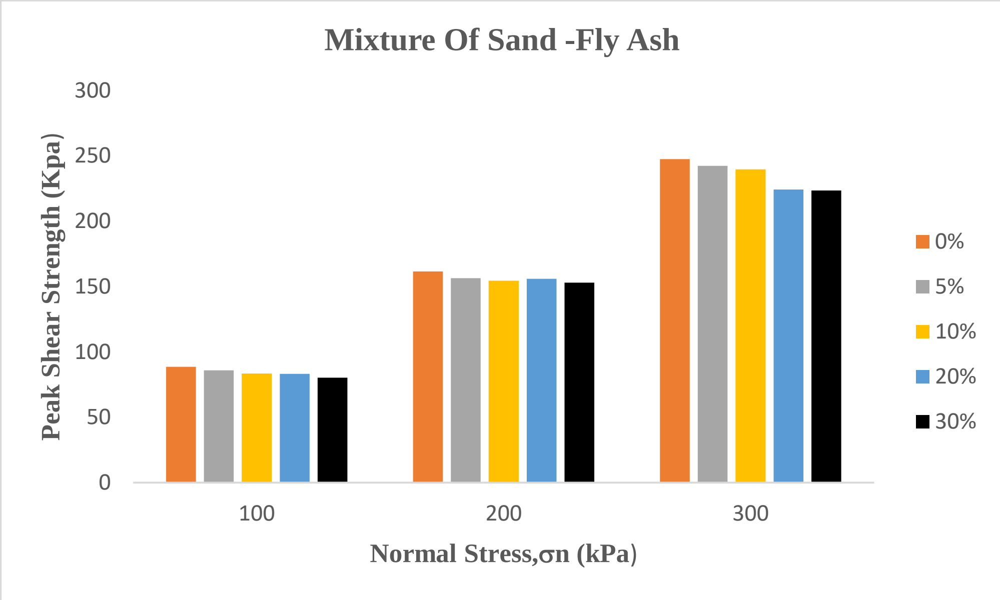
The results found indicate at each type of fines induces a small different behavior compared to other types. And we can conclude that for Zemmouri Sand, we notice that there is no improvement in terms of resistance.



(a)


Mixture Of Sand -Kaolin
Peak Shear Strength(kPa)
300
250
200
150
100
50
0
100
200
300
Normal Stress,σn (kPa)
0%
5%
10%
20%
30%

(b)



(c)

Figure 3.10: Influence of different types of fines fraction on the shear resistance at the peak of Zemmouri sand.

a) -Zemmouri sand –Bentonite mixtures,

b) -Zemmouri sand-Kaolin mixtures,

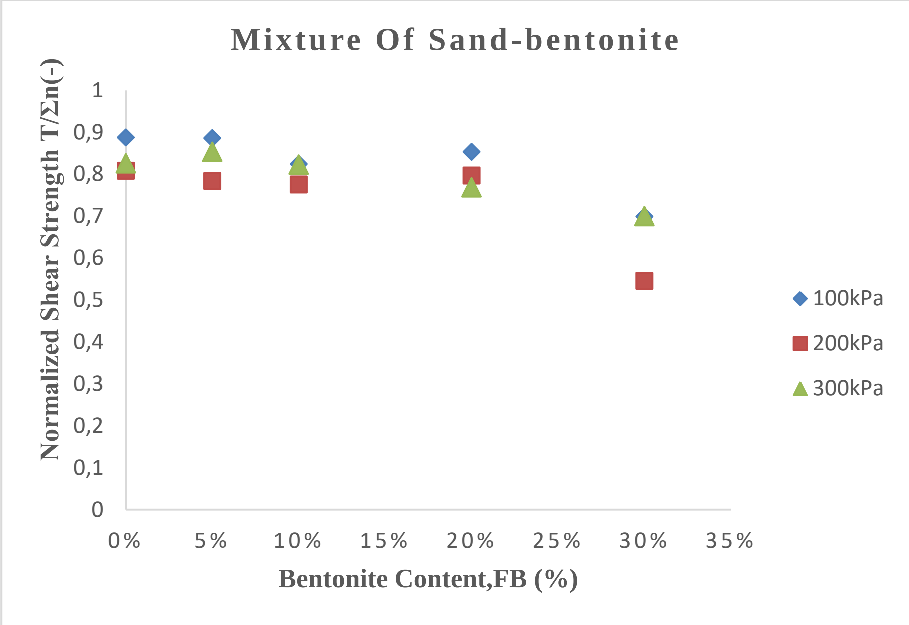
c) -Zemmouri sand –fly ash mixtures

3.4 Effect of the different types of fines fraction of on the normalized resistance (τ/σn)

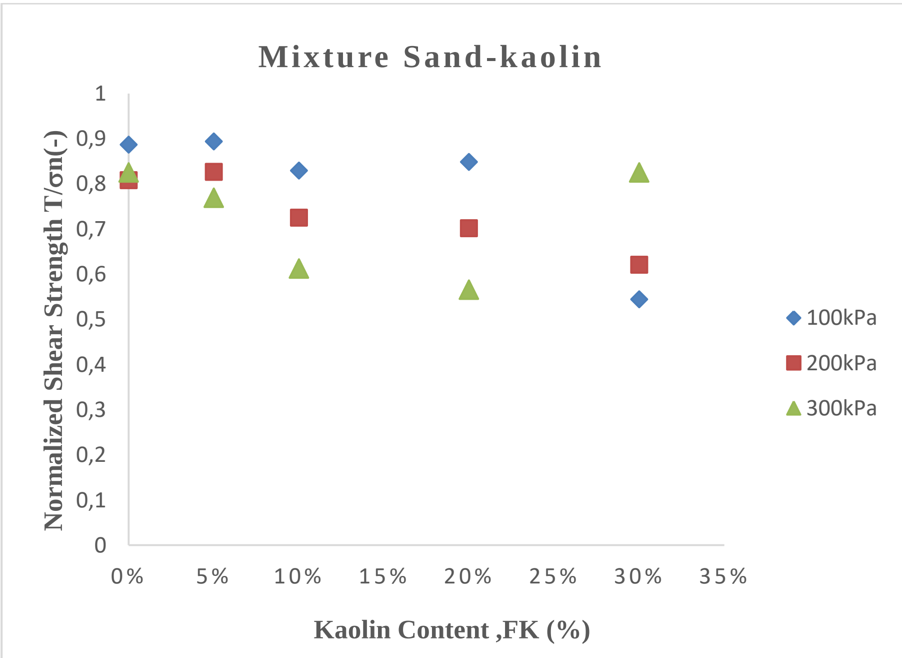
Figure 3.11 illustrates the effects of the fraction of fines for the three types of fines considered ((**bentonite as a high plastic material**), kaolin (as low plastic) and fly ash (non-plastic)) on the normalized shear strength (τ/σn) of the samples reconstituted by the dry pluviation method for an initial relative density (Dr=55%).

It can be seen that the values of normalized shear strength decreases with increase in fly ash fraction **(Figure 3.11c)** for the three normal stresses. On the other hand, it is observed that normalized shear strength decreases with the increase in fine content (**Figure 3.11a)** up to a threshold of FB=10% and after that an increase up to (FB=20%) then a decrease until (FB=30%) for initial normal stress of 100 kPa and 200 kPa was recorded. While showing an inverse result for initial normal stress (300kPa) we have an increase until FB=5% and after a decrease in increase of the bentonite content.

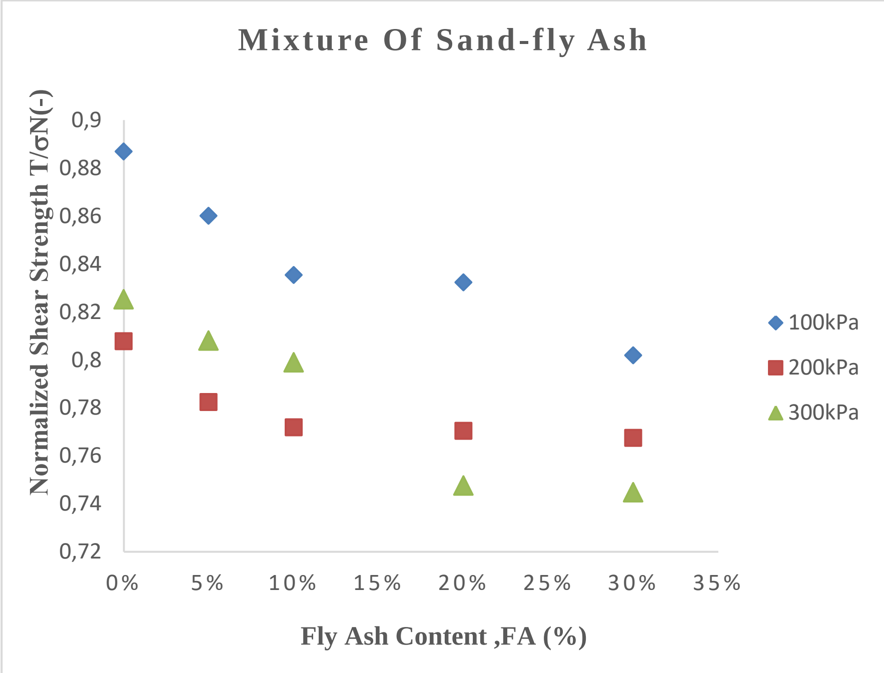
Figure 3.11b shows that the normalized shear strength remains stable up to 5% of fine content, then it decreases with an increase of (FK=20%) while decreasing again with fine content.


Mixture Of Sand-bentonite
Normalized Shear Strength T/Σn(-)
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0%
5%
10%
15%
20%
25%
30%
35%
Bentonite Content,FB (%)
100kPa
200kPa
300kPa

(a)


Mixture Sand-kaolin
Normalized Shear Strength T/σn(-)
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0%
5%
10%
15%
20%
25%
30%
35%
Kaolin Content ,FK (%)
100kPa
200kPa
300kPa

(b)



(c)

Figure 3.11 : Influence of the fraction of different types of fines on the normalized shear of Zemouri sand mix.

a) -Zemmouri sand-Bentonite mixture ,

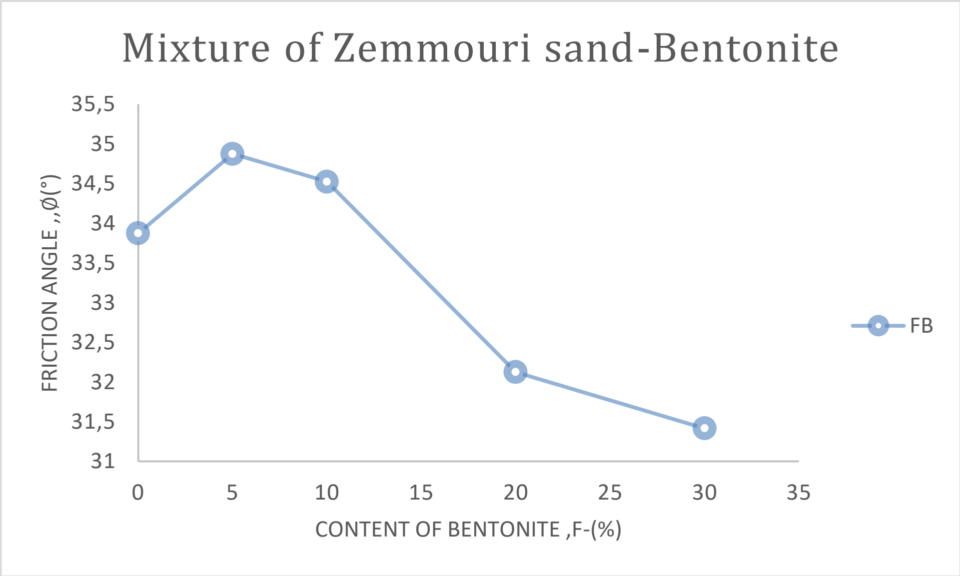
b) -Zemmouri sand-Kaolin mixture,

c) -Zemmouri sand-Fly ash mixture

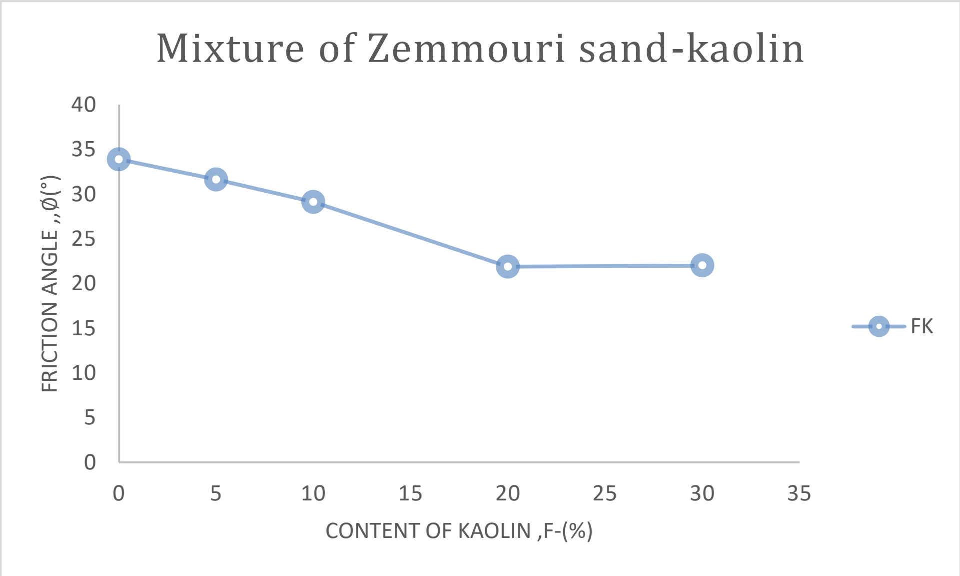
3.5. Effect of different types of fines fraction on the internal friction angle

The data obtained in the present study (**Figures 3.1-3.9)** are reproduced in the **Figure 3.12**, for the purpose of studying the impact three types of fine as follows: (bentonites as a high plastic soil, Kaolin as low plastic and fly ash as non-plastic) on the internal friction angle of the Zemmouri sand-bentonite mixtures, Zemmouri sand–kaolin mixtures and Zemmouri sand–fly ash mixtures. All the samples were reconstituted at an initial relative density (Dr=55%).

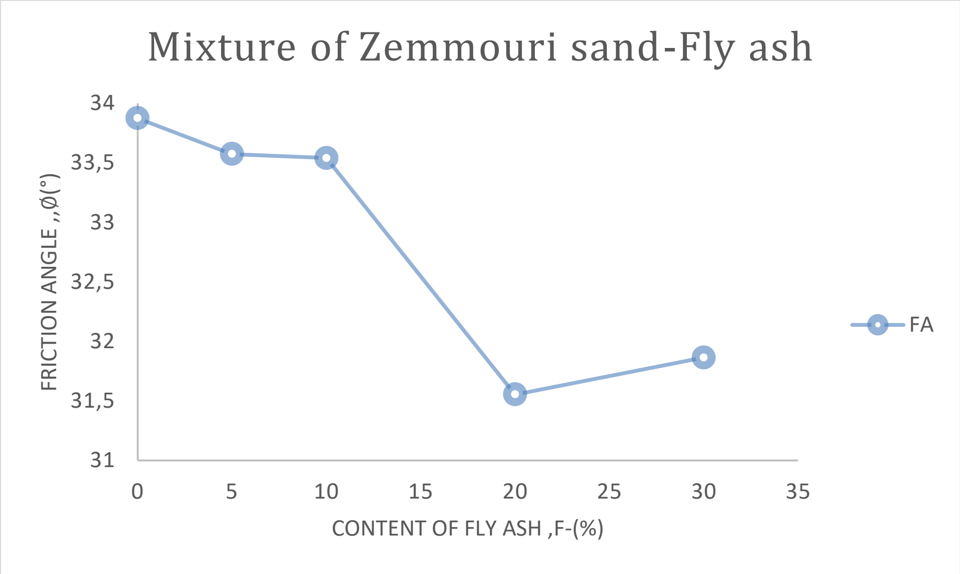
From this figures, it can be seen that the friction angle decreases with an increase of bentonite,fly ash and kaolin content for all parameters tested.They all induce a continuous decrease of the internal friction angle.


Mixture of Zemmouri sand-Bentonite
FRICTION ANGLE ,,Ø(°)
35,5
35
34,5
34
33,5
33
32,5
32
31,5
31
0
5
10
15
20
25
30
35
CONTENT OF BENTONITE ,F-(%)
FB

(a)


Mixture of Zemmouri sand-kaolin
FRICTION ANGLE ,,Ø(°)
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
CONTENT OF KAOLIN ,F-(%)
FK

(b)



(c)

Figure 3.12 : influence of the fraction of different types of fines on the friction angle of Zemmouri sand mix

a) -Zemouri sand –bentonite mixtures,

b) -Zemouri sand –kaolin mixtures ,

c) -Zemouri sand-fly ash mixture

Conclusion

In this chapter we have carried out an in-depth study of the influence of different types of fines fraction, bentonite as high plastic fines; kaolin as low plastic fines and fly ash as non-plastic fines, on the mechanical behavior, shear strength at the peak, normalized shear resistance and finally on internal friction angle of Zemmouri sand forming three groups. each group is subdivided to give five samples according to the percentages set for the related fine at 0%, 5%, 10%, 20%, 30%. Totaling 15 samples altogether. All samples are reconstituted by the dry funnel pluviation method with an initial constant relative density (Dr = 55 %). and subjected to three normal stresses (σn=100,200 and 300 kPa).

The obtained test results shows that the fines fraction parameter studied, controls the mechanical response of the mixtures; Zemmouri sand-bentonite , Zemmouri sand -kaolin and Zemmouri sand fly-ash respectively.

From the observation, the results clearly show that the fines induce a behavior of almost the same similarity, although a few difference in bentonite and kaolin for normal stress σn of 300 kPa, where the shear strength at the peak decreases slightly for the first and sharply for the second.

For 100 and 200 kPa the variation of shear strength remains almost the same for kaolin and bentonite, even though their plasticity indexes are very different, just we noticed that the diference is at 30% of fines, where the resistance decreases with a small amount for bentonite and the contrary was observed for kaolin for 200 kPa.

For fly ash two initial normal stress (σn=100 and 300kPa) shows that the shear strength decrease with an increase of fly ash fraction. A slight difference of variation is recorded at normal stress of 200kpa.

The results found after calculating the friction angle confirm the roles in which fines fractions plays for each type of fines used (bentonite, kaolin and fly ash).

- The friction angle decreases with an increase of bentonite,fly ash and kaolin content for all parameters tested. In addition, At 20% and 30 % for kaoline the friction angle drops sharply reflecting and emphasizing its behavior.

The addition of all the three fine content to Zemmouri sand induces a continuous decrease of the internal friction angle. And **no soil improvement was recorded or observed.**

4.1 Introduction

Several researchers have shown important effect of the presence of fines as plastic or non-plastic, as silts or clay, in the sand matrix. According to the published literature, we notice that there is a lot of discrepancy and contradictory in the results, this means that the behavior of the sand mixture is not yet well understood.

Mahmoudi et al. (2020) studied the influence of silts as a very low plastic fines on the mechanical response in terms of undrained shear resistance. They noted that an increase in fines content leads to a decrease in undrained shear strength. This decrease is insignificant for low to medium fines content from Fc = 0% to 20%, and becomes very pronounced for the higher silts fines content of Fc= 40%. However, very limited research that has investigated the impact of the fines nature in terms of plasticity index (comparison between the mechanical behavior of different types of fines such as “low plastic” silt, kaolin, “very high plastic” bentonite, “non-plastic” fly ash…, for a given fine content). (Bayat et al. 2014) carried out monotonic triaxial tests on mixed sand samples with two types of plastic fines, kaolin and bentonite, considering the ranges of fractions (FK=0-20% and FB=0-30%, respectively). They showed that for samples containing 10% of kaolin or bentonite, the maximum shear strength values are very close to each other. Moreover, it was observed that the bentonite content has considerable effects on the mechanical behavior of sand compared to kaolin ,on the other hand, before and after reaching this point (Fc= 10%), the decrease or increase in shear strength is considerable in sand-bentonite samples. Undrained triaxial compression tests on sand samples was reported by Kermatikerman et al. (2018), they showed that the addition of fly ash in the sand samples changed the behavior in terms of stress strain. They found that the undrained shear strength increases with increasing fly ash mixtures.This increase in resistance due to the fact that the fly ash contributed to the inter-granular forces of sands.

In this chapter we present an in-depth analysis of the experimental tests results in a direct shear box, in order to study the impact of different types of fines (fly-ash as non-plastics, bentonite as high plastic and kaolin as low plastic) on the mechanical response of Zemmouri sand which was collected at a shallow depth along the beach of Zemmouri el Bahri from liquefied soil deposit area. The samples of the mixtures (FA, FB and FK = 0%, 5%, 10% ,20% and 30%) were reconstituted at the laboratory with the dry pluviation method at an initial relative density

Of 55% and subjected to three normal stresses (σn= 100, 200 and 300kPa)

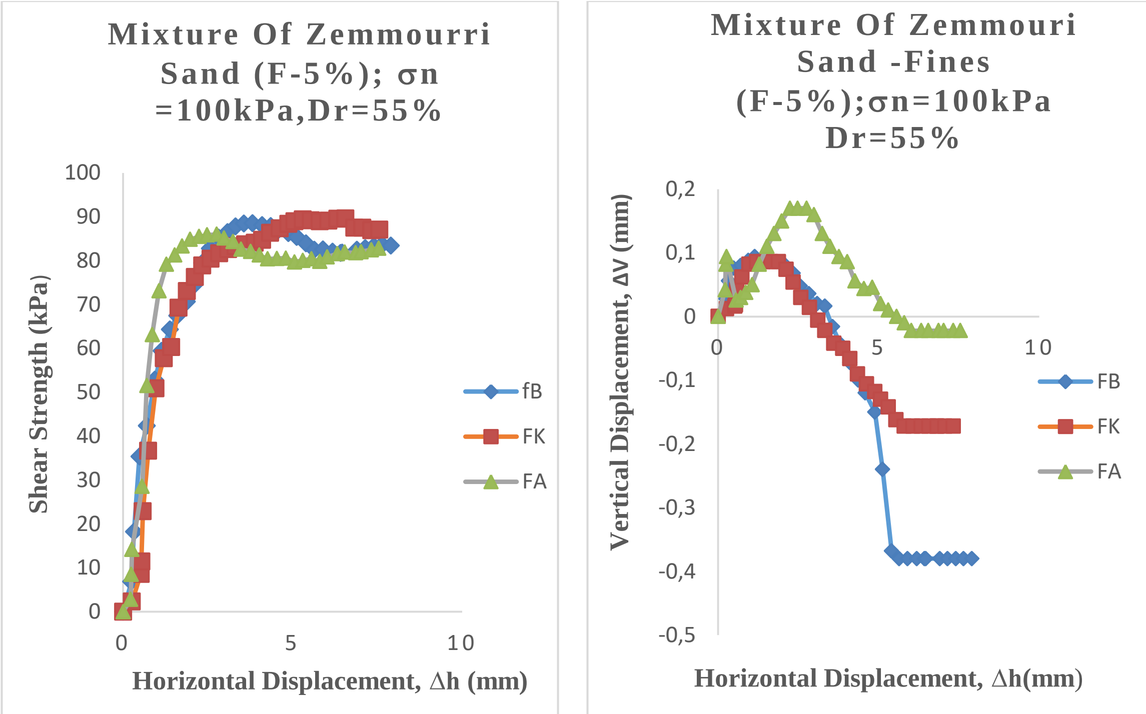
4.2 Results of the tests carried out

4.2.1 Zemmouri sand-fines mixed at 5% of Fly-ash, Bentonite and Kaolin

Figure 4.1,4.2 and 4.3 present the results of the direct shear tests carried out on Zemmouri sand mixed with different types of fines: high plastic “bentonite”, low plastic “kaolin” and non-plastic (fly ash) with the same percentage of 5%. The samples of different mixtures were reconstituted at the laboratory with the dry pluviation method, and subjected to three normal stresses (σn=100,200 and 300kPa). The relative density imposed was kept constant at 55%. The mixtures tested show that the fines nature influence Zemmouri sand response.

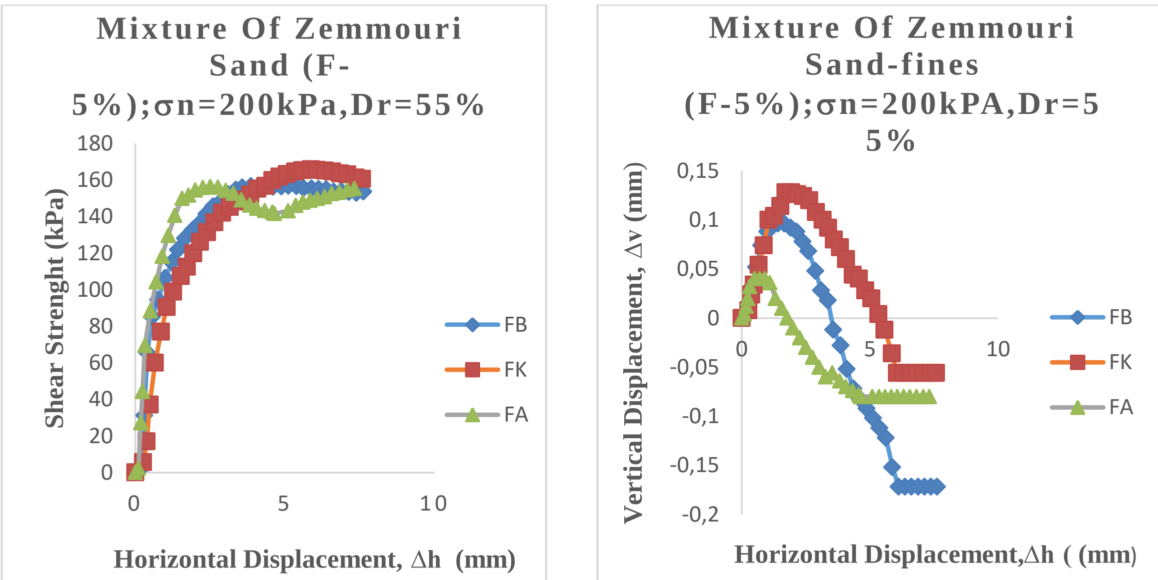
Zemmouri sand - fly ash mixture results at 5% show a small difference of shear strength (τpeak =86.0019kPa, 156.465kPa and 242.415 kPa) with Zemmouri sand-bentonite mixture results (τpeak=88.513kPa, 156.627kPa and 255.948kPa) and Zemmouri sand –kaolin at the same percentage (τpeak=89.375kPa, 165.321kPa and 230.787kPa respectively. As presented **in Figure 4.1a,4.2a and 4.3a**.The obtained results are in good agreement work reported by (Bayat et al 2014).

Evolution of vertical displacement in fonction of horizontal displacement is illustrated in **Figure 4.1b,4.2b and 4.3b.** The results obtained shows that fly ash (non plastic) has a remarkable phase of dilantacy compared to kaolin (plastic) and bentonite (high plastic).



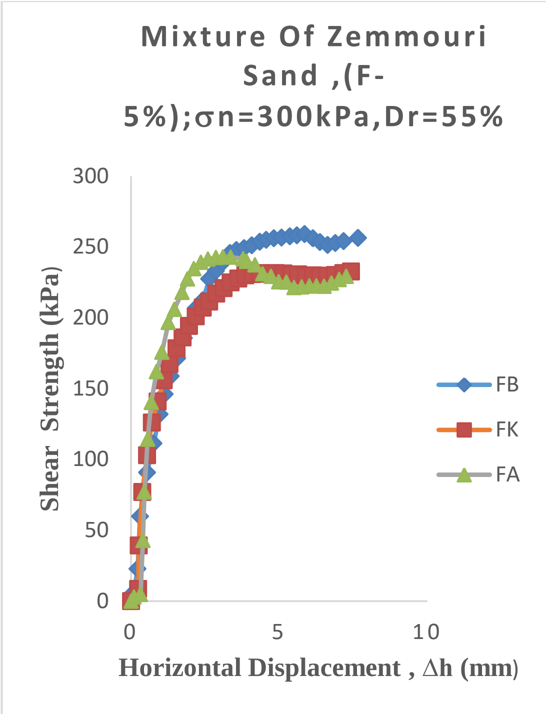
(a) (b)

Figure 4.1 : Effect the of fines nature on the mechanical behavior of Zemmouri sand (FB,FK,FA=5%, σn=100kPa,Dr=55%)
(a) Evolution of shear stress,
(b) Evolution of vertical displacement vs horizontal displacement

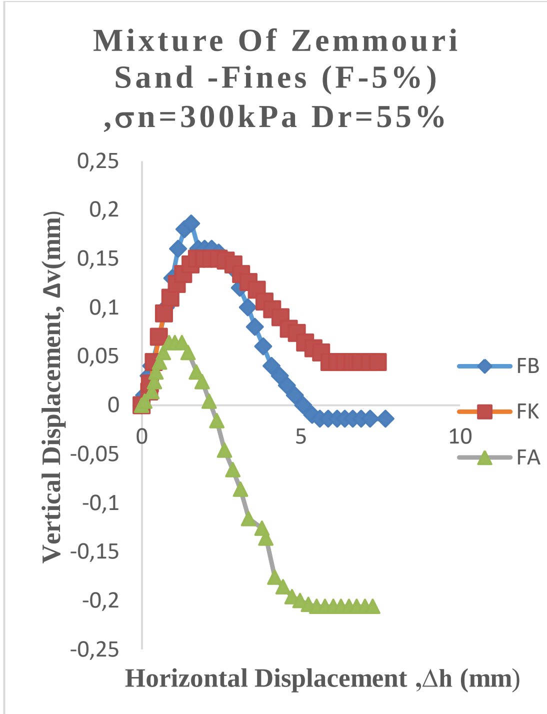


(a) (b)

Figure 4.2 : Effect the of fines nature on the mechanical behavior of zemmouri sand (FB,FK,FA=5%, σn=200kPa,Dr=55%)
(a) Evolution of shear stress (b) Evolution of vertical displacement vs horizontal displacement



(a)



(b)

Figure 4.3 : Effect the of fines nature on the mechanical behavior of zemmouri sand (FB,FK,FA=5%, σn=300kPa,Dr=55%)
(a) Evolution of shear stress,
(b) Evolution of vertical displacement vs horizontal displacement

<u>4.2.2 Zemmouri sand-fines mixed at 10% of Fly-ash, Bentonite and Kaolin</u>

Mixture of sand-fines at 10% have been reported to show effect of the nature of fines (Bentonite, kaolin;plastic and fly ash ;non-plastic) on the mechanical response of Zemmouri sand, for this purpose **Figure 4.4, 4.5 and 4.6** are established.

The samples of different mixtures of fines (FB, FK, FA=10%) were reconstituted at the laboratory with the dry pluviation method and subjected to three normal stress (σn=100,200 and 300kPa) for a medium relative density (Dr=55%).**Figure 4.4a, 4.5a and 4.6a**, show how the results is influenced. The samples of Zemmouri sand-fines for initial normal stress (σn =100kPa) shows a small difference of shear strength at the peak between them.

Figure 4.4b,4.5b and 4.6b illustrate evolution of vertical displacement in fonction of horizontal displacement showing the influence of the fines. It is observed that the nature of the fines have a significant influence on the mechanical behavior of sands in terms of contractancy and dilatancy. Kaolin a plastic fine show remarkable phase of contractance compared to bentonite(plastic) and fly ash (non plastic).

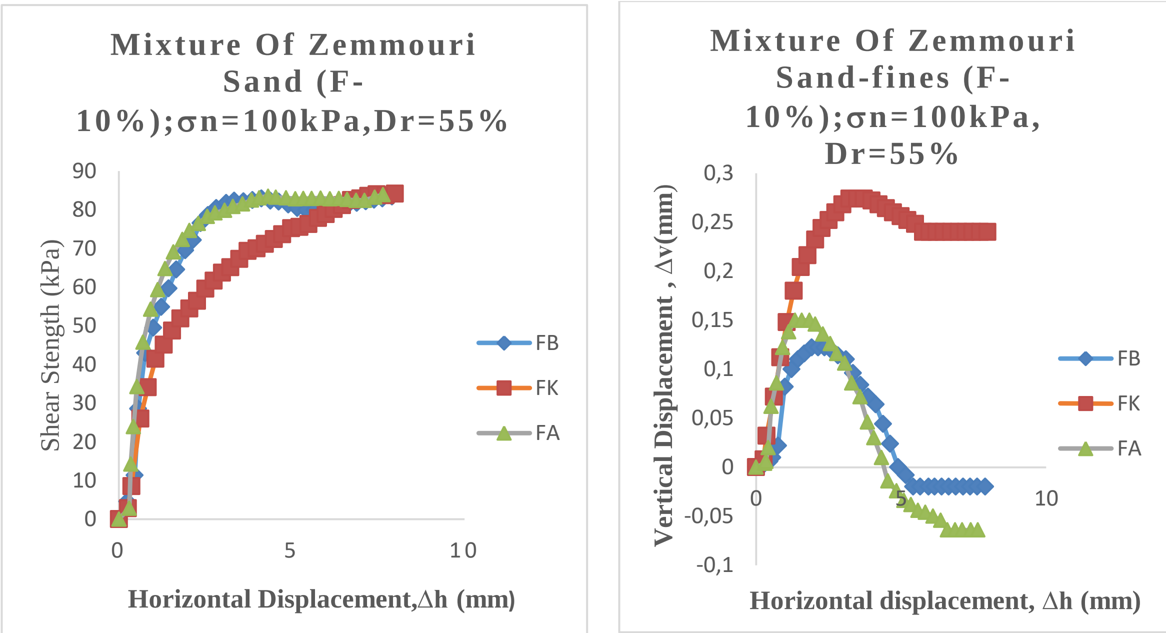
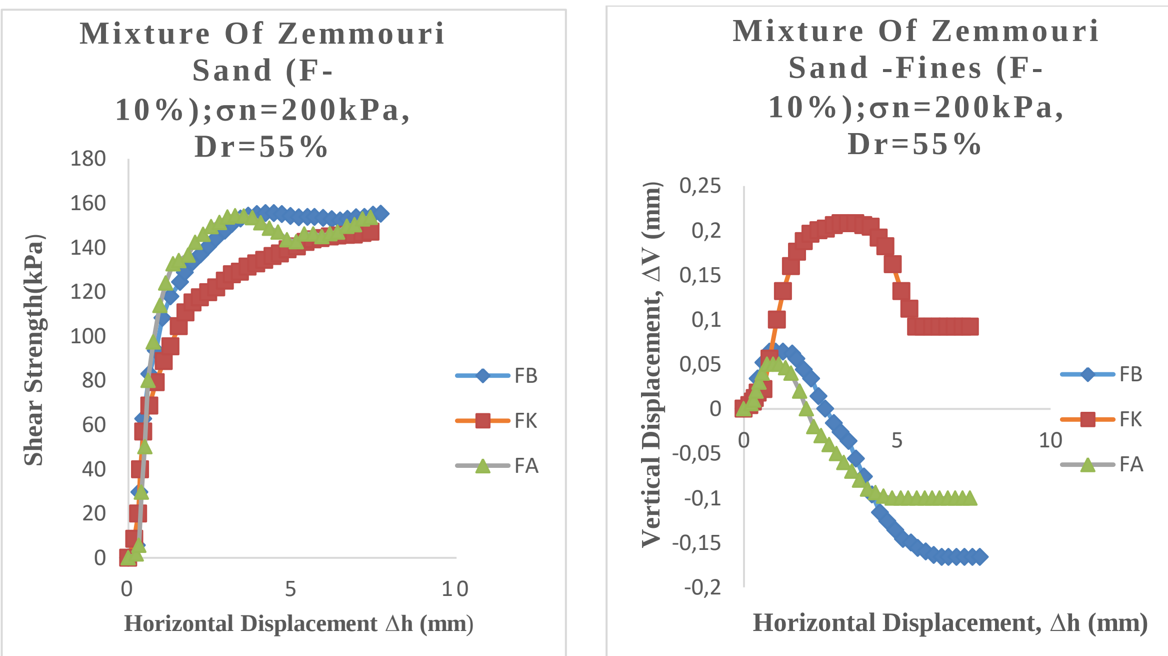
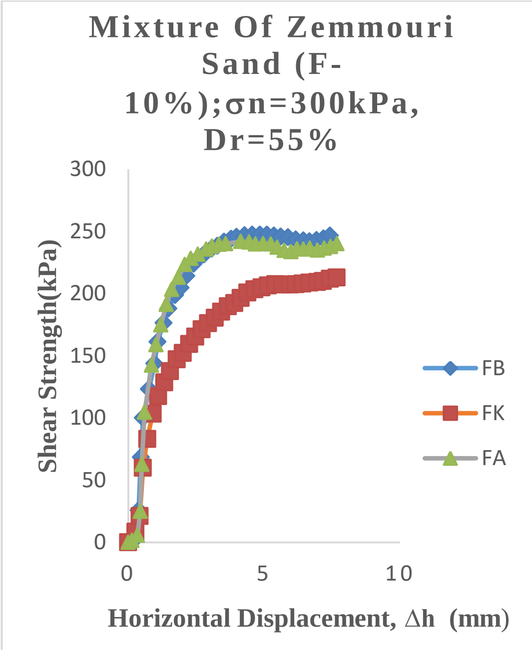


Figure 4.4 : Effect the of fines nature on the mechanical behavior of Zemmouri sand (FB,FK,FA=10%, σn=100kPa,Dr=55%)
(a) Evolution of shear stress,
(b) Evolution of vertical displacement vs horizontal displacement



(a) (b)

Figure 4.5 : Effect the of fines nature on the mechanical behavior of zemmouri sand (FB,FK,FA=10%, σn=200kPa,Dr=55%)
(a) Evolution of shear stress
(b) Evolution of vertical displacement



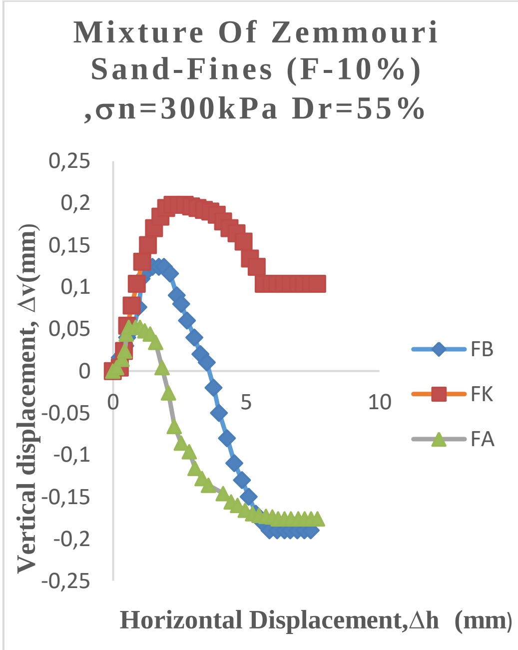


Figure 4.6: Effect the of fines nature on the mechanical behavior of zemmouri sand (FB,FK,FA=10%, σn=300kPa,Dr=55%)
Evolution of shear stress
Evolution of vertical displacement vs horizontal displacement

4.2.3 Zemmouri sand-fines mixed at 20% of Fly-ash, Bentonite and Kaolin

Mixture of sand-fines at 20% have been reported to show effect of the nature of fines (Bentonite, kaolin;plastic and fly ash ;non-plastic) on the mechanical response of Zemmouri sand. For this purpose, **Figure 4.7, 4.8 and 4.9** are established. The samples of Zemmouri sand-fines show a small difference in terms of shear strength.

The results shows that the sand-fly-ash mixture exhibit higher values of shear strength at the elastic phase compared to sand-kaolin mixture and bentonite sand mixture for the three normal stresses (σn =100, 200 and 300kPa), respectively. This behavior can be explained by the remarkable phase of dilantacy at the elastic phase, compared to bentonite (high plastic) and kaolin (low plastic), in which the sand-kaolin mixture and sand bentonite mixture reach the contractance phase before sand-fly-ash mixture.

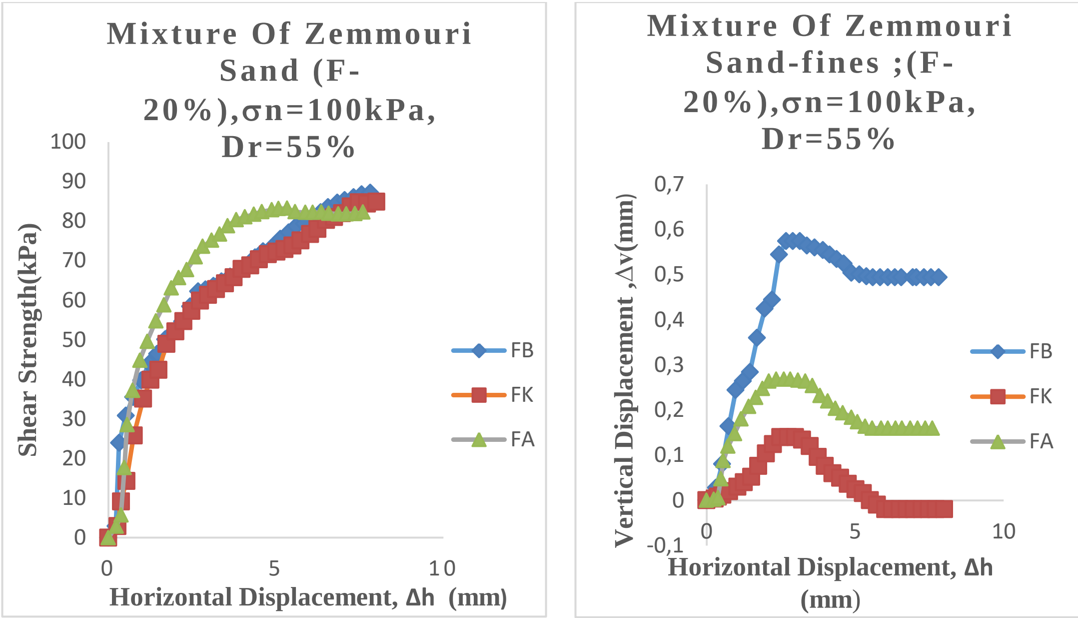


Figure 4.7 : Effect the of fines nature on the mechanical behavior of zemmouri sand (FB,FK,FA=20%, σn=100kPa,Dr=55%)
(a) Evolution of shear stress
(b) Evolution of vertical displacement vs horizontal displacement

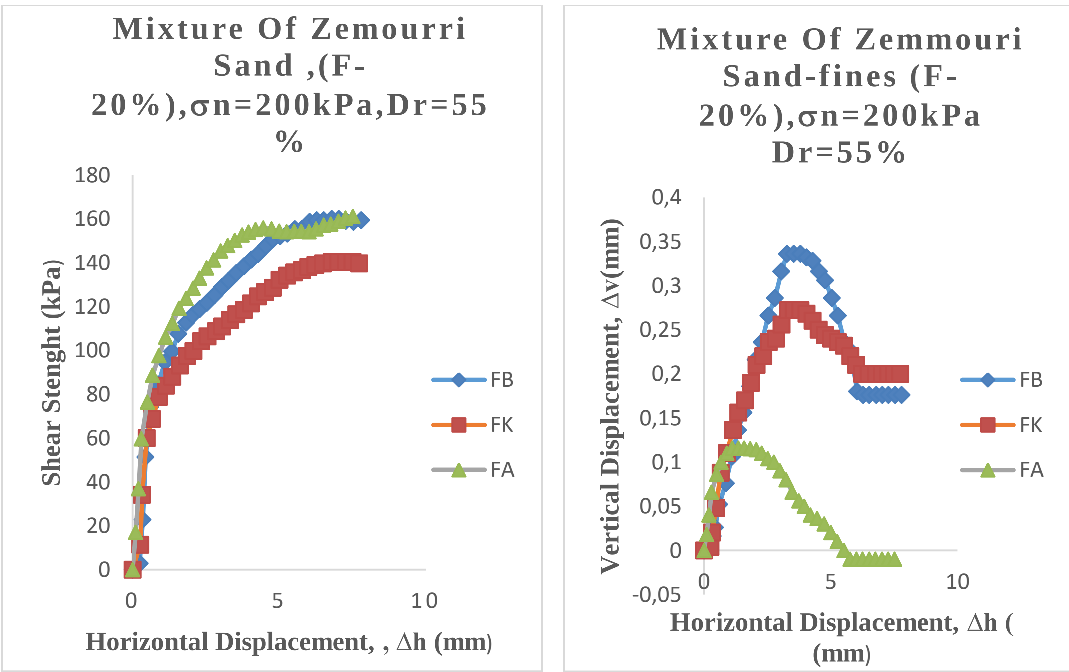


Figure 4.8 : Effect the of fines nature on the mechanical behavior of zemmouri sand (FB,FK,FA=20%, σn=200kPa,Dr=55%)
(a) Evolution of shear stress,
(b) Evolution of vertical displacement vs horizontal displacement

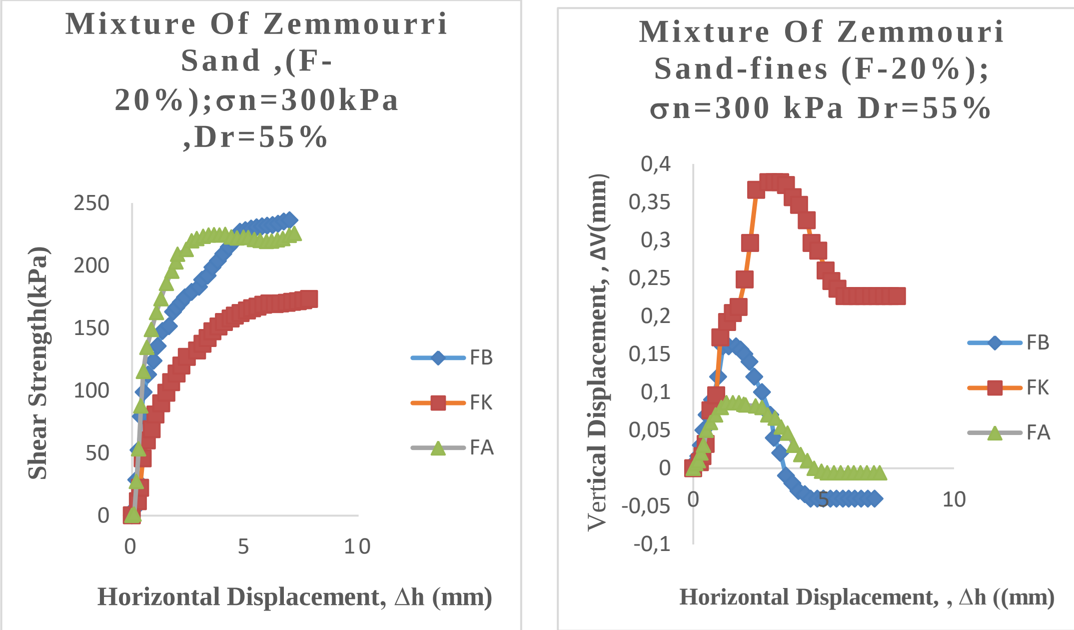


Figure 4.9 : Effect the of fines nature on the mechanical behavior of zemmouri sand (FB,FK,FA=20%, σn=300kPa,Dr=55%)
Evolution of shear stress
Evolution of vertical displacement vs horizontal displacement

4.2.4 Zemmouri sand-fines mixed at 30% of Fly-ash, Bentonite and Kaolin

The samples of different mixtures of fines (FB, FK,FA=30%) were reconstituted in the laboratory with the dry pluviation method and subjected to three initial stress (σn=100,200 and 300kPa) for a medium initial relative density (Dr=55%). **Figure 4.10a, 4.11a and 4.12a** shows how the results are influenced. The samples of zemmouri sand –fly ash mixture indicate a higher shear strength from the elastic phase up to the steady state in comparison to sand-bentonite and sand-kaolin mixtures. However, the results shows that mixture of sand-fly-ash exhibit higher values of shear strength at the peak and also at the elastic phase compared to sand-kaolin mixture and to sand bentonite for the three normal stresses (σn =100, 200 and 300kPa), respectively.

It is observed in **(Figure 4.10b,4.11b and 4.12b)** that the nature of the fines have a significant influence on the mechanical behavior of sands in terms of contractancy and dilatancy. fly ash as (non plastic) show remarkable phase of dilantacy compared to bentonite as high plastic and kaolin as low plastic.

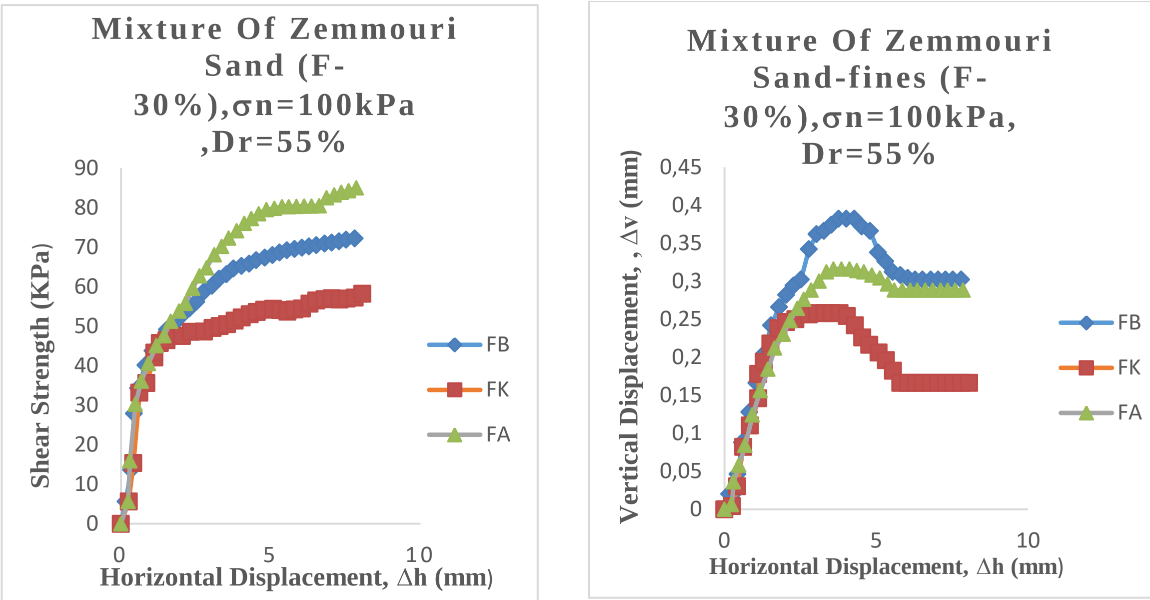


Figure 4.10 : Effect the of fines nature on the mechanical behavior of zemmouri sand (FB,FK,FA=30%, σn=100kPa,Dr=55%)
(a) Evolution of shear stress,
(b) Evolution of vertical displacement vs horizontal displacement

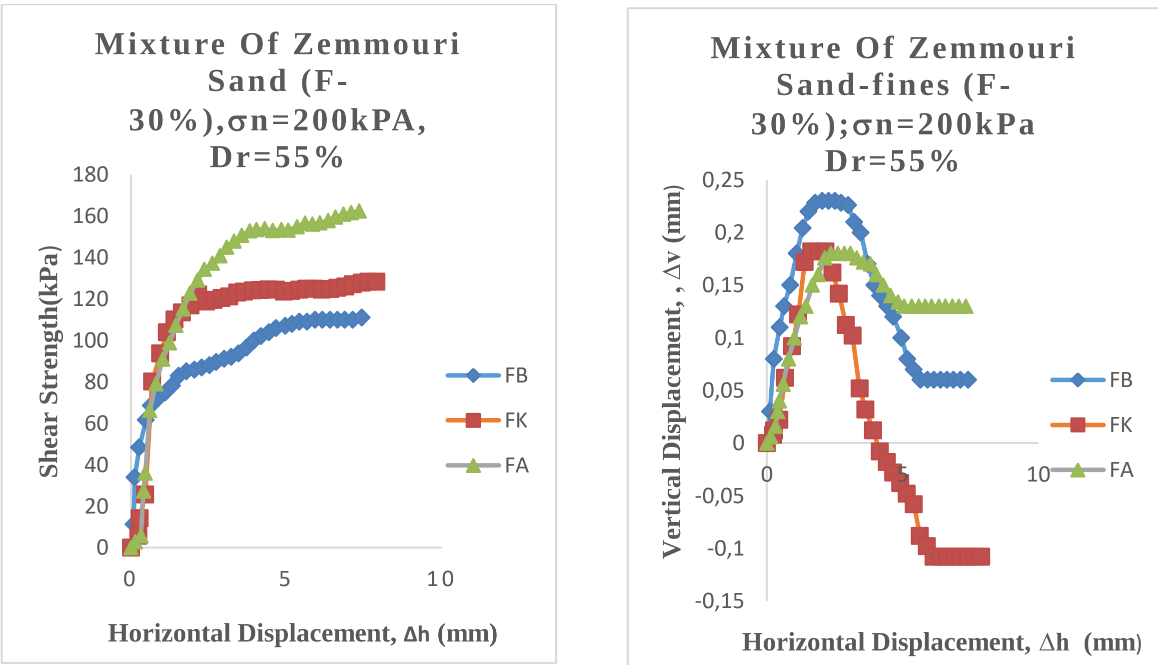
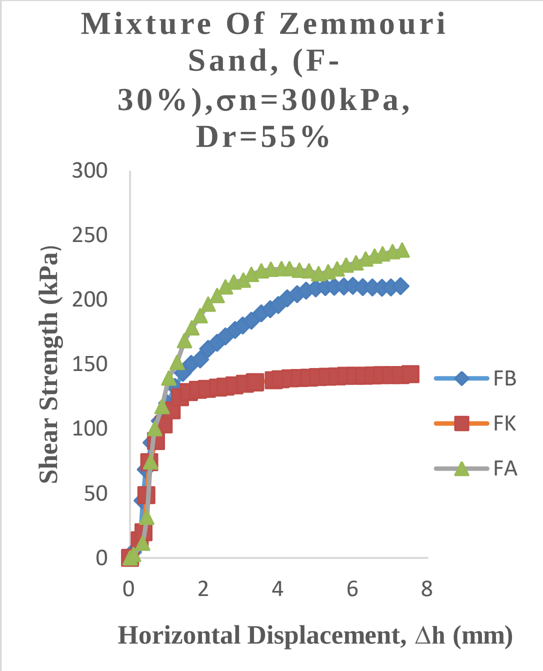


Figure 4.11 : Effect the of fines nature on the mechanical behavior of zemmouri sand (FB,FK,FA=30%, σn=200kPa,Dr=55%)
(a) Evolution of shear stress,
(b) Evolution of vertical displacement vs horizontal displacement



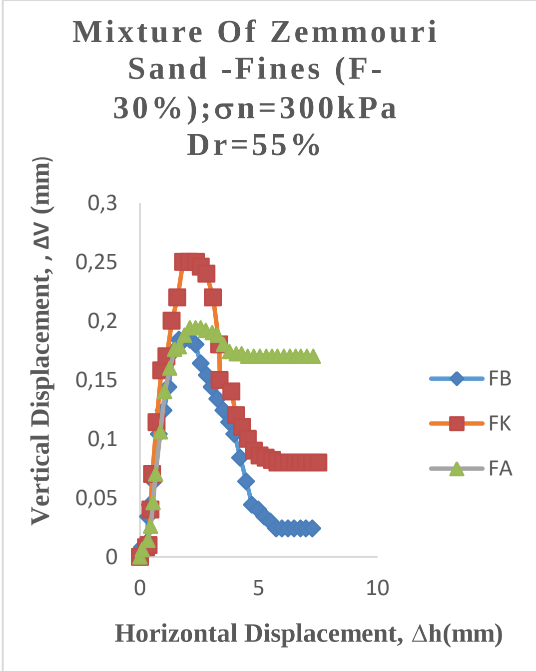
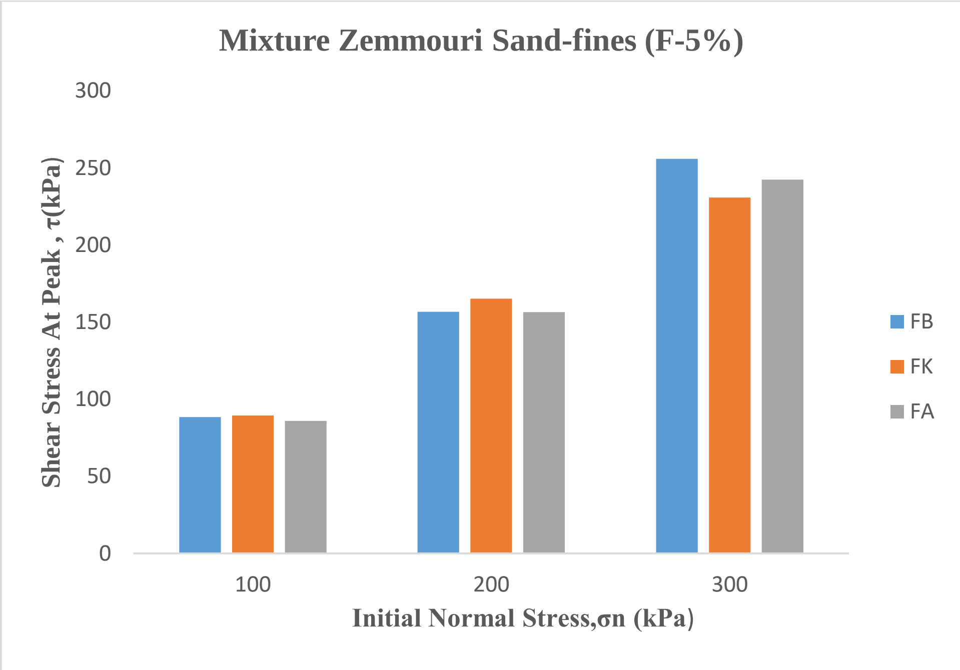


Figure 4.12 : Effect the of fines nature on the mechanical behavior of Zemmouri sand (FB,FK,FA=30%, σn=300kPa,Dr=55%)
(a) Evolution of shear stress,
(b) Evolution of vertical displacement vs horizontal displacement

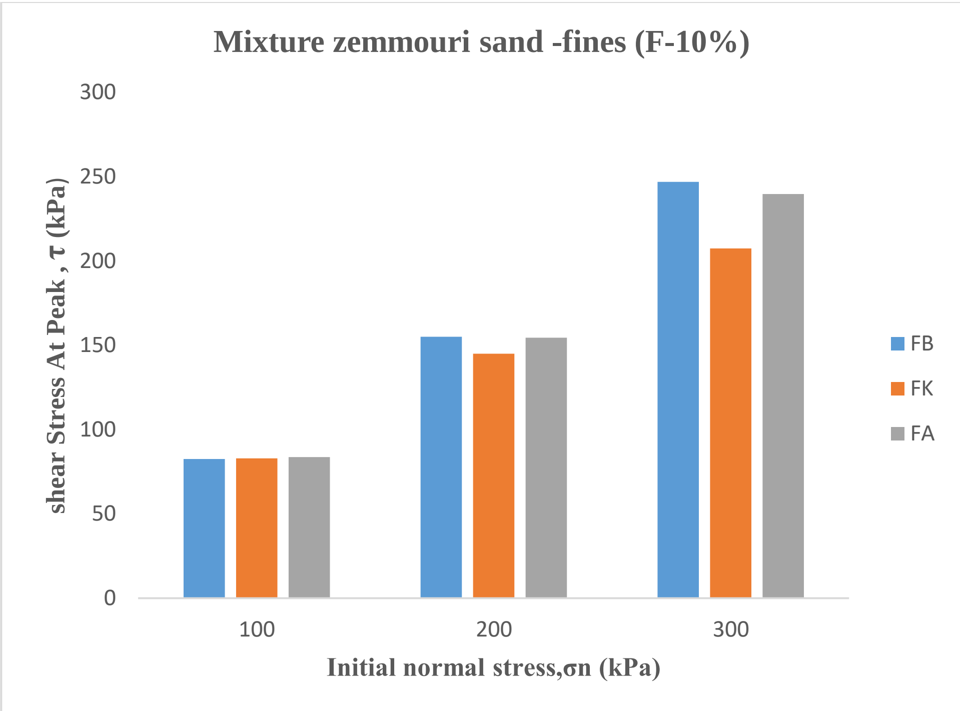
4.3 Effect of the nature of fines on the shear strength at the peak on Zemmouri sand

Figure 4.13 shows the results obtained in the present study ,for the objective of analyzing the impact of fines nature parameter (bentonite,kaolin ;plastic and fly ash (non-plastic) on the shear strength of zemmouri sand. In the laboratory the sample of different mixture (FB,FK and FA =0%, 5%, 10%, 20% and 30%) were reconstituted with a medium initial relative density (Dr=55%) and subjected to three normal stresses (σn=100, 200 and 300 kPa).

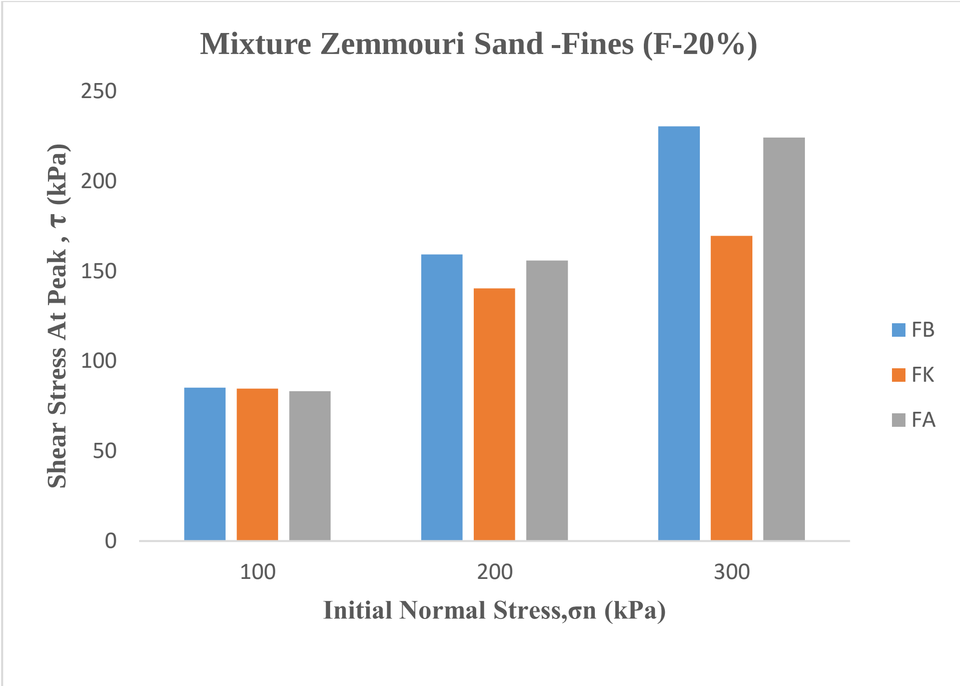
Zemmouri sand samples mixed with fly ash (non plastic) induces higher peak shear strength values compared to bentonite and kaolin(plastics) for 30% but when decreasing the percentages of fines we notice the opposite results and these are true for the peak shear resistance and not for the steady state.


Mixture Zemmouri Sand-fines (F-5%)
Shear Stress At Peak , τ(kPa)
300
250
200
150
100
50
0
100
200
300
Initial Normal Stress,σn (kPa)
FB
FK
FA

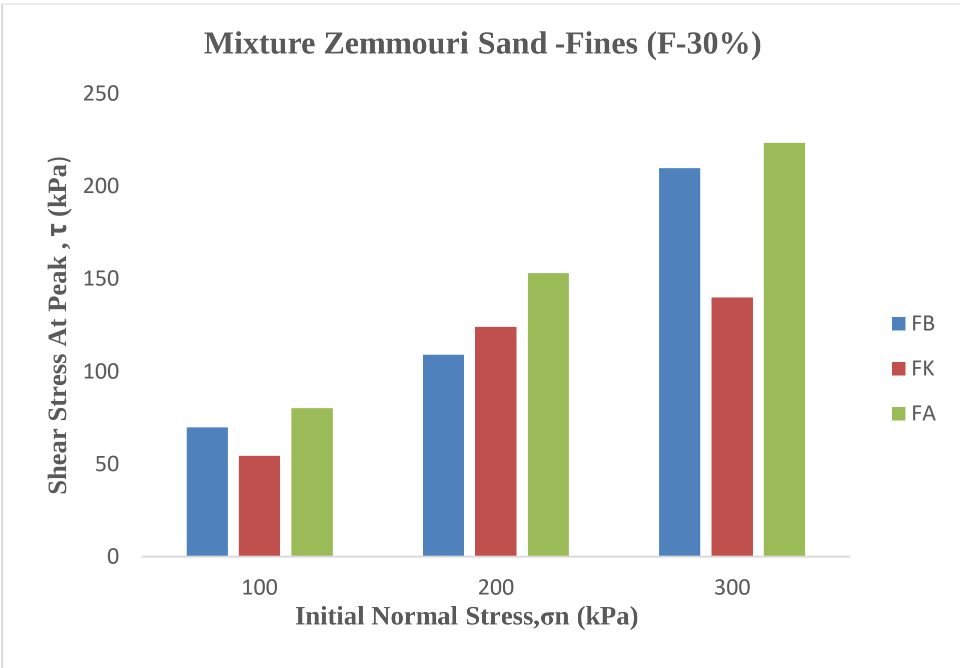
(a)


Mixture zemmouri sand -fines (F-10%)
shear Stress At Peak , τ (kPa)
300
250
200
150
100
50
0
100
200
300
Initial normal stress,σn (kPa)
FB
FK
FA

(b)



(c)



(d)

Figure 4.13 : Effect of the nature of fines on the shear strength at peak,(Dr=55%)
(a) FB, FK and FA=5%
(b) FB, FK and FA =10%
(c)FB, FK and FA=20%
(d)FB,FK,FA=30%

4.4. Effect of the nature of fines on the friction angle

Samples of different types of fines were reconstituted in the laboratory with a medium initial relative density (Dr=55%).Figure 4.14 shows the impact of the fines nature as follows: bentonite as high plastic clay; kaolin as low plastic clay and and fly ash as non-plastic fines on the friction angle.

According to the plot presented below, Zemmouri sand- bentonite samples shows more pronounced values of friction angle followed by Zemmouri sand -bentonite and lastly zemmouri sand-kaolin mixtures. However,the values were close to each other despite their difference in plasticity index.

At 20% and 30% for kaoline the friction angle drops sharply reflecting and emphasizing its behavior. While for bentonite and fly ash at the same threshold the friction angle remained almost the same.

So when we compare, we notice that there is no improvement of the soil response while adding different nature of fines.

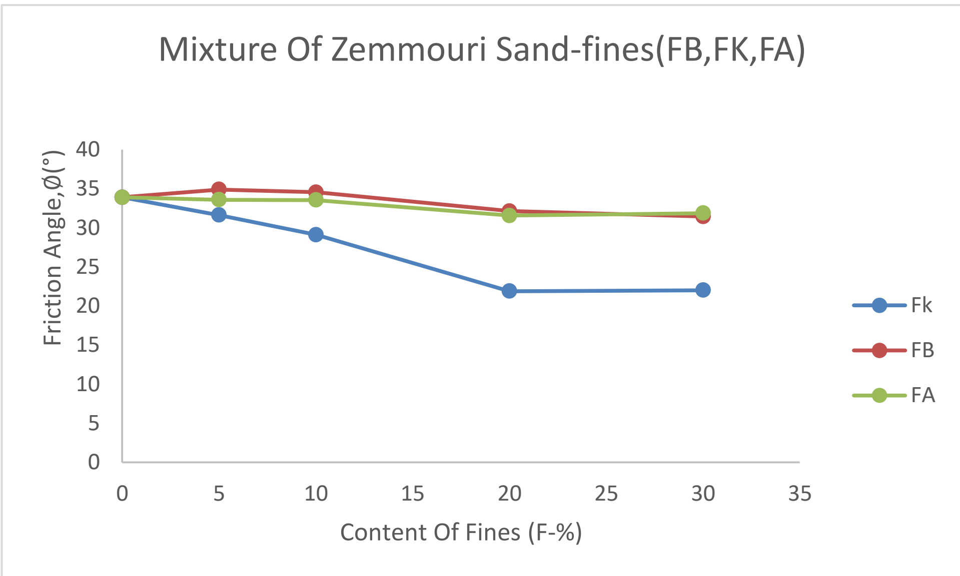


Figure 4.14 : Effect of the nature of fines on friction angle (Dr=55%)

Conclusion

This chapter showed direct shear box tests results for a purpose of evaluating the influence of the fines nature of bentonite as very high plastic soil, kaolin as low plastic soil and fly ash as non-plastic material on the mechanical behavior of a liquefied clean natural Zemmouri sand. This later was mixed with fines fraction ranging from (0%,5%,10%,20% and 30%, giving a sum of 15 samples all together.

At the laboratory, samples of different mixtures were reconstituted with dry pluviation method and subjected to three normal stress (σn=100, 200 and 300 kPa) at a medium initial relative density of 55%.

Through which the results found, we concluded that the nature of the fines has a remarkable effect on the mechanical behavior of zemmouri sand in terms of shear resistance at the elastic phase, shear resistance at the peak, mechanical response at steady state and the friction angle.

Zemmouri sand- bentonite samples shows more pronounced values of friction angle followed by Zemmouri sand -bentonite and lastly zemmouri sand-kaolin mixtures. However,the values were close to each other despite their difference in plasticity index.

At 20% and 30 % for kaoline the friction angle drops sharply reflecting and emphasizing its behavior. While for bentonite and fly ash at the same threshold the friction angle remained almost the same.

So when we compare, we notice that there is no improvement of the soil response while adding different nature of fines.

General Conclusion

Several search works were based on the impact of fines fraction and their types on the sand shear strength. Most search reports have shown the sand shear strength increases with the increase of non-plastic fine contents. On the other hand, other researches have shown opposite results, noting a decrease of shear strength with the increase of fine content in the mixture tested. In this case we conclude that the difference in types of fines is among the parameters that must be correctly identified in the control of mechanical response of granular soils.

The main objective of this experimental research is to study the influence of three types of fines on the mechanical and physical behavior of Zemmouri sand. The choice of this material, is due to the particular violent earthquake that shook this area, on May 21, 2003, causing enormous damages to the structures and enormous deformations to the soil such as: landslides and liquefaction.

The sand studied was collected from an area which had undergone liquefaction, located at Zemmouri el Bahr (wilaya of Boumerdès, North Algeria). This latter was mixed with three types of fines "Zemmouri sand- fly ash mixtures, Zemmouri sand-bentonite mixtures and Zemmouri sand-kaolin mixtures" considering five fines content (Fly ash" FA", bentonite "FB", kaolin "FK" at 0%, 5%, 10%, 20%, 30%. All samples were reconstituted by the dry funnel pluviation method with an initial constant relative density (Dr = 55 %) and subjected to three normal stresses σn of 100 kPa, 200 kPa and 300 kPa.

In general, it was found that:

- The phase of dilation decreases progressively with the increase of the bentonite fraction for all the sand bentonite mixtures considered. In addition, the shear strength decreases progressively with the increase in the content of plastic kaolin for the two normal stresses 200kPa and 300kPa studied. while its variation for (100kPa), remains almost the same from 0% to 20% after that it decreases about 36%.
- When comparing the three groups of samples, we notice that adding fines decreases relatively the shear resistance with the increase of fine content percentage for the three

normal stresses, as well as, the three types of fines. Furthermore, the trend cited, is well pronounce and is clearly noticed in the case of sand kaolin-mixtures, where the shear strength falls sharply with the increase of the fine percentage, at the highest normal stress.

- For the three types of fines a small difference is recorded. And we can conclude that for Zemmouri Sand, we noticed that there is no improvement in terms of resistance.
- Zemmouri sand- bentonite samples shows more pronounced values of friction angle followed by Zemmouri sand -bentonite and lastly zemmouri sand-kaolin mixtures.

- it can be seen that the friction angle decreases with an increase of bentonite,fly ash and kaolin content for all parameters tested. . However,the values were close to each other despite their difference in plasticity index.At 20% and 30 % for kaoline the friction angle drops sharply reflecting and emphasizing its behavior.And **no soil improvement was recorded or observed.**

Finally, we hope that this work can find a continuation. Some perspectives can be proposed: in order to better validate our conclusions, in particular:

- Contribution to the study of cyclic and static triaxial tests of the same materials used in our research, in order to better validate our results.
- Contribution to the study of the influence of grain size, through the extreme diameters "Dmax", "Dmin" and the mean grain diameter "D50" adding the same types of fines with the same percentages on the behavior of the same soil.

Bibliographic Reference

- Arab,A.,Hamoudi,S.,Shahrour,I.and Lancelot,L., 2009. Effect des fines peu plastiques sur le comportment d'un sable limoneux.''Etude d'un melange sable limon peu plastique.
- Bayat M, Bayat E, Aminpour H, Salarpour A. [2012] "Shear strength and pore-water pressure characteristics of sandy soil mixed with plastic fine" DOI 10.1007/s12517-012-0753-9.
- Benghalia.Y, Bouafia.A, Canou.J, Dupla J.C [2014] "Liquefaction susceptibility study of sandy soils: effect of low plastic fines" Arab J Geosci, DOI: 10.1007/s12517- 013-1255-0.
- Belhadri imene et Bouziane Rahmani sarra .[2021] ''Influence de la nature des fines sur le comportement mécanique de sable de dune''mémoire de master. Université Hassiba Ben Bouali-Chlef.
- Bouchibane et Ben abdelmoutaleb. [2020] "Etude en laboratoire de la réponse mécanique du sable de chlef : impact des différents types des fines" thème de master. Université Hassiba Benbouali de Chlef.
- Flitti, A, Della, N Ramiro D. Flores, V [2016] " experimental study of the shear resistance of granular material: influence of initial state. Journal of theoretical and applied mechanics", DOI: 10.15632/jtam-pl.55.2.523.
- Hazout L. [2018] "Contribution à l'etude de la liquefaction statique des sol pluverulents ".Thése de doctorat, Univesité de Blida 1, Algérie.
- Keramatikerman, M, Chegenizadeh, A & Nikraz, H. [2018]" Effect of Fly ash on Post-Cyclic Behavior of Sand".Journal of Earthquake Engineering. ISSN: 1363- 2469 (Print)1559-808X.
- Merni et Elezzar. [2019] " Etude expérimentale de la réponse mécanique d'un mélange sable cendre volante : Influence de la taille des grains" thème de master. Université Hassiba Benbouali de Chlef.
- Troncoso J.H. [1990] " Failure risks of abandoned tailings dams", proceedings, Int. Symp on safety and rehabilitation of Tailings Dams, CIGB ICOLD, Sydney, Australia, pp.34-47.