UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingenierías

Effect of fossil diatom type on fine soils macroscopic behavior

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The following document consists of a short academic paper written by undergraduate student Paúl Alejandro Villacrés Lozada. Its content includes material's description, methodology, results and conclusions of an investigation conducted throughout during the 9th semester of the Civil Engineering career. It was intended to be presented in a scientific magazine until the last days of February.

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RESUMEN

Los suelos con presencia de diatomeas describen propiedades poco usuales como son un alto valor para límite líquido, compresibilidad y resistencia al cortante. Por aquello en años recientes este tema ha adquirido una importante presencia en el campo de la Geotecnia. Sin embargo el esto de la relación existente entre el comportamiento mecánico macroscópico y las características para un tipo de diatomea continúa siendo un tema con poca investigación previa. El presente estudio aborda el análisis de las características microscópicas en diatomeas analizando una de forma elongada (*Epithemia Gibberula*) y otra con forma de disco (*Cyclotella Distinguenda*), con el objetivo de establecer la influencia de las propiedades morfológicas en parámetros vinculados con los límites de consistencia, consolidación y resistencia al corte. Los resultados obtenidos demuestran una relación significative entre el grado de fisuramiento de la diatomea y las propiedades macroscópicas, siendo la diferencia significative en la cantidad de partículas fisuradas producida posiblemente por las diferencias morfológicas entre los tipos de diatomea estudiados.

Palabras clave: Diatomeas, mezcla, fractura, límites de consistencia, compresibilidad, ángulo de fricción

ABSTRACT

Diatomaceous soils are described as having uncommon soil properties, such as high values in liquid limit, compressibility and shear strength. Becoming this topic in recent years an important study field in Geotechnics. Nevertheless, the relation between macroscopic behavior and diatom specimen characteristics presented on fine soils mixtures constituted a subject with few previous investigations. The present study addressed the analysis of diatom microscopic characteristics analyzing an elongated (*Epithemia Gibberula*) and disc shape (*Cyclotella Distinguenda*) diatom type in order to define the influence of morphological properties on parameters related with the consistency limits, consolidation and shear strength. The obtained results demonstrate a significant relation between the diatom fracture degree and the macroscopic behavior, being this significant difference in the fracture particles amount possible produce by the morphological differences between the studied diatom specimens.

Keyword: Diatoms, mixtures, fracture, consistency limits, compressibility, friction angle

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EFFECT OF FOSSIL DIATOM TYPE ON FINE SOILS MACROSCOPIC BEHAVIOR

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Abstract- Diatomaceous soils are described as having uncommon soil properties, such as high values in liquid limit, compressibility and shear strength. Becoming this topic in recent years an important study field in Geotechnics. Nevertheless, the relation between macroscopic behavior and diatom specimen characteristics presented on fine soils mixtures constituted a subject with few previous investigations. The present study addressed the analysis of diatom microscopic characteristics analyzing an elongated (*Epithemia Gibberula*) and disc shape (*Cyclotella Distinguenda*) diatom type in order to define the influence of morphological properties on parameters related with the consistency limits, consolidation and shear strength. The obtained results demonstrate a significant relation between the diatom fracture degree and the macroscopic behavior, being this significant difference in the fracture particles amount possible produce by the morphological differences between the studied diatom specimens.

Keyword: Diatoms, mixtures, fracture, consistency limits, compressibility, friction angle

INTRODUCTION

Diatoms are unicellular algae microorganisms with multiple sizes and shapes that are able to develop an external exoskeleton called frustule. Through time, diatoms fossils sediments in lacustric and marine habitats, being possible to find these elements on ancient water environments (Xu et al., 2023). Diatomaceous soils produced by the presence of diatom fossils have been described on different studies, reporting extreme compressibility, significant liquid limits and high shear resistant, being these properties unusual properties for common soils samples (Zhang et al., 2022). Even though the relation between macroscopic behavior and diatom type constituted a topic with lack of investigation (Zulaga-Astudillo et al., 2022). The present study evaluated an elongated and disc shape diatom type using fine soil mixtures with different diatom proportion, demonstrating that the major fracture degree present on the elongated diatom influence substantially on the macroscopic soil behavior, being this condition possible produce by the mention morphology.

MATERIALS AND METHODS

This study analyzed two different species: Epithemia Gibberula and Cyclotella Distinguenda, which in the following sections are going to be referred as C1 and M1 respectively. These diatom species were selected because of their differences both on shape and granulometric properties. In order to produce the soil mixtures is select a fine-grained soil with clay characteristics, being this material referred as S1.

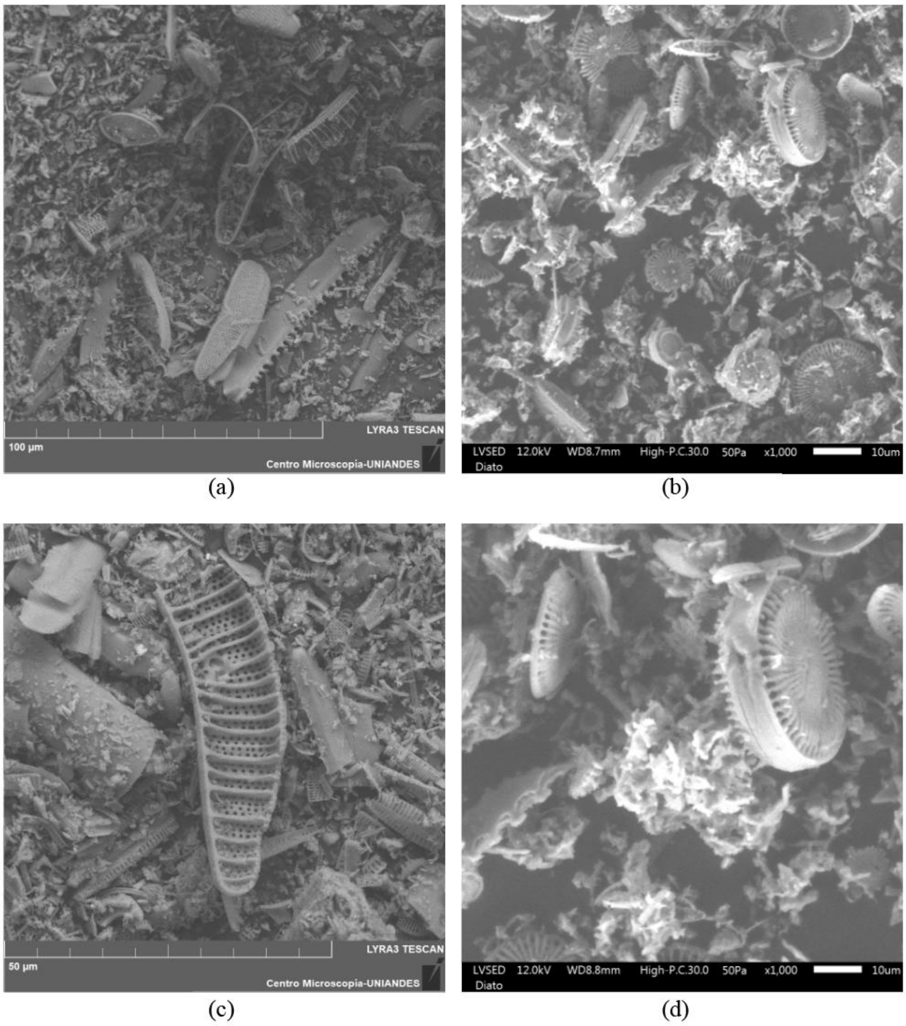


Fig. 1 SEM images for different amplification of: (a,c) E. Gibberula (C1) ; and (b, d) C. Distinguenda (M1)

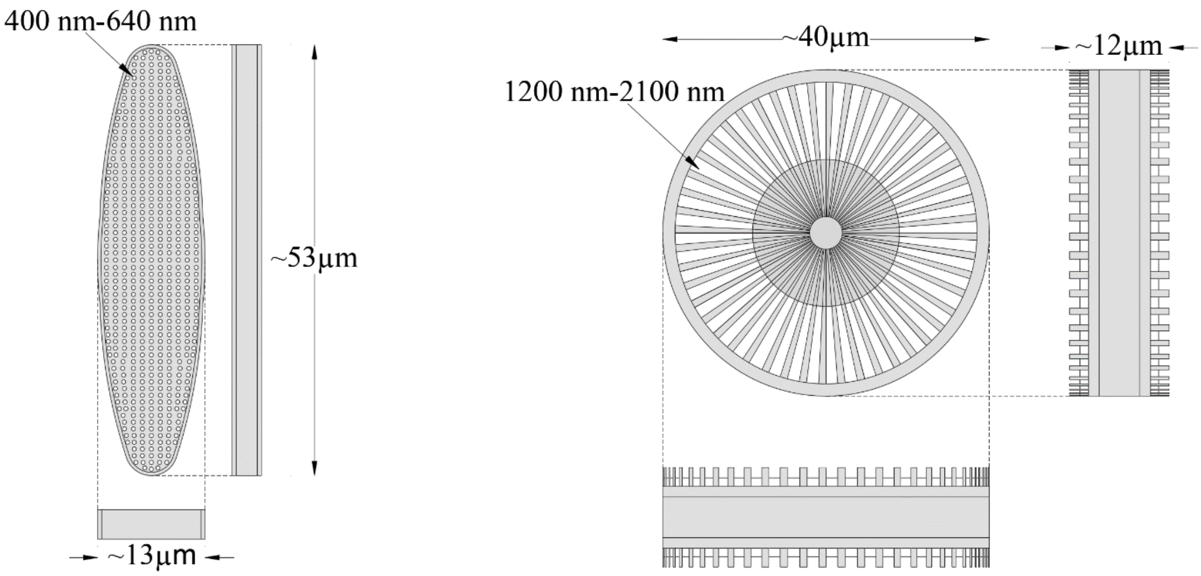
The SEM images on figure 1 and geometry characteristics on figure 2 illustrated the main diatoms micro-features:

- Epithemia Gibberula (C1): Elliptical elongated shape with partial axial symmetry, longitudinal and maximum transversal length have an average value of ~53 µm and ~13 µm respectively, with a frustule thickness wall of ~0.5 µm. External layers have pores with a variable diameter from 400 to 640 µm, blocking S1 particle entrance. The superficial pores correspond to 48% of the particle surface while the void rate reaches

1.87. SEM images show an important degree of particle fracture, generating a 2.38% ratio between complete particle area and total area. This measurement could only be taken as an approximation for the specimen fracture condition because of the tridimensional sample reality (Zhang et al., 2022).

- Cyclotella Distinguenda (M1): Disc shape with radial symmetry, an average diameter length of ~40 µm, ~12 µm for height and a frustule thickness wall of ~1.3 µm. External layers have pores with radial shape and variable diameter from 1200 to 2100 µm, allowing the S1 particles entrance. The superficial pores ratio is 22% and the void ratio presented a value of 1.58. SEM images shows a partial degree of fracture with significantly minor ratio of 20.94%

Is important to mention that the geometry characteristics observed could explained the major fracture degree present on C1, because of the elongated shape present a significant variation between the strong and weak inertia axis, while M1 describes uniformity on the value of both inertia axis because of the radial symmetry.



Volumes	Solid	686 μm³
	Central cavity, accessible by water	1169 μm³
	Holes, accessible by water	112 μm³
	Void ratio (holes+cavity)	1.87

Volumes	Solid	4247 μm³
	Central cavity, accessible by water	5358 μm³
	Holes, accessible by water	1337 μm³
	Void ratio (holes+cavity)	1.58

Fig. 2 Layout of typical shape for (a) E. Gibberula (C1) and (b) C. Distinguenda (M1)

The mentioned diatom types in combination with S1 were characterized in terms of their specific gravity, consistency limits, particle size, and repose angle as shown on table 1. The first parameter carried out according to ASTM D 854 (ASTM, 2002) shows a value of 2.65 for S1, being the material with major specific gravity, followed by 2.35 for C1 and 2.1 for M1. Consistency limits were determined applying ASTM D 4318 (ASTM, 2000) with Casagrande cup utilization for C1 and S1 liquid limit. For M1, because of specimen thixotropy this value was defined using a previous investigation that studied this diatom specie (Ibagón et al., 2023). The obtained values show a maximum limit liquid of 144 for M1, decreasing this parameter to114 for C1 and 37 for S1. In the case of plastic limit only is reported the value of 23 for S1, being both diatoms described as non-plastic because their thixotropy.

The materials granulometry was reached applying ASTM D 422 (ASTM, 2002) with the hydrometer H151 analysis, for that reason is important to note that diatom particles presented irregular shapes, being this method only an approximation. Figure 3 shows a major particle size for M1, followed by S1 and C1. Additionally, C1 and S1 described a same size distribution and M1 developed a uniform size distribution. The proportion of particles lower than 2μm and d50% determined M1 as the material with major particle size distribution, followed by S1 and C1. These results also confirm the significant C1 fracture degree, being observed in previous studies that matrix soils for mixtures have a minor particle size than test diatoms (Xu et al., 2023).

Table 1 Properties of the fine-grained soil and diatoms used in the study.

	$\rho_s: g/cm^3$	w_L:%	w_p:%	$Proportion < 2\mu m$:%	$d_{50}: \mu m$
	ASTM D 854	ASTM D 4318-00		ASTM D 422	
Fine-grained soil (S1)	2.65	37	23	27.91	12.8
Epithemia (C1)	2.17	114	-	47.57	2.2
Cyclotella (M1)	2.35	144	-	4.13	19.4

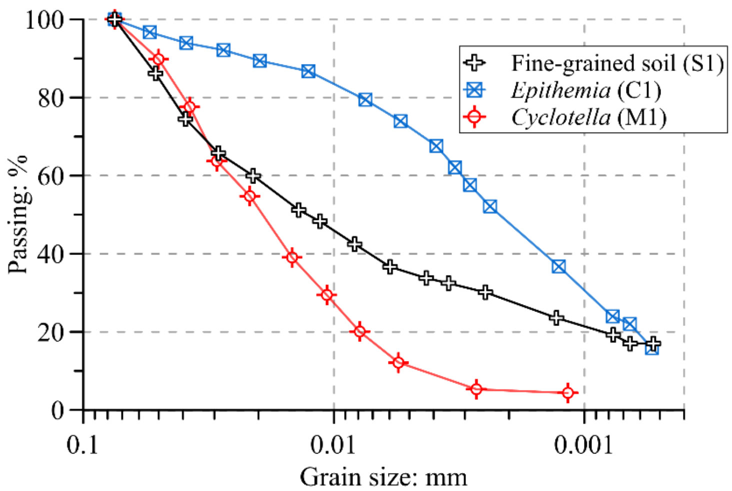


Fig. 3 Grain size distributions for S1, C1 and M1 (measured by hydrometer analysis)

The repose angles were obtained by image analysis, calculating the average slope for the diatom mixture placed on a horizontal surface using a funnel. Is observed in figure 4 the relation between the increase on diatom content and a major value for repose angle, being possible to detected higher values for M1 mixtures, possibly because of the particle angularity and size.

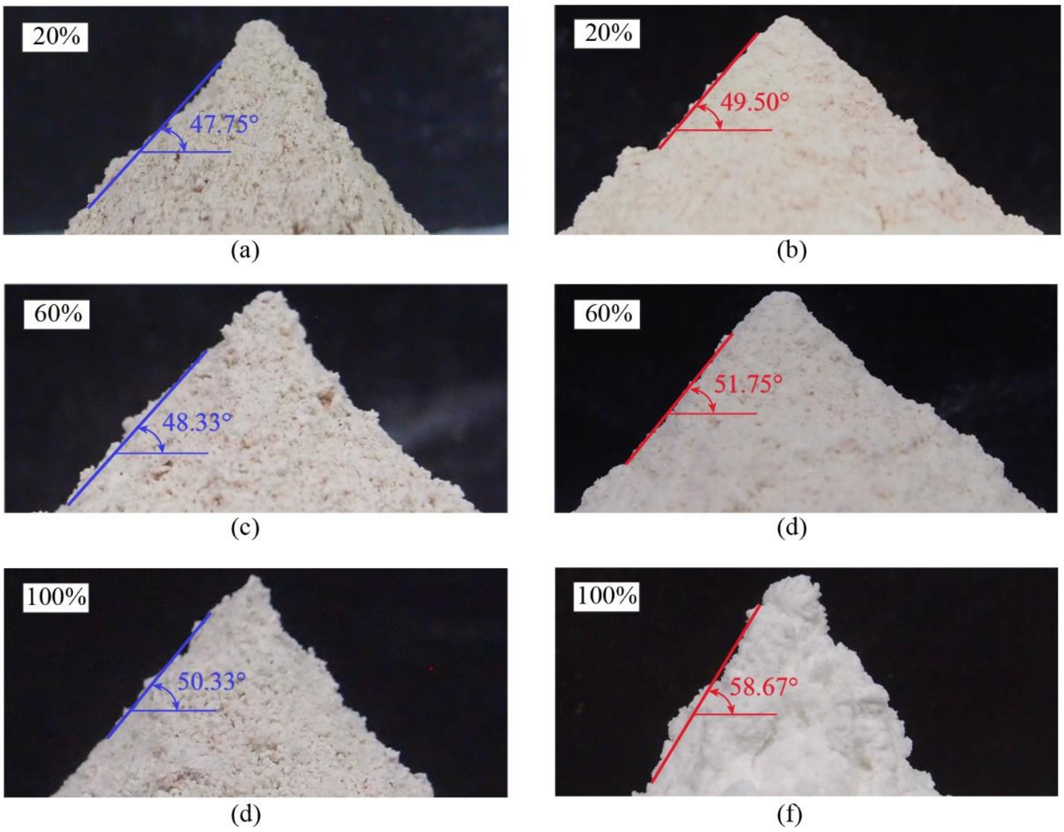


Fig. 4 Repose angle for (a, c, d)) E. Gibberula (C1) and (b, d, f) C. Distinguenda (M1)

The following results involved the determination of diatom mixtures parameters for consistency limits, unidirectional consolidation, and drained direct shear. In the first case ASTM standards applied are the same as previously mentioned, consolidation tests are effectuated according with ASTM D 2435 (ASTM, 2003) preparing the specimen with a water content of 1.5 times the material liquid limit. Finally direct shear tests are carried out following ASTM D

3080 (ASTM, 2011) with a velocity of 0.0028 mm/min, resulting on a 10 mm shear during 2.5 test days.

RESULTS

Index properties

In figure 5 is observed for both types of diatoms the increase on liquid and plastic limit with a major diatom mixture concentration, existing a diverge behavior between diatom species. C1 presents a constant increase rate for all mixtures concentration, in contrast with M1 minor increment from 0 to 20%, increasing this rate from 40% to 100%. These phenomena could be explained by considering M1 size pores that allow S1 particles enter the diatom cavity, affecting the water storage capacity for mixtures with high S1 concentration.

On the contrary, C1 water storage mainly depends on surface pores size, being impossible for S1 particles to enter. This effect explains the linear proportionality between water storage and diatom concentration. Plastic limit on C1 also shows this linear behavior described previously, nevertheless M1 mixtures tendency could not be defined because of the no plasticity for samples with 40% or higher diatom concentration.

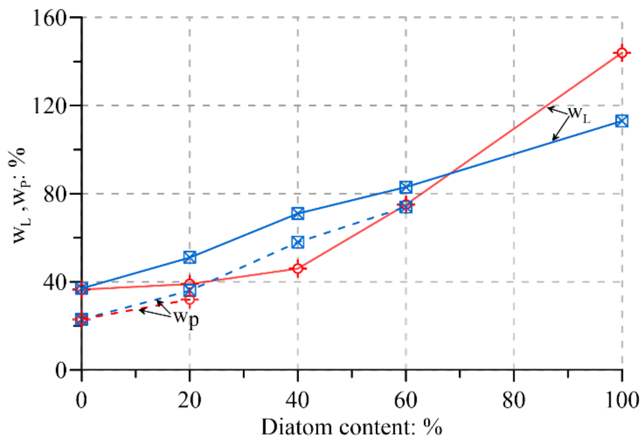


Fig. 5 Liquid and plastic limits for S1, and the diatom species

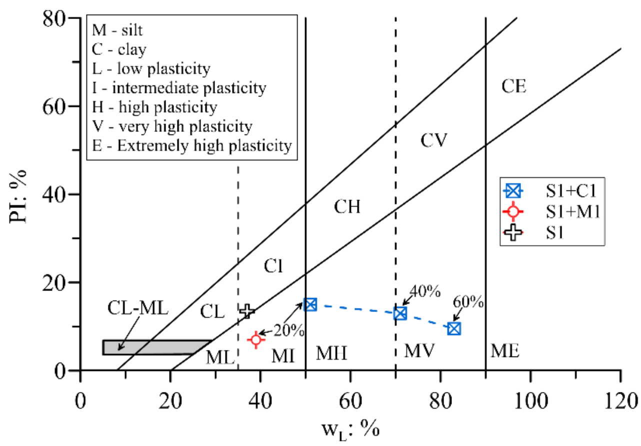


Fig. 6 Casagrande Plasticity chart and the classification of S1 and diatom mixtures

Figure 6 shows the diatom mixtures evaluated on a traditional soil classification chart, where is linked the liquid limit and plasticity index, being defined S1 as a clay with intermediate plasticity, M1 at 20% as silt with intermediate plasticity, and C1 mixtures as silt with a plasticity range from high at 20% to very high at 60%. These results are only congruent with S1 particle size, while C1 and M1 particle sizes correspond to clay materials, illustrating the deficiencies present on traditional soil classification (Zulaga-Astudillo et al., 2022).

Figure 7 describes the relationship between plasticity index and liquid limit in relation with particle size, using as measurement the proportion of particles lower than 2 µm. In M1 mixtures is observed a similar behavior reported in Kaolin and Coscinodiscus mixtures (Caicedo et al., 2019), describing a no defined relation for plastic index and an increase in liquid limit with the increase on mixture concentration and size particles. In C1 mixtures develop an inverse behavior decreasing the particle size and increasing both plastic and liquid limit. This could be explained by the diatom granulometric properties mentioned in the previous section, being pore storage responsible on the increase of both values not related with particle size.

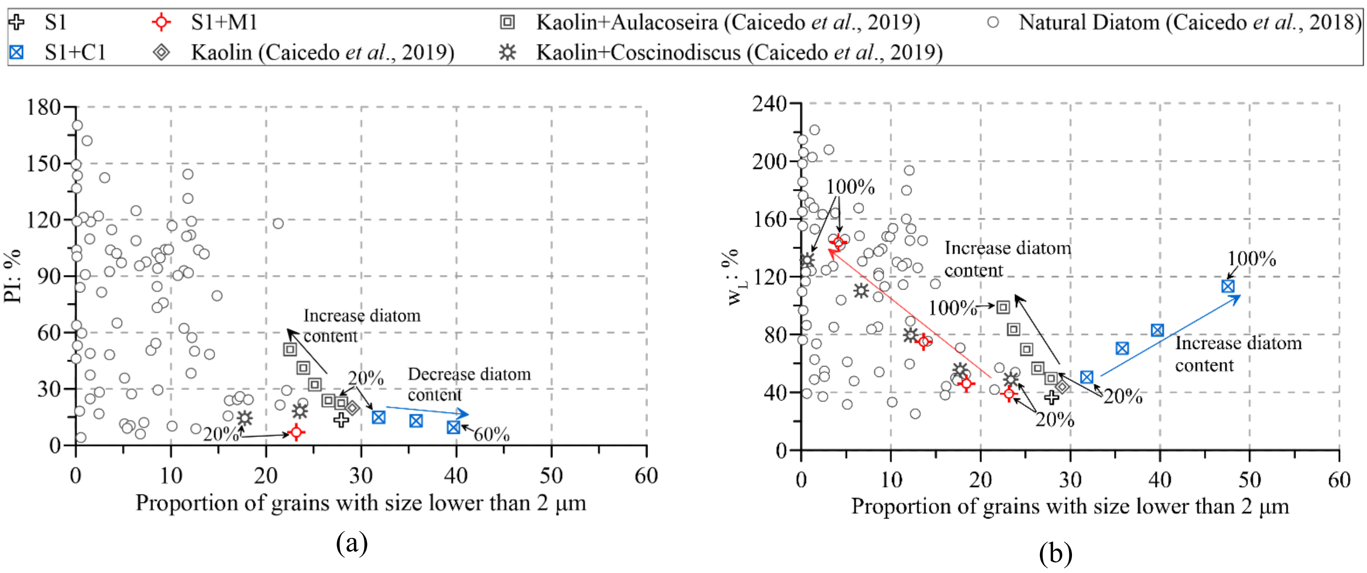


Fig. 7 (a) Activity plot for diatoms mixtures and results of previous investigation results (Caicedo et al., 2018, 2019); (b) relationship between liquid limit and diatom portion of particles lower than 2 μm with previous investigation results (Caicedo et al., 2018, 2019)

Compressibility

Figure 8 illustrates for both diatom mixtures the increase on void ratio and compressibility coefficient with the increase on diatom concentration, being this phenomenon possibly explained by the increase on both cavity and pore voids. M1 shows for both parameters a major increase explained by the diatom internal cavity dimensions.

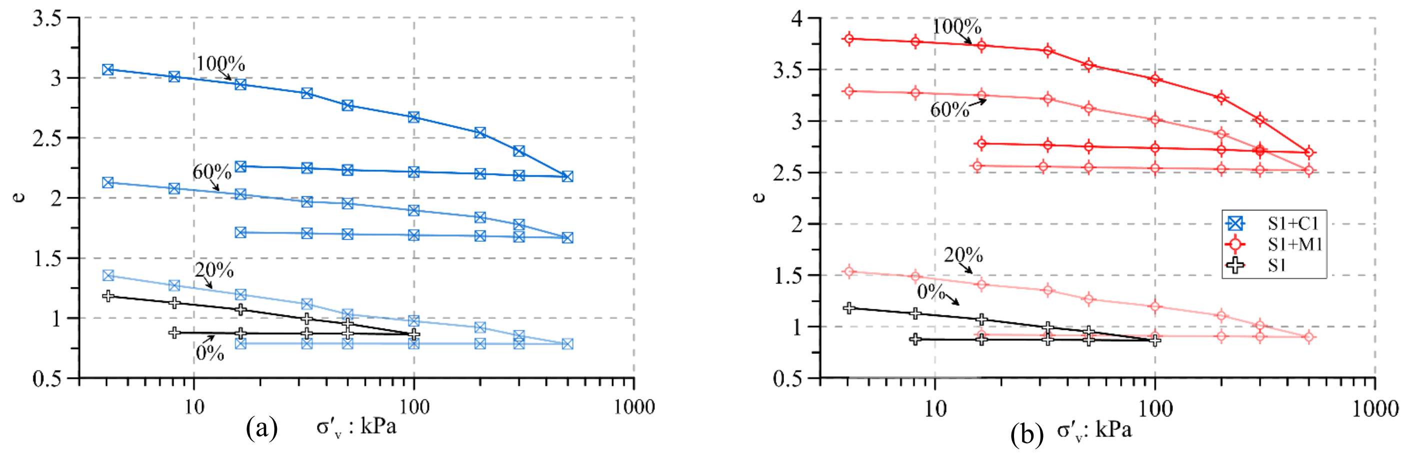


Fig. 8 Oedometric compression curves for mixtures of (a) C1 and (b) M1

Figure 9 describes a similar behavior for the compressibility coefficient, presenting M1 mixtures values equivalent to 1.33 times the maximum coefficient reached by C1 mixtures. Both increases could be explained by the increase on voids and M1 diatom pores dimensions.

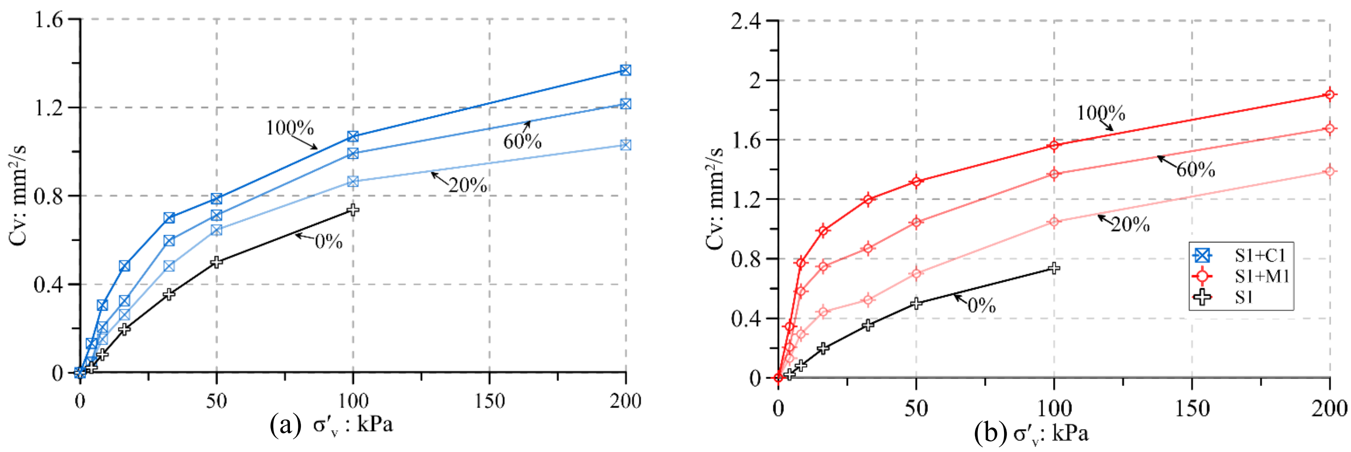


Fig. 9 Compressibility coefficient in relation with apply stress for (a) C1 and (b) M1

In figure 10 is possible to observed for both diatoms the increase on compressibility coefficient and liquid limit with the increase on diatom concentration, being C1 mixtures on the lower correlation tendency side described in previous investigations (Caicedo et al., 2018, 2019), and M1 mixtures on the upper side. This behavior is possibly explained by the void increase with diatom content and shows the major impact of M1 micro/features on its major parameter values.

Figure 11 describes for both diatoms the increase on void relation with diatom content and applied strength, even though C1 shows a linear rate increase while M1 describes an increase rate between 20%-60% which lowers down on 60%-100% interval. This could be explained by the interaction between M1 and S1 particles, increasing in a significant amount the void rate with the diatom concentration increases because of cavities and void addition, until the mixture reaches the 60% where possibly S1 particles are distributed mainly on M1 particles interstices, generating this condition a minor increase on void ratio with minor S1 concentrations because interstice voids would continue existing.

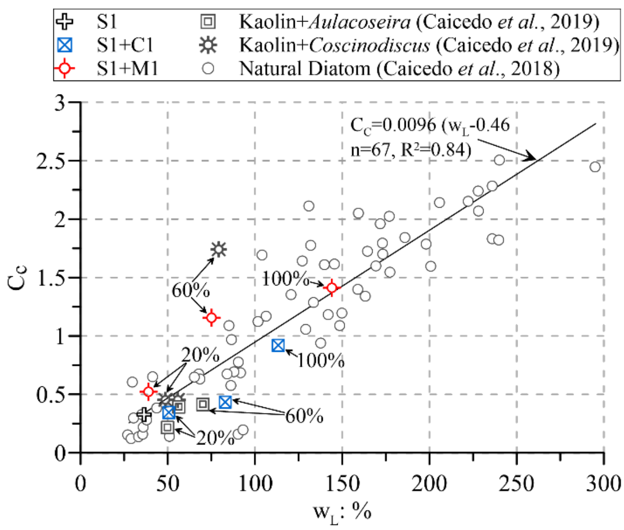


Fig. 10 Relationship between compressibility coefficient and liquid limit for diatom mixtures and previous investigation results (Caicedo et al., 2018, 2019)

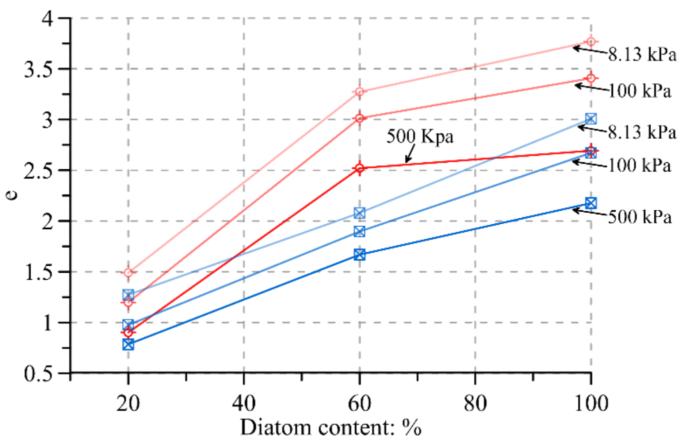


Fig. 11 Relationship between void ratio and diatom content for different mixtures

Shear strength

Figure 12 illustrated for M1 mixtures a maximum friction angle value of 51.30º at 100% diatom concentration, while C1 describes a minor increase of 37.96º, this behavior could be also observed on repose angle results where M1 reach a maximum of 58.67° at 100%, while this value corresponds to 50.33º for C1. These phenomena could correspond to the differences between particle size and shape. In the case of M1 particles the angularity and major particles size increase the shear strength, meanwhile C1 presents a particle size significantly lower because of the elongated shape and the fracture condition.

The divergence on the diatom behavior is clearly visible between 40% and 60%, being this interval describe in friction angle analysis on previous studies (Zulaga-Astudillo et al., 2022) In addition, it would be expected that friction angle for C1 decrease with concentration increase because of the particle size which is lower than S1 (Slebi-Acevedo et al., 2021), demonstrating this phenomena that particle angularity for C1 could be benefit by fracture, acting as a counterpart to particle size negative effect.

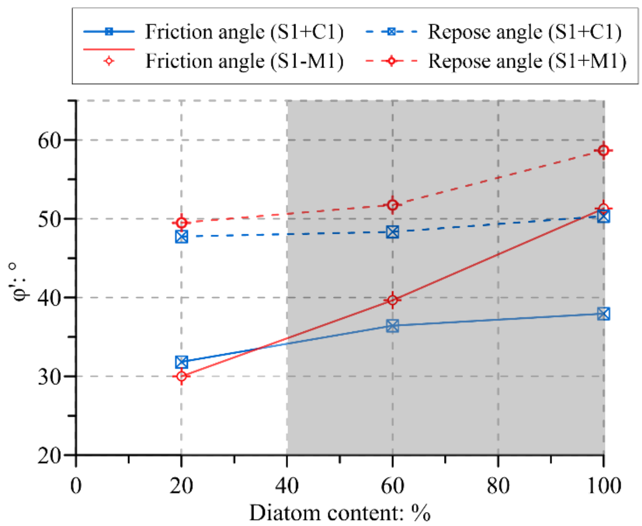


Fig. 12 Friction and repose angle and diatom content for different mixtures

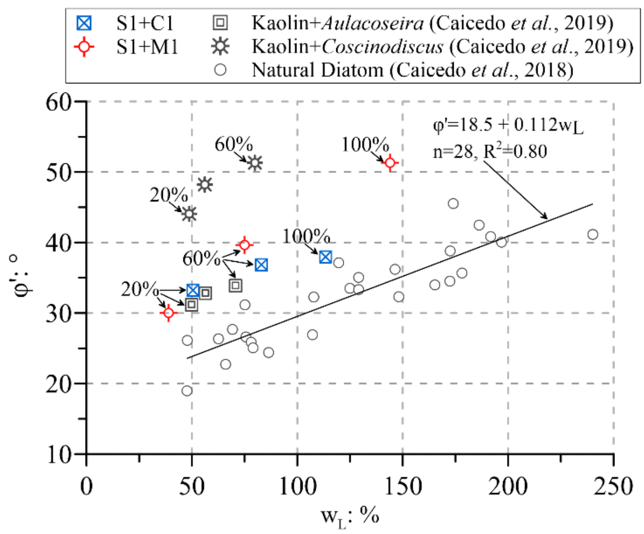


Fig. 13 Relationship between friction angle and liquid limit for diatom mixtures and previous investigation results (Caicedo et al., 2018, 2019)

The relationship between friction angle and liquid limit present on figure 13 shows for both diatoms an increase on this angle and liquid limit with the increase of diatom concentration, being the behavior of C1 mixtures similar to Aulacoseira and Natural diatom soil describe in previous studies (Caicedo et al., 2018, 2019)

CONCLUSION

The results demonstrated an important relation between the mixture macroscopic behavior and diatom particle characteristics, being possible to described this in the following aspects:

- M1 shows the mayor increased in all the studied parameters with the major amount of mixture concentration, being possible to link this fact with the mayor particle, pore, and cavity size in contrast with C1 because of the fracture degree observed on this diatom specimen.
- Values for liquid limit, compressibility coefficient and void ratio show a linear increase rate for C1, while M1 present a different increase rate between 60% to 100%, being this phenomenon possibly explained by the S1 particle size and M1 morphology.
- C1 fracture degree generated a negative effect on consistency and compressibility parameters, however in shear strength parameters is possible to consider a negative effect on particle size and a positive one on angularity, being this fact a plausible explanation for the friction and repose angle values reports in the study.

Finally, is important to mention the lack of bibliography about diatom fracture (Zulaga-Astudillo et al., 2022), for this reason in order to confirm the possible explanations mention on this study it would be important to develop the study of fracture and the effect produce by this variable on macroscopic diatom behavior.

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