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# Effects of Organic Matter on Physical Properties of Dredged Marine Sediments

Fawzi Hamouche<sup>1</sup> · Rachid Zentar<sup>1</sup>

## Abstract

Dredged sediment, listed as waste according to European classification, is available in significant quantities. With the announced shortage of standard materials to supply civil engineering sector (specifically road construction domain), the beneficial use of these wastes could lead to better management of waste and optimize the use of standard materials. Dredged sediments consist of a mineral phase, an organic phase (in various forms) and a liquid phase (generally water). However, the presence of organic matter (OM) in sediment, even in small amounts, can affect its physical properties. The main objective of this study is to investigate the effects of the OM content on physical properties of dredged sediments. The physical parameters studied are considered as a key parameter in the field of road construction. To undertake this study, a specific procedure for samples preparation was developed. This procedure allows undertaking tests on samples ranging from 2.5 to 15% in terms of organic matter content. The results on the prospected properties show that the material classification in the field of road construction is almost unaffected.

**Keywords** Organic matter · Dredged sediments · Valorization · Physical properties

## Statement of Novelty

The undertaken research work is proposed to promote and enhance the beneficial use of sediments in civil engineering works. In roads construction sector, the limiting parameter to use sediments in roadworks is the amount of organic matter. Understanding the effects of organic matter content on physical properties is the first step to understand the effect in terms of materials classification. The obtained results, in the case of treatment to remove organic matter, could help to know to which extent the treatment could be performed.

## Introduction

Dredging operations generate large volumes of sediments. In Europe, the annual amount of dredged sediments is estimated to about 200 million m<sup>3</sup> [1]. In France, this amount is about 30 million m<sup>3</sup> [2]. These sediments, when the environmental impacts are not prejudicial, are traditionally dumped at sea in controlled areas a few kilometres from the coast. However, due to the harmful effects of dumping sediments on the aquatic ecosystem, combined with the announced shortage of standard material in the civil engineering sector, the beneficial use of this waste as a new resource could contribute considerably to better management of dredged sediments [3–11].

In France, civil engineering uses over 400 million tons of material per year, of which 96% are standard materials [12]. Roads construction sector is the greatest consumer, with a yearly consumption of about 200 million tons of material per year. Hence, the valorization of dredged sediments for roads construction constitutes an interesting solution.

However, dredged sediments are composed by a mineral phase, an organic phase (in various forms: soluble or insoluble and different stages of degradation) and a liquid phase (generally water). The organic phase is composed of natural

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organic compounds from the remains of organisms such as plants and animals and their waste products in the environment or by industrial organic compounds. The presence of organic matter (OM) in sediments, even in small amounts, can affect its physical properties.

The main objective of this study is to investigate the effects of the OM content on physical properties of dredged sediments. Previous studies on the effects of organic matter on the physical and geotechnical properties of soils (few studies on sediments are performed) revealed that the organic matter had an effect on some engineering and index properties [4, 13–28]. However, the impacts recorded on the physical parameters seemed to be dependent on the type and the nature of the constituents of the mineral phase (amount and types of clays) as the organic phase (soluble organic matter, insoluble organic matter) [4, 27]. Moreover, the samples preparation in the studies could also induce important impacts on the recorded measurements.

Samples preparation used by Rashid and Brown [15], to study the effects of organic compounds on engineering properties of remoulded sediments, consist in treating marine sediments with hydrogen peroxide to reduce the organic matter content from the initial value (2% on a dry weight basis) to a free organic matter content sample. For samples with higher organic matter content, enrichment with natural humic substances is made to reach an organic content of about 4%. Rashid and Brown [15] showed an increase of about 8% in the liquid and plastic limits for an increase of organic matter content from 2 to 4%. The same increase is observed on the plastic limit values. The plastic index values remain almost constant. The decrease of organic matter content with the use of hydrogen peroxide (from 2% to about zero) has induced a decrease of the liquid limit of about 12% and negligible effects on the plastic limit. This induces a substantial decrease of plastic index values.

Booth and Dahl [20] prepared samples by mixing original material with 3.2% organic carbon content with different proportions of the same material treated with hydrogen peroxide. They showed a decrease in the liquid limit values of about 40%, the plastic limit values of about 13% and plasticity index values of about 17% over 2.6% decrease in organic content. If we assume that the organic matter content could be deduced from the organic carbon content using a ratio of 1.724 [29], this result induces a change in the liquid limit of 40% for a 4.5% change in organic matter content.

Malkawi et al. [22] explored the effects of a large range of organic matter content by adding peat to illitic soil between almost 0 and 30% of organic matter. The organic matter content was deduced from Walkey Black method [30]. They showed that the specific area values of the mixes decrease with the increase of organic matter content (between free organic matter samples and 15% of organic matter content). Then, the specific surface area values increase with the

increase of organic matter content above 15%. The liquid limit values record an increase from 80% to about 100% for an increase of organic matter content between 0 and 30%, whereas the plastic limit values change from 45% to about 85%. The higher increase of the plastic limit values in comparison to the liquid limit values induces a dramatic decrease in the plastic index values. However, in the range between 0 and 10% of organic matter content, a constant value seems to be more adequate to interpret the change of the plastic index values.

The study of Zeng et al. [27], involving samples enriched by a soluble or insoluble component of organic matter, showed that the change in liquid limit (increase or decrease) depends on the value of the liquid limit of the original material and the type of organic components (soluble or insoluble organic matter).

Stanchi et al. [28], based on experiments on different soils with different amount of organic matter content, showed that the Atterberg limits are well correlated to the total organic carbon (TOC) in the fraction smaller than 0.425 mm. They also observed the marked effects of soil organic matter on liquid limit and plastic limit values, whereas the liquid limit seems more affected by the clay fraction.

Regarding the correlation between Atterberg limits and organic matter content, few studies argued that the consistency limits are not well correlated to the organic carbon [31], or less correlated than to clay fractions or the cation exchange capacity for example [19].

From the few compiled research finding, it is clear that it is difficult at present to be able to clearly generalize the effect of organic matter on the physical characteristics of a given material. It appears that this effect is related to the nature of the mineral phase, the nature of the organic matter and more probably to the methodologies of samples preparation used in the different studies.

The main objective of this study is to explore the effects of the organic matter content on a few physical parameters of dredged sediments. In this paper, the studied parameters (grains size distribution, Atterberg Limits, Methylene Bleu Value) are considered as key physical parameters in the roads construction sector. The assessment of the effects of the organic matter content on the physical parameters will allow anticipating the mechanical behaviour of such materials.

Moreover, in roads applications, under different practice guidelines developed in different countries, the use of organic materials is limited to materials with organic matter content between 2 and 4% for road pavement material and between 5 and 7% for use as embankment materials [32]. The argument used for the limitation of the amount of organic materials is generally linked to the evolution of organic matter with time, which was supposed to increase the void ratio and hence the compressibility of the material.

In this context, as a first step in the valuation of dredged sediments in roads construction, it was considered important to explore the effects of organic matter content on the key physical properties of dredged sediments and to what extent the material classification is affected. From these results, it will be possible to anticipate the effects on the mechanical behaviour in terms of compressibility for example.

For samples preparation, as mentioned above, different technics and methodologies exist. In this study, a specific methodology was developed. The methodology includes tests on reconstituted samples (by mixing inorganic material with organic material) and on dredged sediments (impoverished or enriched with organic matter).

## **Methodology, Studied Materials and Experimental Program**

In order to investigate the effects of organic matter content on the physical characteristics of dredged sediments, various methodologies to select the materials were discussed and explored. The first method which consists in identifying different samples, in the studied site, with different amount of organic matter was very quickly discarded. It was found that the change in the organic matter content at the studied site was linked to the nature of the mineral phases. The sandy specimens contained less organic matter than the silty specimens. It is worth noting that in this case, it is not possible to explore the effect of organic matter on the physical properties because the mineral phases in the different samples are very different. The second method explored was to treat organic sediments with hydrogen peroxide, in order to produce different specimens with decreasing amounts of organic matter. It was found that a huge volume of hydrogen peroxide is needed to remove completely the organic matter in the sediments. The third methodology explored consists in separating the mineral phases from the organic phases in order to reconstitute the samples with the desired amount of organic matter. For this method, two different processes of separation were tested. The first involved manual separation by flotation (as organic matter present lower bulk density than the mineral phases) and the second using the principle of centrifugation. Booth and Dahl [20] reported good results on small specimens by centrifugation; however, in this study, to prepare substantial quantities for the tests (few kilogrammes), these methods were assumed time-consuming and inappropriate. The fourth method explored and used in this study was a combination of two different approaches. To prepare samples with organic matter content slightly lower than the initial value measured, the sediments were treated with hydrogen peroxide. In this case, the volume of hydrogen peroxide added to the sediments was determined from a preliminary study about the correlation of the volume

of hydrogen peroxide added to a sample of sediments and the reduction in the OM measured on the same sample. For higher values of organic matter content than the measured initial value, an organic material (the compost) was added to marine sediments. This methodology allows comparison of results, on the one hand, obtained on the same material with different organic matter contents induced by hydrogen peroxide treatment and, on another hand, the effect of organic matter content on samples enriched with an additional organic material.

For comparison, the second series of test was undertaken on a totally recomposed material by mixing the organic material (the compost) used above with an inorganic material. This study has allowed on one hand to confirm the result obtained on dredged marine sediments and on another hand to explore the effect of organic matter at a low content of organic matter (< 5%).

## **Studied Materials and Basic Characteristics**

In this study, the studied sediments (S) is dredged from the Dunkirk Harbour, which is the third most important French harbour. By its location, it is ranked as the seventh port on the northern European side, extending from Le Havre to Hamburg. The dredging operations in the harbour generate, each year, more than 3 million of m<sup>3</sup>. The dredged sediments for this study, after a period of natural dewatering on site and sampling, were stored in barrels at the laboratory.

The organic material used in this study for specimen enrichment with organic matter was industrial compost (C). This later is a mix of peat, sphagnum, seaweed and manure produced by Scotts Company in the north of France.

Prior to mixing with sediments or with the inorganic material, a specific procedure of preparation was developed in order to ease the preparation of the mixes.

The inorganic material (IM) used in this study is a fine material generated during washing of crushed granular materials in a quarry. This fine material is characterized by a very low organic matter content.

Before studying the effects of organic matter content on the physical properties, it is necessary to characterize the used materials. This characterization includes the grain size distribution, the initial water content, the organic matter content, the specific gravity, the methylene blue value, the Atterberg limits and the specific surface area. The tests are undertaken following the tests standard in use [33–39]. The results of the tests are reported in Figs. 1, 2 and Table 1. From these results, it appears that the grain size distributions of sediments and inorganic material are similar. Both materials are mainly silty. The organic material used in the study is coarser than the two other materials. However, it is worth noting that this grain size

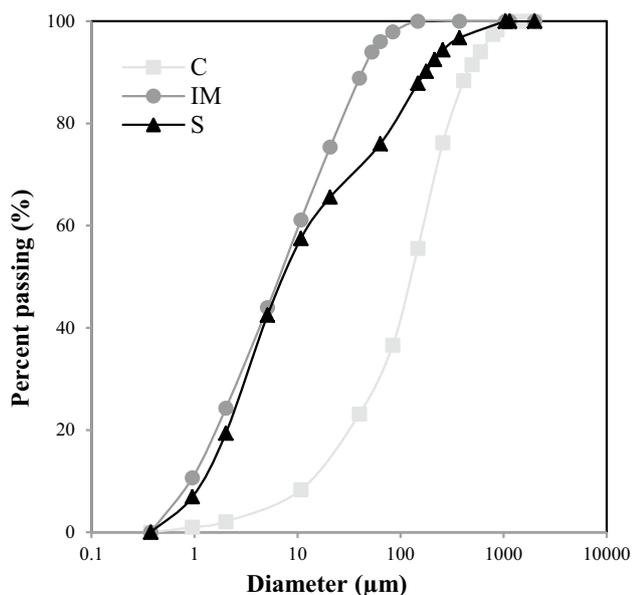


Fig. 1 Grain size distribution of studied materials

distribution is a result of the preparation of this material. Regarding the water content, the sediments used in this study exhibit a very low water content in comparison to freshly dredged sediments. This result is mainly due to the dewatering process undertaken on site. The inorganic material also exhibits very low water content, also due to the dewatering process used in the quarry. For the compost, the initial water content is measured after the preparation procedure. This procedure includes a natural dewatering process at room temperature, a grinding process (to reduce the grain size distribution of the original material) and a sieving process (to eliminate all the particles with grains size diameter higher than 400 µm). The used procedure explains the low value of water content measured

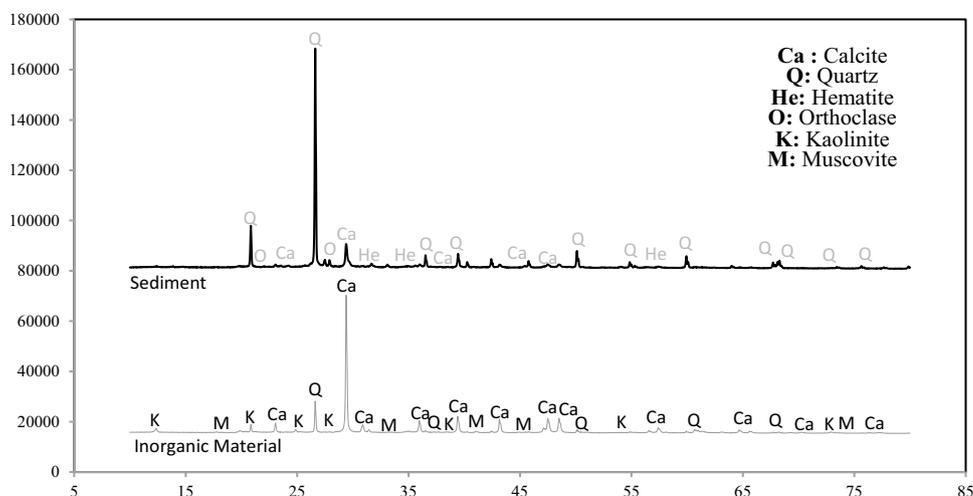
on the compost. The organic matter contents for the three materials, defined by the loss on ignition test at 450 °C (which is considered as a test reference in the field of road construction), range between 1% in the inorganic material and 42% in the organic material. The studied marine sediments exhibit a value of 8%, which could be considered as a moderate value in comparison to other silty sediments dredged from French harbours. The liquid limit and the plastic limit of the sediments and inorganic material are also comparable. For the organic material, due to its fibrous structure, it was not possible to perform these tests.

The methylene blue value for the sediments, the inorganic material and the organic material are comparable. Again, comparisons of a specific surface area of the sediments and the inorganic material show a similar trend, while the organic material again exhibits a smaller value. Regarding the specific density, the results are mainly influenced by the organic matter content, as shown in Table 1.

Table 1 Physical properties of studied materials

Samples	S	IM	C
Grains size < 2 µm (%)	20.26	24.26	2.07
2 µm < grains size < 63 µm (%)	63.16	71.73	29.35
63 µm < grains (%)	16.58	4.01	68.58
Water content (%)	20.19	0.80	23.02
Organic matter content (OM) (%)	8.01	1.27	42.24
Liquid limit ( $L_L$ ) (%)	43	28	–
Plastic limit ( $P_L$ ) (%)	32	22	–
Plasticity index ( $P_I$ ) (%)	11	6	–
Methylene blue value (MBV) (g/cm <sup>3</sup> )	1.09	1.66	1.03
BET specific surface area (SSA) (m <sup>2</sup> /g)	6.70	9.56	0.94
Specific gravity ( $G_s$ )	2.55	2.72	1.92

Fig. 2 XRD spectra of sediment and inorganic material



## Samples Preparation, Experimental Program and Test Equipment

### Samples Preparation

Prior to the preparation of the different samples, the three materials were at first oven dried at low temperature to eliminate water (40 °C).

The organic material, as explained above, was grounded in a blender to reduce the size of its constituents. The obtained material was sieved at 400 µm according to the French standard [38].

The inorganic material and the sediments were dried and gently pulverized in an agate mortar. The organic matter content in the different materials is measured by loss on ignition (under 450 °C) according to test standard [35].

To prepare samples with a lower organic matter content than the measured initial value, the sediments are treated with hydrogen peroxide according to the procedure described in the Belgian standard [40]. In order to define the efficiency of the treatment with hydrogen peroxide, preliminary tests were performed to determine the amount of hydrogen peroxide needed to destroy a given amount of organic matter in the sediments. In this study, according to the preliminary tests, a mass ratio of one to five (1 g of sediments for 5 g of hydrogen peroxide) was found to be sufficient to decrease the organic matter content from 8 to 5%. To prepare samples with higher organic matter contents than the initial value, enrichment was achieved by mixing the sediments with the organic material (S + C). The samples were prepared in order to present organic matter contents ranging between 10 and 15%, with a step of 2.5%.

To prepare the different samples composed of the inorganic material and the organic material (IM + C), the same procedure as above was used. The samples are prepared in order to present organic matter content ranging between 2.5 and 15% with a step of 2.5%.

The twelve samples studied in this work are shown in Fig. 3. It is worth noting that for each amount of organic matter, two types of sample are studied.

Thus, the experimental program enables a wide range of organic matter content to be explored from low organic materials (1%) to highly organic materials (15%). The choice of these ranges of values will also make it possible to analyse whether the limits set for valorization in roadworks express a significant variation in physical properties.

### Experimental Program and Equipment

As mentioned above, the experimental program focused on the measurements of physical parameters in relation to the

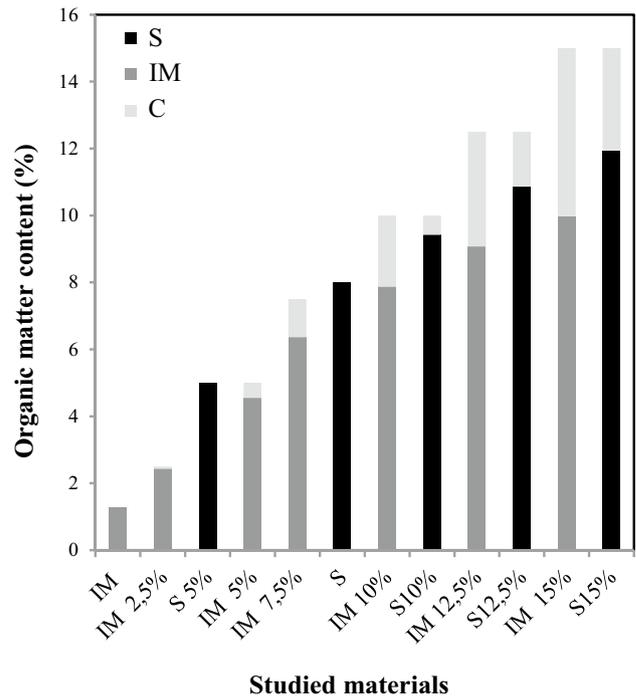


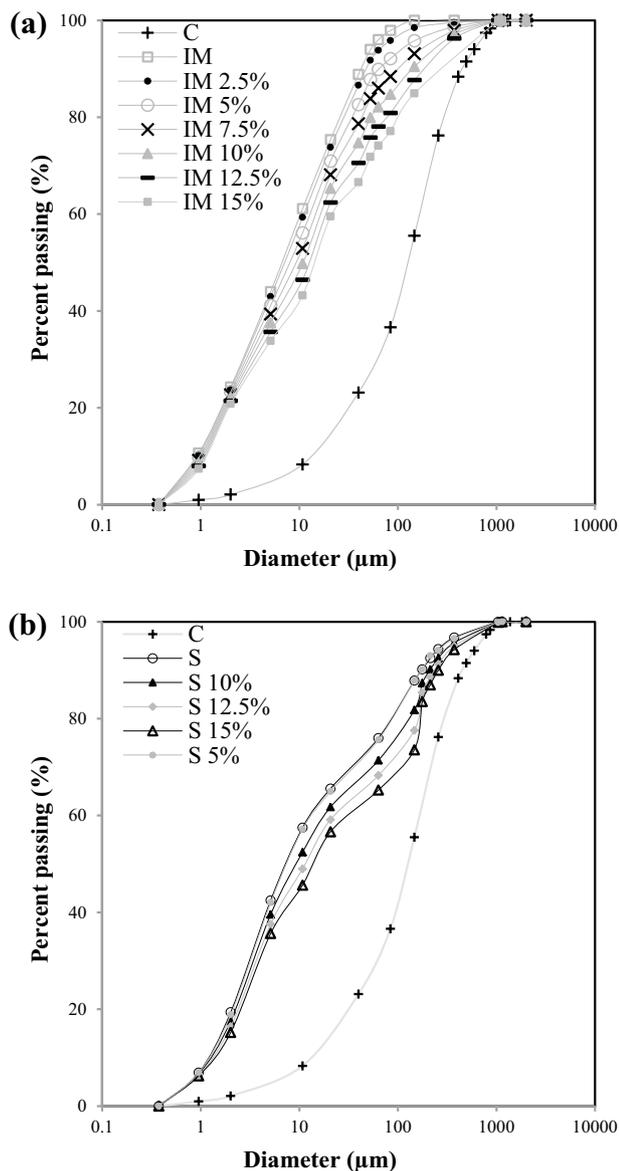
Fig. 3 Composition of the studied samples with different amounts of organic matter

material classification in the road construction sector. The main parameters selected are the grains size distribution, the Atterberg limits, the methylene blue value, the loss on ignition, the specific gravity and the BET specific surface area. The tests were undertaken following the standard mentioned above. For the sediments, the tests were undertaken on five samples with different organic matter contents ranging between 5 and 15%. For the second test series, the experimental program concerns tests on seven reconstituted samples with organic matter content ranging between 2.5 and 15% (Fig. 4).

## Test Results and Discussion

### Grains Size Distribution

Figure 4a, b illustrates the grain size distribution tests results of the different samples. It is worth noting that the grain size distribution of sediments and the inorganic material are comparable. The addition of organic material to the sediments or to the inorganic material drives the grain size distribution curves to the right. This result is predictable as the grain size distribution of the organic material is coarser than that of the sediments and the inorganic material. The measured values of  $d_{10}$ ,  $d_{50}$  and  $d_{90}$  on the different curves (note that  $d_{10}$ ,  $d_{50}$  and  $d_{90}$  correspond, respectively, to the



**Fig. 4** Grains size distribution of the studied samples. **a** Samples made by mixing (IM) with (C), **b** samples made by mixing (S) with (C)

**Table 2** Measured values of  $d_{10}$ ,  $d_{50}$  and  $d_{90}$  on grain size curves of studied materials

Samples	IM samples [diameter (μm)]	S samples [diameter (μm)]
$d_{10}$	0.9–1	1–1.2
$d_{50}$	7–20	7–20
$d_{90}$	40–280	180–280

diameter corresponding to 10% passing, 50% passing and 90% passing) are reported in Table 2. From these results, it is worth noting that the  $d_{10}$  and  $d_{50}$  of the different samples are similar. Also, the percentages of particles less than 75 μm represent more than 60% in the different samples. This allows classifying all the different samples as silty materials. It is worth noting that the comparable grain size distributions of the different samples allow better highlighting of the effects of the organic matter content in the following tests.

### Grain Specific Gravity ( $G_s$ )

The effect of organic matter on the grain specific gravity value ( $G_s$ ) is evident from Table 3 and Fig. 5. The  $G_s$  values of the samples decrease with the increase of organic matter content. For the samples composed of the inorganic material and the compost, the  $G_s$  values decrease from 2.7 to 2.37. The lower values correspond to the sample which contains 15% of organic matter. For sample made by mixing the sediments and compost, the values decrease from 2.55 to 2.43. It is to note that the measured value on the sample of sediments with 5% of organic matter content (created by treatment of the sediments with hydrogen peroxide to lower its initial value of organic matter content) is in line with the measured values for higher organic matter content. This result allows showing that the organic matters in the compost induce similar trend than the organic matter contained in the sediments at least for the discussed parameter. The decrease in  $G_s$  values with the increase of organic matter is due mainly to the low value of the specific gravity of the organic matter. The obtained results in this study are in agreement with several published results [15, 20, 23, 41].

### BET Specific Surface Area

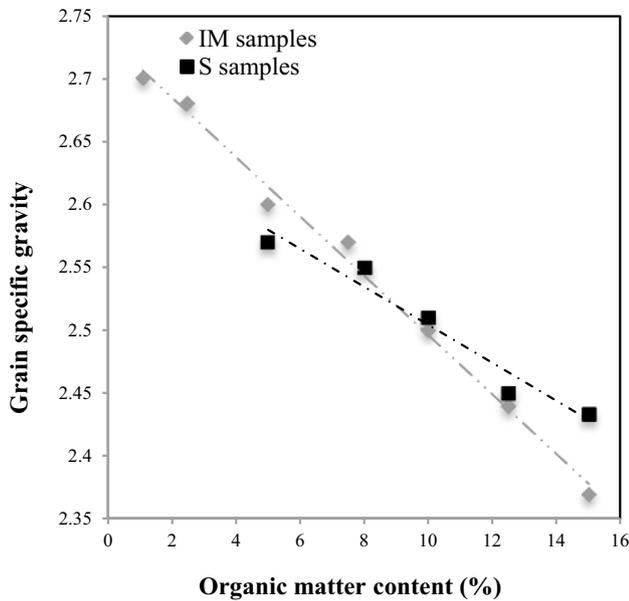
The specific surface area of a granular material is in general linked to the shape and the diameter of the particles and its grain porosity. The specific surface area of the sediments and the inorganic material used in this study are comparable. However, the organic material exhibits a lower specific surface area as shown in Table 1. Without denying the impact of the shape and the porosity of the particles, this lower value could be attributed to the higher grains size distribution of the organic material.

The specific surface area values measured on the different samples studied in this research work are shown in Fig. 6. As expected, the BET specific surface area decreases with the increase of organic matter content in the samples. This result seems to be in agreement with the finding of Malkawi et al. [22] for organic matter content ranging between 0 and 10%.

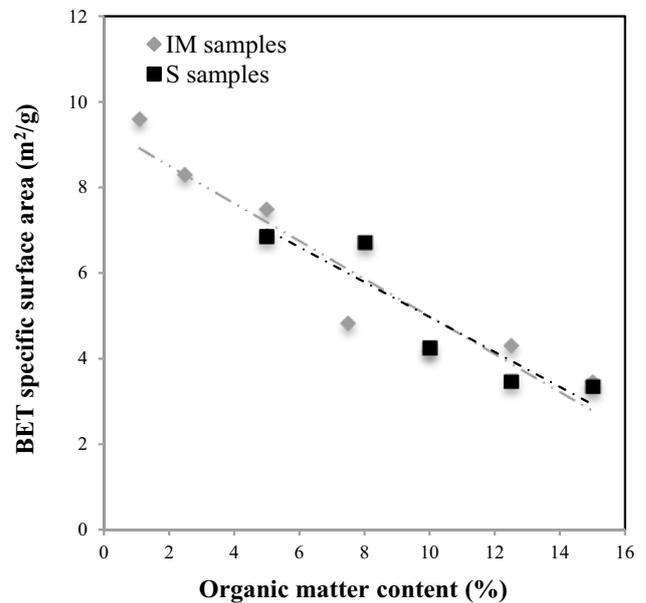
**Table 3** Liquid limit, plastic limit, plasticity index, MBV, BET specific surface area and specific gravity of studied samples

Samples	Liquid limit $L_L$ (%)	Plastic limit $P_L$ (%)	Plastic index $P_I$ (%)	Methylene blue value MBV ( $\text{g}/\text{cm}^3$ )	BET SSA <sup>a</sup> ( $\text{m}^2/\text{g}$ )	Bulk specific gravity $G_s$
S $\text{H}_2\text{O}_2$	29	17	12	0.93	6.84	2.57
S	43	32	11	1.09	6.70	2.55
S 10%	48	34	14	1.39	4.25	2.51
S 12.5%	52	40	12	1.38	3.48	2.45
S 15%	62	50	12	1.49	3.36	2.43
IM	28	21	7	1.42	9.56	2.70
IM 2.5%	30	22	8	1.46	8.28	2.68
IM 5%	34	22	12	1.59	7.47	2.60
IM 7.5%	38.5	28	10.5	1.64	4.82	2.57
IM 10%	44	35	9	1.79	4.18	2.50
IM 12.5%	49	41	8	1.93	4.30	2.44
IM 15%	54	44	10	1.98	3.47	2.37

<sup>a</sup>Brunauer–Emmett–Teller specific surface area



**Fig. 5** Grain specific gravity versus organic matter content



**Fig. 6** The specific surface area versus organic matter content

## Atterberg Limits

### Liquid Limit

To explore the effects of organic matter content on the liquid limit, the experimental results of the tests performed on samples based on the dredged sediments and on reconstituted samples (made of an inorganic material mixed with organic material) are reported in Fig. 7a, b. From these results, it appears that the values of the liquid limit increase with the amount of organic matter in both series of tests.

The increase of the liquid limit values with organic matter content is shown in Fig. 8. It appears that the

relationship between the increase of the organic matter contents and the increase of the liquid limit values is linear. An increase of 1% in organic matter content induces an increase of 2–3% in liquid limit value (Table 3). Comparisons of the results obtained in this study with those from other research show that a similar trend is generally observed [4, 15, 16, 22, 25]. As shown in Table 4, quantitative comparisons of the results of this study and those published by different researchers are difficult.

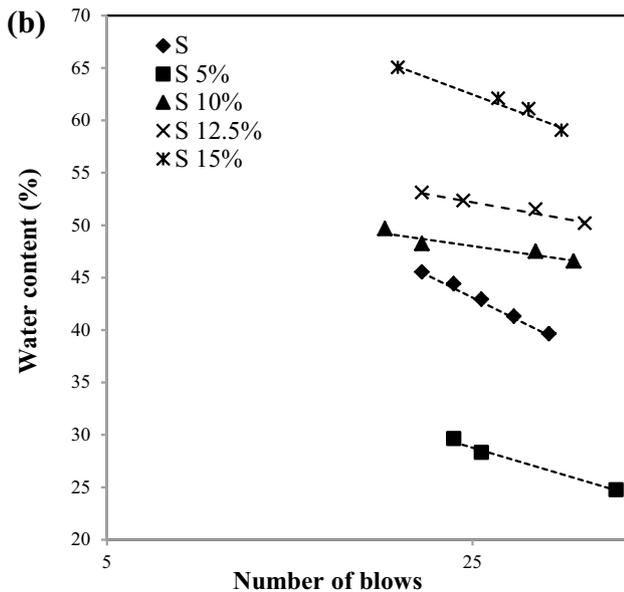
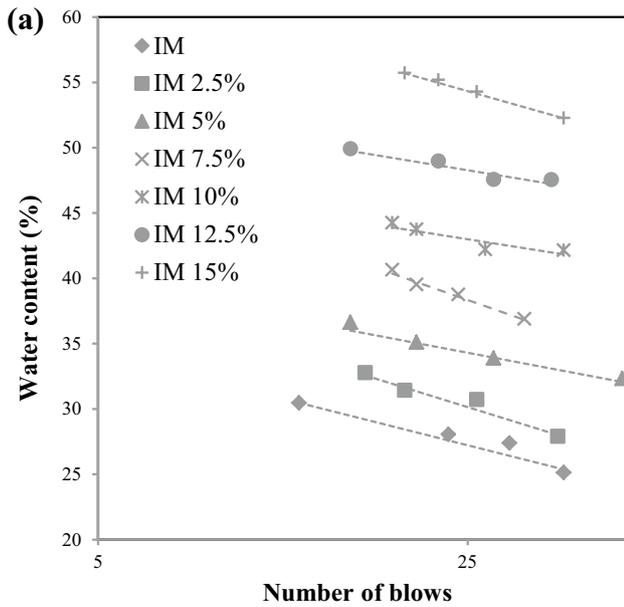


Fig. 7 Test results of liquid limit tests for samples made by mixing: a (IM) with (C), b (S) with (C)

### Plastic Limit

In Fig. 9, the experimental results of the rolling test method show an increase in plastic limit values with an increase in organic matter content. These results are in agreement with several studies [4, 15, 18, 22, 25]. In this study, it is to note that the increase of plastic limit values with the increase of the organic matter contents is in the same order as the increase of liquid limit values (Table 5).

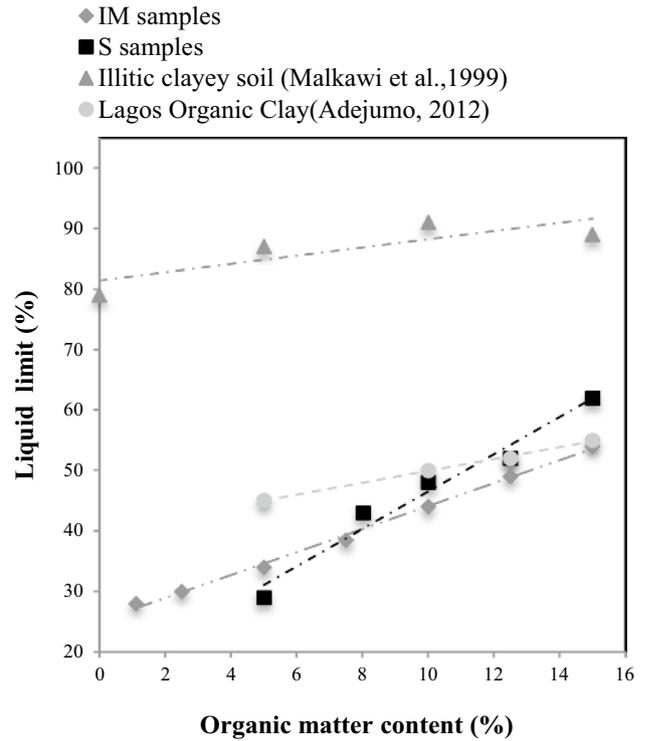


Fig. 8 Effect of organic matter content on liquid limit test results

Table 4 Predictive equations of  $L_L$  from organic matter content

Samples	Regression predictive equation	$R^2$
This study—IM samples	$L_L (\%) = 1.89 \times [\text{OM}(\%)] + 25.13$	0.99
This STUDY—S samples	$L_L (\%) = 3.08 \times [\text{OM}(\%)] + 15.61$	0.96
Malkawi et al. [22]	$L_L (\%) = 0.68 \times [\text{OM}(\%)] + 81.40$	0.70
Adejumo [25]	$L_L (\%) = 1.02 \times [\text{OM}(\%)] + 42.0$	0.98

The results by Malkawi et al. [22], for organic matter contents between 1 and 15%, exhibit the same trend.

### Plasticity Index

As expected, the similar increase in the liquid limit and plastic limit with the increase of organic matter content results in unchanged values of plasticity index. The results showed in Fig. 10 confirm this trend. In Table 6, the small value of the correlation number for the results from this study and those of Malkawi et al. [22] confirms the neutral impacts of organic matter content on the plasticity index. The results from Adejumo [25] seem not able to support the addressed conclusion above.

Concerning the compressibility of natural materials, several studies showed a positive correlation between the compression index and the plastic index [42]. For dredged sediments, the unchanged values of the plastic index with

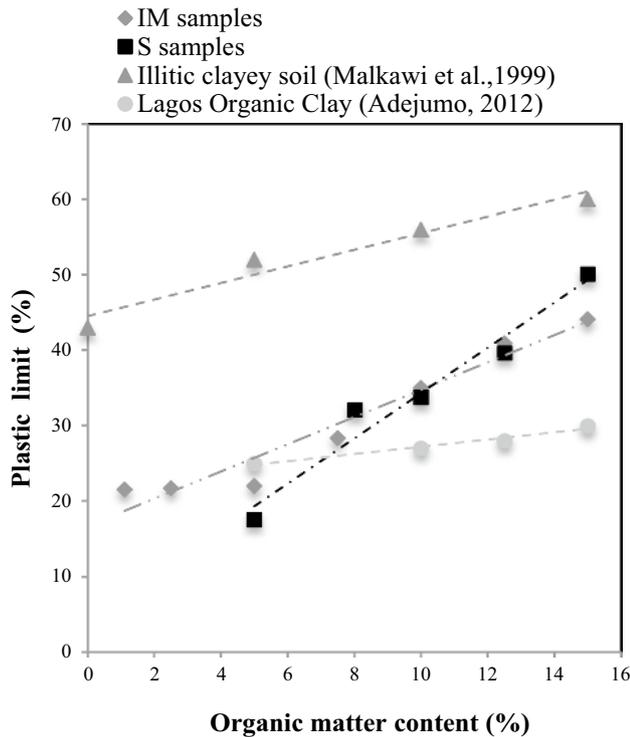


Fig. 9 Effect of organic matter content on plastic limit test results

Table 5 Predictive equations of  $P_L$  from organic matter content

Samples	Correlation equations	$R^2$
IM samples	$P_L (\%) = 1.80 \times [OM(\%)] + 16.70$	0.95
S samples	$P_L (\%) = 3.00 \times [OM(\%)] + 4.32$	0.96
Malkawi et al. [22]	$P_L (\%) = 1.10 \times [OM(\%)] + 44.5$	0.95
Adejumo [25]	$P_L (\%) = 0.52 \times [OM(\%)] + 25.1$	0.97

increasing values of organic matter content allow expecting a similar compressibility of the dredged sediments independently of the organic matter content. This result allows envisaging the use of sediments with organic matter content above the traditional limits of 2–7% in the road construction field.

### Methylene Blue Value (MBV)

The experimental results of the MBV test measured on prepared samples with various organic matter contents for both types of materials are reported in Fig. 11. From these results, it seems that the MBV values are not (or slightly) affected by the organic matter content. In the range of organic matter content studied in this research work, the classification on the basis of MBV test results is unchanged. This result is also predictable and supports the positive correlation assumed in several studies between the MBV and the plastic index [43].

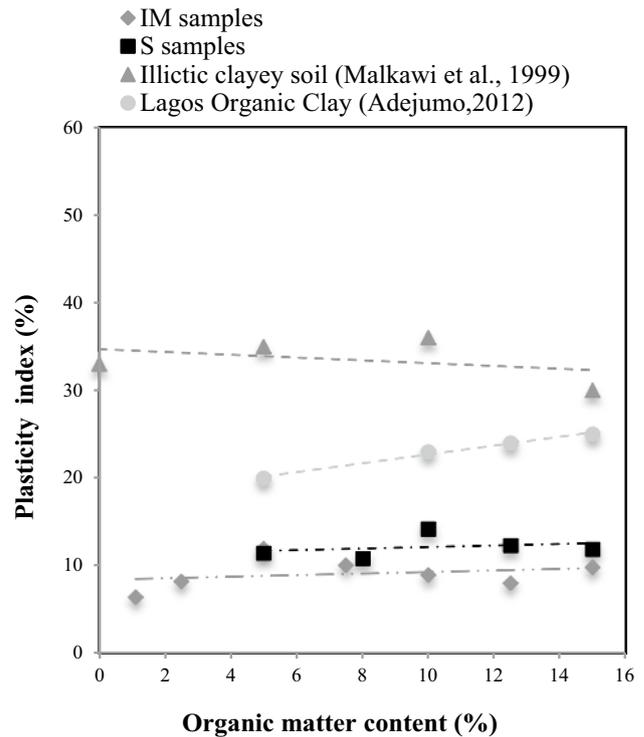


Fig. 10 Effect of organic matter content on plasticity index results

Table 6 Predictive equations for  $P_I$  from organic matter content

Samples	Correlation equations	$R^2$
IM samples	$P_I (\%) = 0.09 \times [OM(\%)] + 8.42$	0.06
S samples	$P_I (\%) = 0.08 \times [OM(\%)] + 11.29$	0.06
Malkawi et al. [22]	$P_I (\%) = -0.16 \times [OM(\%)] + 34.70$	0.15
Adejumo [25]	$P_I (\%) = 0.50 \times [OM(\%)] + 17.65$	0.98

### Effects of Organic Matter Content on Material Classification

Following the analysis of the effects of organic matter content on the physical characteristics of the studied materials, in this section, the effects on material classification are discussed.

On the basis of the Casagrande chart of material classification (Fig. 12), the measured values (liquid limits and plasticity index) on the different samples with various organic matter contents do not seem to affect the material classification. The same trend is also observed in other studies [15, 20].

In the field of valuation in roads construction sector, the same trend in terms of material classification is also observed. On the basis of the French soil classification system dedicated to roadworks [43], aside from the

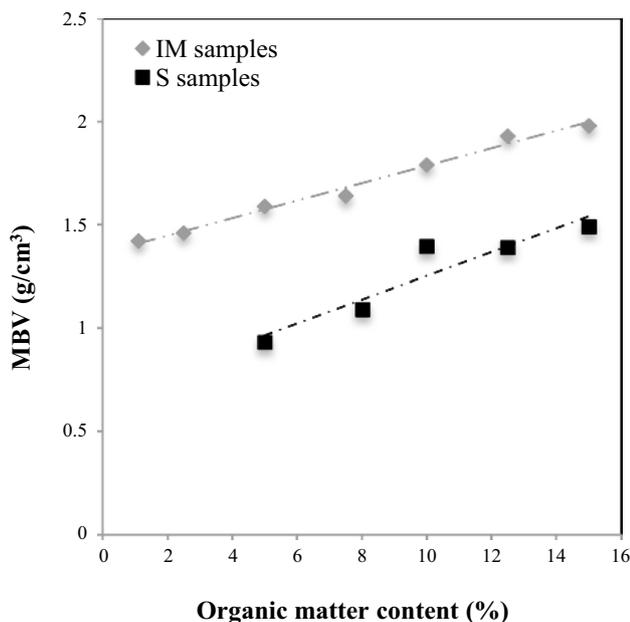


Fig. 11 Methylene blue tests results versus organic matter content

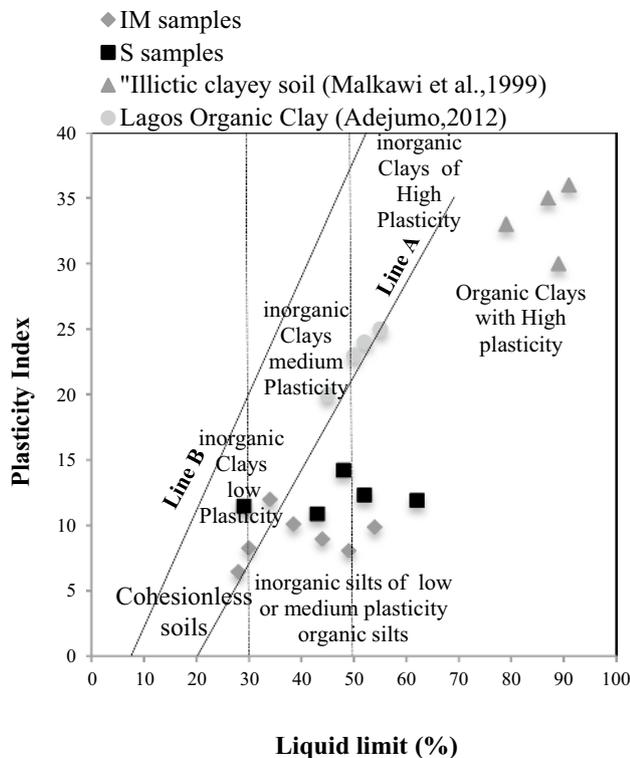


Fig. 12 Classification of tested samples in Casagrande chart of materials classification

differences in the organic character of the samples, the material classification based on grain size distribution, consistency limits and MBV value stay within the same class of materials (Fig. 13). The twelve materials are classified in group  $A_1$  which regroups the materials with low plasticity.

On the basis of soils classification of the American Association of State Highway and Transportation Officials [45], the different samples are classified as clayey soil (for samples made of dredged sediments) and silty soil (for samples made of the inorganic material) (Table 7). On Table 7, the Group Index Number (GIN) evaluated on the different samples show that the GIN changes between 6 and 12. It is to note that the limit value of 8 is considered as acceptable for the use as road fill material or in local roads or streets.

## Conclusions

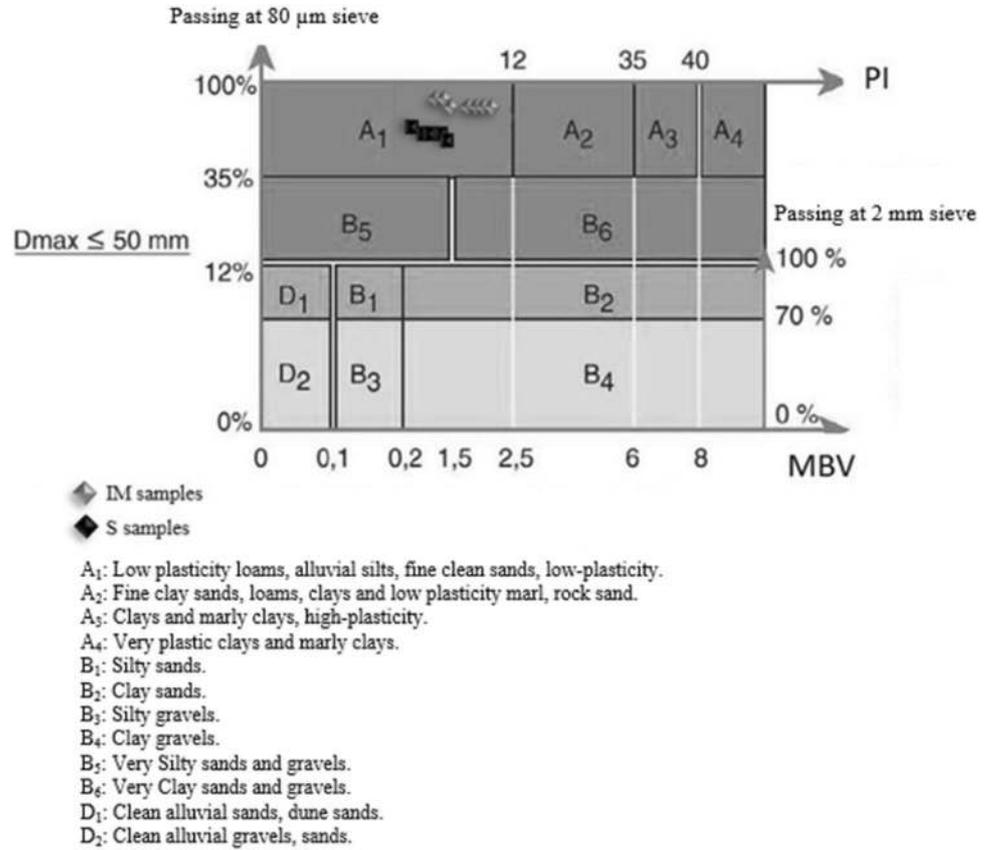
The main objectives of this paper were as follows:

- To assess a methodology to prepare reconstituted samples with a controlled amount of organic matter contents. The results of this work are prejudicial in upcoming research work on preparing samples for assessing the effects of organic matter content on the mechanical behaviour of the sediments.
- To explore the effect of organic matter content on a few physical characteristics of marine dredged sediments in order to explore the beneficial use of these materials in roads construction.
- To anticipate, the mechanical behaviour of organic samples from the measured physical properties.

From the obtained results, comparisons of test results on reconstituted samples (IM + C samples) and on samples made with marine sediments (S + C samples) show a good agreement in terms of the evolution of the physical parameters discussed in this paper. The results of samples treated with hydrogen peroxide are also in the continuity of the results obtained by enrichment of samples with organic matter. This allows validating the proposed method to reconstitute samples with different amount of organic matter contents. This preliminary work will allow preparing the volume of materials needed to assess the impacts of organic matter contents on the mechanical properties.

Regarding the effects of organic matter contents on the physical characteristics selected, it appears that a linear relationship exists between the decrease of the specific gravity of the material with the increase of the organic matter content. This relation is also well-established on natural material with comparable mineral phases. The organic matter content is positively correlated to the liquid limit and the plastic

**Fig. 13** Effect of organic matter content on the classification of materials according to GTR classification [44]



**Table 7** Samples classification according to the soils classification system of the American Association of State Highway and Transportation Officials (AASHTO)

Samples	$L_L$ (%)	$P_L$ (%)	$P_1$ (%)	No. 10	No. 40	No. 200	GIN	Classification
S H <sub>2</sub> O <sub>2</sub>	29	17	12	100	99.51	79.11	8	A-6 Clayey soil
S	43	32	11	100	99.37	79.03	10	A-7-5 Clayey soil
S 10%	48	34	14	100	99.24	73.51	12	A-7-6 Clayey soil
S 12.5%	52	40	12	100	99.04	69.54	10	A-7-5 Clayey soil
S 15%	62	50	12	100	98.76	66.43	11	A-7-5 Clayey soil
IM	28	21	7	100	99.84	98.23	6	A-4 Silty soil
IM 2.5%	30	22	8	100	99.07	94.15	7	A-4 Silty soil
IM 5%	34	22	12	100	97.87	92.09	11	A-6 Clayey soil
IM 7.5%	38.5	28	10.5	100	97.25	88.39	11	A-4 Silty soil
IM 10%	44	35	9	100	96.15	84.71	10	A-5 Silty soil
IM 12.5%	49	41	8	100	94.57	80.84	10	A-5 Silty soil
IM 15%	54	44	10	100	91.21	77.17	11	A-5 Silty soil

limit. In this study, the effects on the plasticity index are of lesser importance. A very limited effect is also observed on the MBV measurements. For the specific surface area, due to the typology of the organic material used, it seems that the surface area decreases with increased organic matter content.

Overall, within the range of organic matter content examined in this study (between 5 and 15% for samples including sediments and 1 and 15% for reconstituted samples), the general classification of the studied materials does not

change within the framework of roads construction regarding grains size distribution, plasticity and activity of fine particles, which are important to consider when exploring the changes in the mechanical behaviour of the materials.

It is worth noting that the characterization of the organic matter is a complex problem. In comparative studies, it is important to quantify this parameter with the same method. Moreover, the preparation of samples with different methodologies affect probably the observed effects of organic

matter content on the properties of the material. In the same line than the characterization of organic matter, in comparative studies, it is suitable using the same methodology of preparation.

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## Compliance with Ethical Standards

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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