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Study of Relationship between Fines Content and Cohesion of Soil

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Author's contribution

This work was carried out by author GOA. He designed the study, collected and prepared the field samples, carried out the laboratory procedure, performed the statistical analysis, managed literature searches and wrote the draft and final manuscripts.

Original Research Article

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ABSTRACT

The relationship between fines content and cohesion of soil was studied. Selected lateritic soil samples were subjected to laboratory analysis. The fines were separated from the coarse component of the soils after which the samples were remoulded in varying ratios (fines:coarse) from 10:100 to 100:0 in 10% increment. Then the samples were subjected to unconsolidated-undrained triaxial test to determine the shear strength parameters. Quantitative relationships between fines content and cohesion of the soil samples were developed. It was found that, the cohesion of the soil samples generally increased with increase in fines content; the polynomial relationships gave the best fitting between the fines content and cohesion of the soil samples.

Keywords: Cohesion; fines content; polynomial, quantitative relationships, shear strength parameters.

1. INTRODUCTION

Cohesion of soil is an important factor of soil consistency. As reported by Yokoi et al. [1], the word cohesion has acquired two connotations. The soil physics [2] defines cohesion as "the cohesive force that takes place between adjacent particles". On the other hand, in soil mechanics, cohesion means "the shear strength when the compressive stresses are equal to zero". This study focuses on soil cohesion as referred to the soil mechanics aspect.

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The shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure along any plane inside it [3]. When this resistance is exceeded failure occurs. The shear strength is usually made up of: (a) internal friction or the resistance due to interlocking of the particles, represented by an angle, ϕ; (b) cohesion or the resistance due to the forces tending to hold the particles together in a solid mass. The cohesion of a soil is generally symbolized by the letter 'c'. The law governing the shear failure of soils was first put up by Coulomb and is given by the equation

$$s = c + \sigma \tan\phi \tag{1}$$

Where s is the shear strength and σ is the normal stress.

USCS [4] and AASHTO [5] define fines as soil particles passing through sieve No. 200 (75µm opening). The fines consist of clay and silt. The fines content in coarse soils are carefully considered because they determine the composition and type of soil and affect certain soil properties such as permeability, particle friction and cohesion. The fines content in soil also plays an important role in phase problems including minimum and maximum void ratios and porosity [6]. Fines have also been found to affect the liquefaction potential, compressional characteristics and stress-strain behaviour of soil [7 - 10]. According to Wang et al [11], fines content could affect significantly the dynamic response of soils. Tatlisoz et al [12] studied the effect of fines on mechanical properties of soil-tyre chip mixtures and found out that the fines have significant effect on the mechanical properties of the soil-tyre mixture. Ayodele [13] studied the effect of fines content on the performance of soil as sub-base material for road construction and found out that the engineering properties of the studied soil samples generally reduced with increase in fines content

Laterite has been widely defined as a highly weathered material, rich in secondary oxides of iron, aluminum, or both. It is void or nearly void of bases primary silicates, but it may contain large amounts of quartz and kaolinite [14]. A distinctive feature of laterite and lateritic soils is the higher proportion of sesquioxides of iron and/or aluminium relative to the other chemical components. A soil is characterized as laterite, lateritic soil or non laterite according to the ratio of silica oxide and sesquioxides present in it. In laterites the ratios are less than 1.33; those between 1.33 and 2.0 are indicative of lateritic soil; and those greater than 2.0 are indicative of non-lateritic soil [15]. Latentic soils are formed in hot, wet tropical regions with an annual rainfall between 750mm to 3000mm (usually in area with a significant dry season) on a variety of different types of rocks with high iron content. The locations on the earth that characterized the condition fall in between latitudes 35ºS and 35ºN. Laterite formation factors include climate (precipitations, leaching, capillary rise, and temperature) to topography (drainage), vegetation, parent rock (iron–rich rocks) and time. Of all these primary factors, climate is considered the most important [16]. Laterites may occur as surface deposits of unhardened clayey soils, gravels, and as hard pans [17]. Thus, genesis and pedological factors (parent materials, climate, vegetation, topography, weathering period), degree or weathering (decomposition, sesguioxide enrichment, clay–size content, degree of leaching), position in the topographic site and depth of soil in the profile have great influence on the geotechnical properties, characteristics and field performance of lateritic soil [18,19].

Experimental studies have been carried out on soil cohesion [1, 20-22]. Previous works emphasized the urgent need of investigating the effect of soil internal stress on shear strength. However, the specific relationship between fines content and cohesion of soil in the study area is not clear; hence, this study. The specific objectives of this study were to: (i) determine the effects of fines content on the cohesion of selected soil samples; and hence (ii) develop regression models (equations) relating the fines content to the cohesion of the soil samples.

2. EXPERIMENTAL PROCEDURE

A total of three (3) lateritic soil samples were obtained from three selected locations (a sample from each location) in Obafemi Awolowo University (OAU) campus, Ile-Ife, Nigeria [23]. Fig. 1 demonstrated the sampling locations. Samples were collected from 1m depth. The soil samples were packed in polythene bags from the sampling locations, properly sealed and labelled for easy identification and then transported to the geotechnical engineering laboratory, department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria. The bulk samples were first air–dried before subjecting them to the basic geotechnical index property tests in accordance with the methods by BS [24].

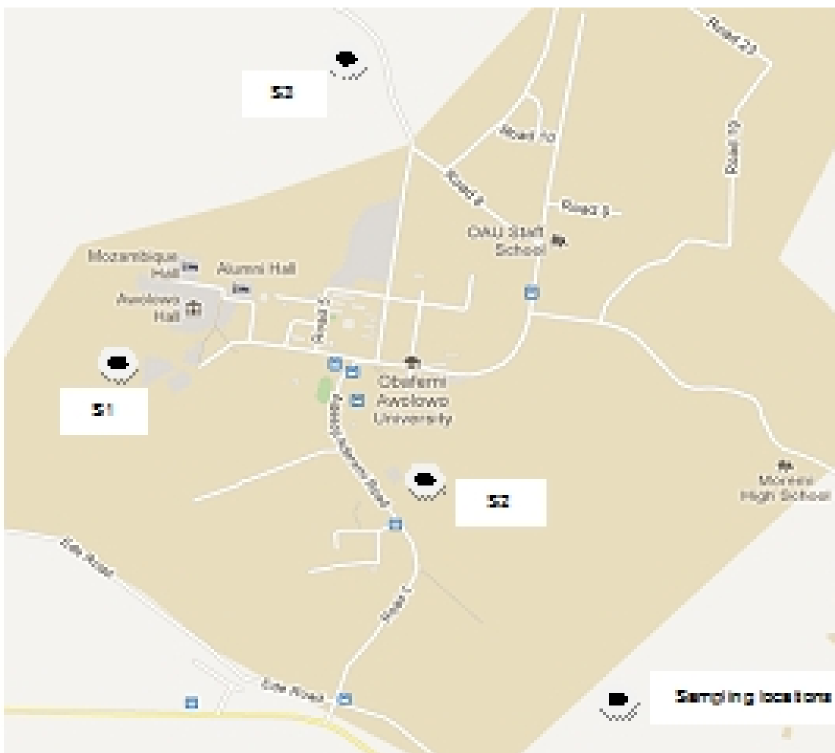

Fig. 1. Location map of OAU campus [25]

The soil samples were soaked in water containing 4% sodium hexametaphosphate, a dispersing agent (commercially named Calgon) in the laboratory for 12-24 hours so that all the fines would get soaked and detached from the coarser soil samples. The soil was then washed through sieve size No. 200 with 75μm opening. The soil passing 75μm sieve size was oven dried and referred to as 100% fines. The soil sample retained on sieve 75μm opening was also oven dried (after thorough mixing) and referred to as 100% coarse.

The pulverized fines and the coarse fractions were added together in varying ratios (fines:coarse) from 10:100 to 100:0 in 10% increment. The ratio started with 10:100 and not 0:100 because, laboratory compaction test could not be carried out on the sample containing 0% fines (i.e. 100% coarse) and thus cohesionless. This is because the process of lubrication which aids compaction is limited to soils containing fines and cohesionless soils are compacted or densified by vibration and not by impact which laboratory compaction utilizes [26].

Then the samples were allowed to homogenise and compacted in the laboratory using standard proctor test to determine the optimum moisture content (OMC) and the maximum dry density (MDD) of each sample. The values of the OMC were used in subsequent unconsolidated undrained triaxial tests [23].

The remoulded soil samples were then subjected to unconsolidated-undrained triaxial test, in accordance with the methods by BS [24]. Mohr-circle diagrams (Fig. 2) were subsequently developed and used to determine the shear strength parameters (i.e. c and ϕ) of the soil samples. Quantitative relationships between fines content and cohesion of soils were then developed. The validity of the developed relationships was verified by the coefficient of determination (R^2), which compares estimated and actual y-values, and ranges in value from 0 to 1. The closer the R^2 to 1, the better the representations.

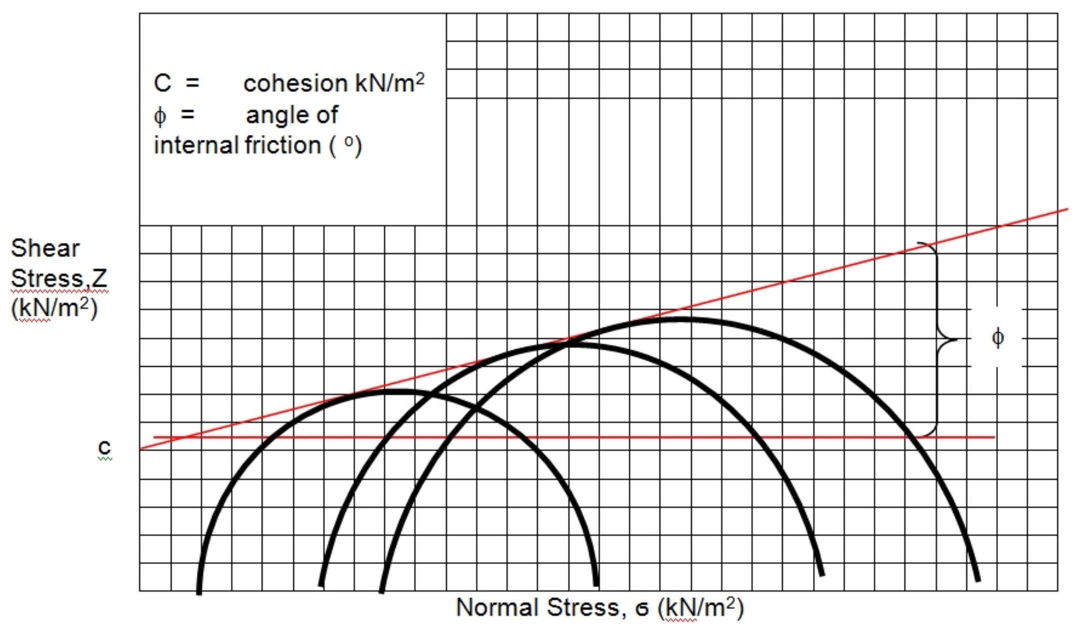

Fig. 2. An illustration of Mohr-circle diagram (not to scale)

Fig. 3 is an overview of the methods used in this study.

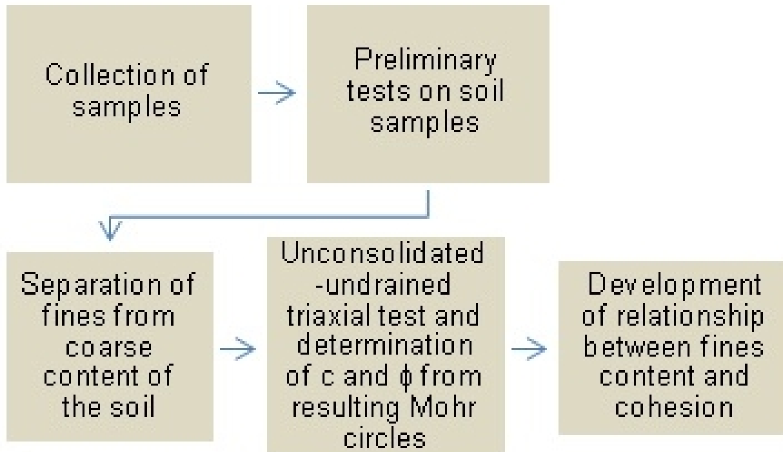

Fig. 3. Overview of methods

3. RESULTS AND DISCUSSION

The results of basic geotechnical index properties tests of the soils (in their natural states) are presented in Table 1. The Table shows that sample S2 has the highest fines content of 55.00%, liquid limit (LL) of 41.00% and plastic limit (PL) of 30.73%. Sample S1, on the other hand, has the lowest fines content of 32.70%, LL of 45.29% and PL of 32.68%. Sample S1 has the highest plasticity index (PI) of 12.61%. This implies that sample S1 has the highest inherent swelling potential shrinkage tendency [19].

The percentage of material passing through No. 200 BS sieve is within the range 30 – 80%, which implies that the soil samples are generally in between coarse-grained and fined grained according to USCS [4, 27]. The values of specific gravity of the tested samples are 2.66 (S1), 2.86 (S2) and 2.69 (S3). Wright [28] stated that the standard range of values of specific gravity of soils lies between 2.60 and 2.80. However, lower specific gravity values indicate a coarse soil, while higher values indicate a fine grained soil [19, 24]. Thus, it could be concluded that sample S2 is fine grained.

According to O'Flaherty [29], as reported by Bello and Adegoke [27] and Adunoye and Agbede [19], the range of values that may be anticipated when using the standard proctor test methods are: for clay, maximum dry density (MDD) may fall between 1.44mg/m^3 and 1.685mg/m^3 and optimum moisture content (OMC) may fall between 20-30%; for silty clay MDD is usually between 1.6 and 1.845mg/m^3 and OMC ranged between 15-25%. For sandy clay, MDD usually ranged between 1.76 and 2.165Mg/m^3 and OMC between 8 and 15%. This confirms that the soils are silty-clay (Table 1).

Table 2 gives a summary of the values of cohesion at various fines content of the soil samples. For sample S1, the cohesion values range between 8 kN/m^2 (for 10% fines) and 63 kN/m^2 (for 100% fines). This represents 55 kN/m^2 (687.5%) increase. For sample S2, the cohesion values range between 5 kN/m^2 (for 10% fines) and 67 kN/m^2 (for 100% fines). This represents 62 kN/m2 (1240%) increase. Similarly, for sample S3, the cohesion values range between 10 kN/m2 (for 10% fines) and 66 kN/m2 (for 100% fines). This represents 56 kN/m2 (560%) increase. The cohesion generally increase with increase in fines content of the soils.

This is in agreement with Ayodele [13]. This is so because cohesion is majorly dependent on clay content in soils [30].

Table 1. Soils classification characteristics

Property	Sample identification		
	S1	S2	S3
Natural moisture content (%)	19.74	16.90	17.05
Specific gravity	2.66	2.86	2.69
Percentage passing sieve No. 200 (Fines content)	32.7	55	41.07
Liquid Limit, LL (%)	45.29	41	39.87
Plastic Limit, PL (%)	32.68	30.73	31.01
Plasticity Index, PI (%)	12.61	10.27	8.86
Optimum moisture content, OMC (%)	17.39	19.42	16.38
Maximum dry density, MDD (mg/m3)	1.77	1.91	1.71

Table 2. Values of cohesion at various fines contents

Fines Content (%)	Cohesion, c (kN/m^2)		
	S1	S2	S3
10	8	5	10
20	10	9	14
30	20	13	19
40	26	19	31
50	41	28	38
60	49	34	46
70	52	51	49
80	57	59	62
90	59	62	64
100	63	67	66

The results of the correlations between fines content and cohesion of the soil samples are as shown in Figs. 4 to 7, while Table 3 gives a summary of the equations representing relationships between cohesion and fines content of soil samples. As indicated by the values of R^2 all the empirical equations are good fits (valid) for the soil samples as they are always increasing just as the data increase. However, logarithmic relationships cannot be said to be valid. This is because there cannot be negative cohesion values (Fig. 5). Furthermore, polynomial relationships give the highest R^2 values for all the samples (0.977 for S1, 0.976 for S2 and 0.984 for S3). This could probably be as a result of the fact that polynomials have the attractive property of being able to approximate many kinds of functions [31]. The polynomial equations (models) fits the data best, and thus give the best representations between fines content and cohesion of the soil samples.

It is noted that the empirical equations are valid for the soil samples and test procedure used in this research. More experiments with more samples from different locations are required to generalize these expressions.

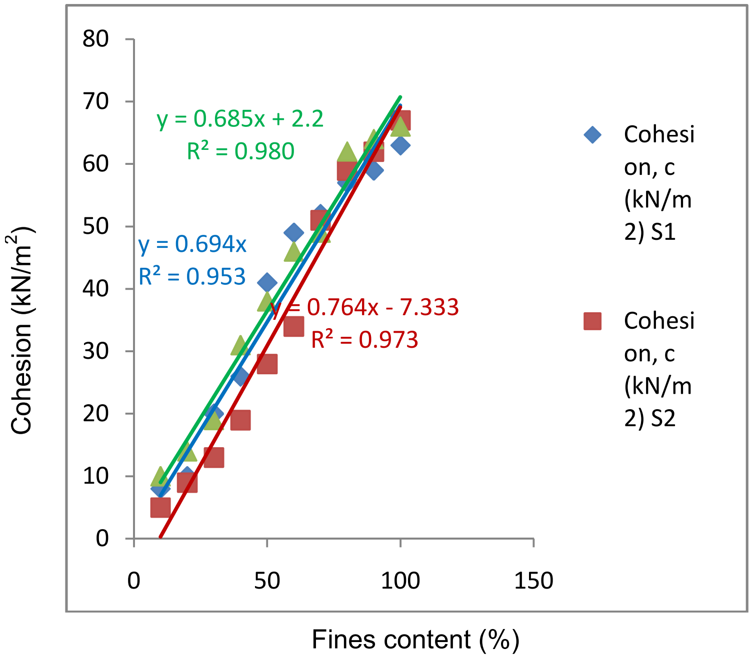

Fig. 4. Cohesion vs Fines content (Linear)

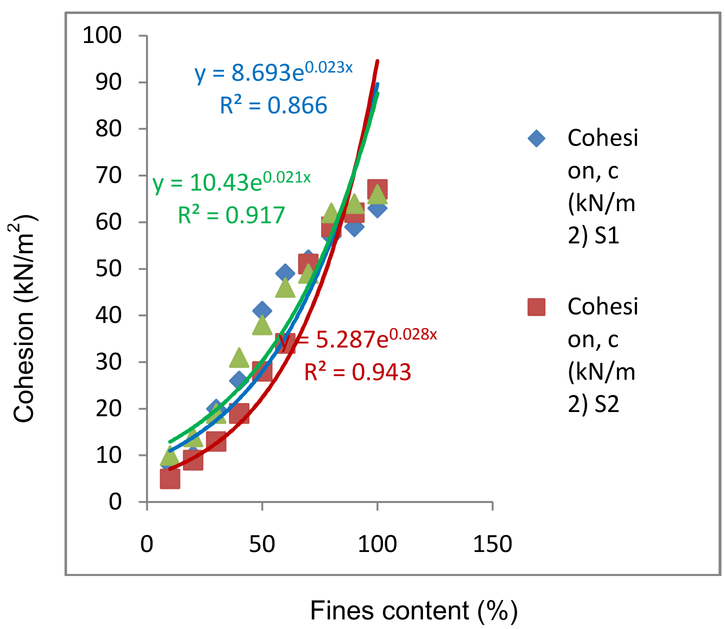

Fig. 5. Cohesion vs Fines content (Exponential)

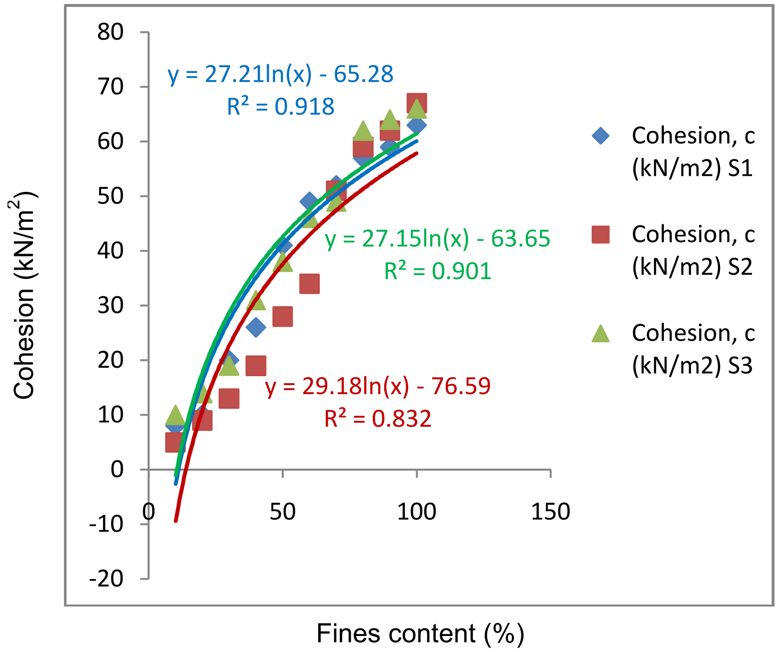

Fig. 6. Cohesion vs Fines content (Logarithmic)

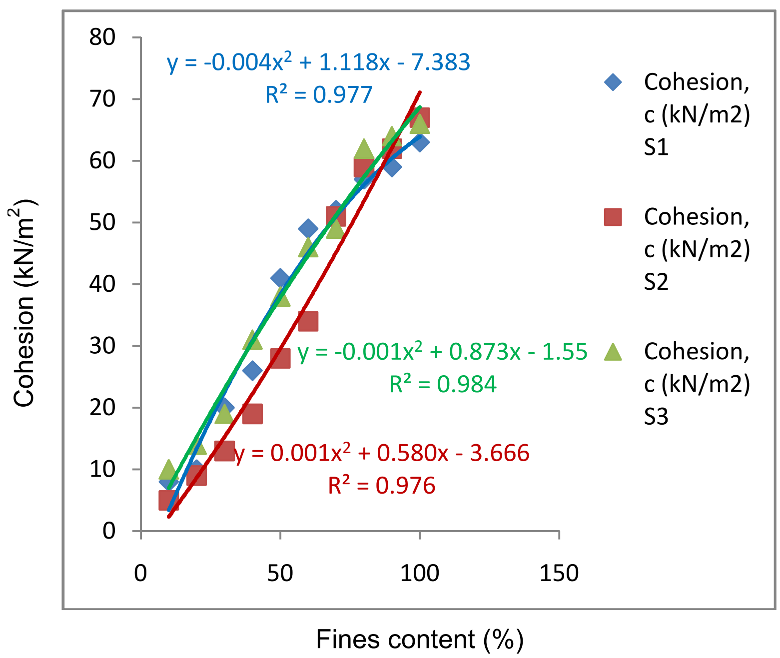

Fig. 7. Cohesion vs Fines content (Polynomial)

Table 3. Equations representing relationship between cohesion and fines content of soil samples

Sample	Equation			
	Linear	Exponential	Logarithmic	Polynomial
S1	$y = 0.694x$; $R^2 = 0.953$	$y = 8.693e^{0.023x}$; $R^2 = 0.866$	$y = 27.21\ln(x) - 65.28$; $R^2 = 0.918$	$y = -0.004x^2 + 1.118x - 7.383$; $R^2 = 0.977$
S2	$y = 0.764x - 7.333$; $R^2 = 0.973$	$y = 5.287e^{0.028x}$; $R^2 = 0.943$	$y = 29.18\ln(x) - 76.59$; $R^2 = 0.832$	$y = 0.001x^2 + 0.580x - 3.666$; $R^2 = 0.976$
S3	$y = 0.685x + 2.2$; $R^2 = 0.980$	$y = 10.43e^{0.021x}$; $R^2 = 0.917$	$y = 27.15\ln(x) - 63.65$; $R^2 = 0.901$	$y = -0.001x^2 + 0.873x - 1.55$; $R^2 = 0.984$

4. CONCLUSION

From the findings of this research work, the following conclusions are made in relation to the objectives of the research: (i) The cohesion of the studied soil samples generally increased with increase in fines content; (ii) the best fitting between the fines content and cohesion of the soil samples was found by the polynomial expression: ($c = -0.004f^2 + 1.118f - 7.383$; $c = 0.001f^2 + 0.580f - 3.666$; $c = -0.001f^2 + 0.873f - 1.55$), where c is cohesion in kN/m^2 and f is fines content in %. The results are valid within the tested materials and the procedure outlined in this paper. It is recommended to perform more experiments to validate the finding in this research.

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COMPETING INTERESTS

There is no competing interest whatsoever that could have influenced the results of this study in any way.

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