Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-683

Mechanical characteristics of non-cohesive soil improved by fibre and cement addition

Caractéristiques mécaniques des sols non cohésifs améliorées par l'ajout de fibres et de ciment

K. Zabielska-Adamska*, P. Dobrzycki**, M. Wasil
Bialystok University of Technology, Bialystok, Poland
*kadamska@pb.edu.pl; **patryk.dobrzycki@pb.edu.pl

ABSTRACT: The work aimed to show changes in the mechanical characteristics of gravelly sand characterized by a lack of fines after adding dispersed reinforcement. Tests were conducted on natural non-cohesive soil or improved with a 1.5% cement additive. 18 mm long fibres were used, which were added in amounts of 0.1%, 0.2%, and 0.3% to the dry mass of compacted soil. The gravelly sand was compacted at the optimum water content to the maximum dry density by the Standard Proctor energy. The soil was sheared in triaxial conditions. The addition of fibres changed the sample behaviour on more plastic. The fibre content increases the maximum shear strength but it is obtained at greater relative strain. The cement lightly bound soil failure mode is diagonal through the failure plane, as in the case of semi-brittle material. Whereas the plane of destruction in the soil sample improved with cement and fibre addition is close to horizontal, which signifies that fibre-reinforced material entered its plastic zone.

RÉSUMÉ: Les travaux visaient à montrer l'évolution des caractéristiques mécaniques des sables graveleux caractérisés par un manque de fines après ajout de renforts dispersés. Les essais ont été réalisés sur sol naturel non cohésif ou amélioré avec un additif cimentaire à 1,5%. Des fibres de 18 mm de long ont été utilisées, qui ont été ajoutées en quantités de 0,1%, 0,2% et 0,3% à la masse sèche de sol compacté. Le sable graveleux a été compacté à la teneur en eau optimale jusqu'à la densité sèche maximale par l'énergie Standard Proctor. Le sol a été cisaillé en conditions triaxiales. L'ajout de fibres a modifié le comportement de l'échantillon sur davantage de plastique. La teneur en fibres augmente la résistance maximale au cisaillement mais elle est obtenue avec une déformation relative plus élevée. Le mode de rupture du sol légèrement lié du ciment est diagonal par rapport au plan de rupture, comme dans le cas d'un matériau semi-fragile. Alors que le plan de destruction dans l'échantillon de sol amélioré par l'ajout de ciment et de fibres est proche de l'horizontal, ce qui signifie que le matériau renforcé de fibres est entré dans sa zone plastique.

Keywords: Compacted soil; polypropylene fibre reinforcement; cement addition; shear strength; triaxial tests.

1 INTRODUCTION

Stabilization with hydraulic binders is an effective way to increase the stiffness of base and subbase layers and to improve the rutting of the subgrade. Another way to improve the soil properties is to use fibre-reinforcement. Scientists agree that fibre content is a recognized method for improving the shear strength and ductility of the stress-strain response of natural (Correia et al., 2021) or hydraulically bonded cohesive soils (Yang et al., 2022) but also natural (Michalowski and Čermák, 2003) and cemented non-cohesive soils (Consoli et al, 1998; Asghari et al., 2004; Haeri et al., 2005). The most used content of fibres to the dry mass of soil is 0.1−0.5%. Binder additives are used in various proportions, and the most common content of lime or cement is 2-10%. Cohesive soils are reinforced with fibres due to their brittleness after cementing or the possibility of cracking when drying. In the case of non-cohesive soils, silty sands are most often reinforced to improve mechanical properties. However, in recent years, research has also been carried out on gravelly sands with poor grain size characteristics, which require improvement due to low compaction possibilities.

The study aimed to investigate the influence of the addition of minimum cement content and polypropylene fibres on the compactibility and mechanical characteristics of post-glacial gravelly sand.

2 MATERIALS AND METHODS

The tested material is a Pleistocene glaciofluvial soil consisting of well-rounded quartz crumbles, as well as angular grains, with a considerable addition of lytic particles and feldspars (Zabielska-Adamska et al. 2021). According to EN ISO 14688-1 standard, the tested soil is gravelly sand (grSa) with a median particle diameter D_{50} of 1.0 mm and the absence of fines (f_c = 0%). The soil is a poorly graded material with uniformity and curvature coefficients equalled 5.27 and 0.91, respectively. The unit weight, γ_s, is 26.0 kN/m^3.

Laboratory tests were conducted on samples of gravelly sand and gravelly sand with 1.5% 42.5R Portland cement addition to the dry mass of soil, and their mixtures with 0.1, 0.2 and 0.3% of the polyamide fibres with a length of 18 mm. The soil and polypropylene fibres are shown in Figure 1.

Figure 1. The polypropylene fibres with 18 mm longest and soil mixed with 0.3% of the fibres.

Compaction parameters, maximum dry density, $\rho_{d\,max}$, and optimum water content, w_{opt}, were found by the Standard Proctor method. The soil or soil and cement were mixed with polypropylene fibres using a laboratory mechanical stirrer, which is of great importance for the homogeneity of the tested samples (Zabielska-Adamska et al., 2023a).

Mechanical characteristics were performed in the triaxial test apparatus with a pneumatic way of applying the confining pressure and axial load. The cylindrical reconstituted samples were prepared in a bipartite mould by dynamic tamping of the material at w_{opt} into three layers to obtain $\rho_{d\,max}$ value from the Standard Proctor method. The diameters of the samples were about 70 mm, and the height was about 140 mm. The samples were tested directly after compaction (unstabilized hydraulically), and after 28 days of curing in constant temperature and humidity, wrapped in foil to avoid drying. All samples were tested with the ratio of shearing 0.1 mm/min by the CD method recommended for non-cohesive (ASTM D7181-20). Samples were not saturated to recreate the conditions prevailing in the pavement subgrade material but their degrees of saturation were about 0.80. After isotropic consolidation samples were sheared under confining pressure $\sigma_3' = 50$, 100 and 150 kPa.

3 TEST RESULTS AND ANALYSIS

3.1 Compaction results

The fibre addition results in an optimum water content decrease and a maximum dry density increase in both uncemented and cemented samples (Figure 2). Increasing fibre content from 0.2% to 0.3% practically does not influence the compaction parameters of gravelly sand and its mix with cement.

The cement addition to the gravelly sand increases the $\rho_{d\,max}$ value while decreasing the w_{opt}.

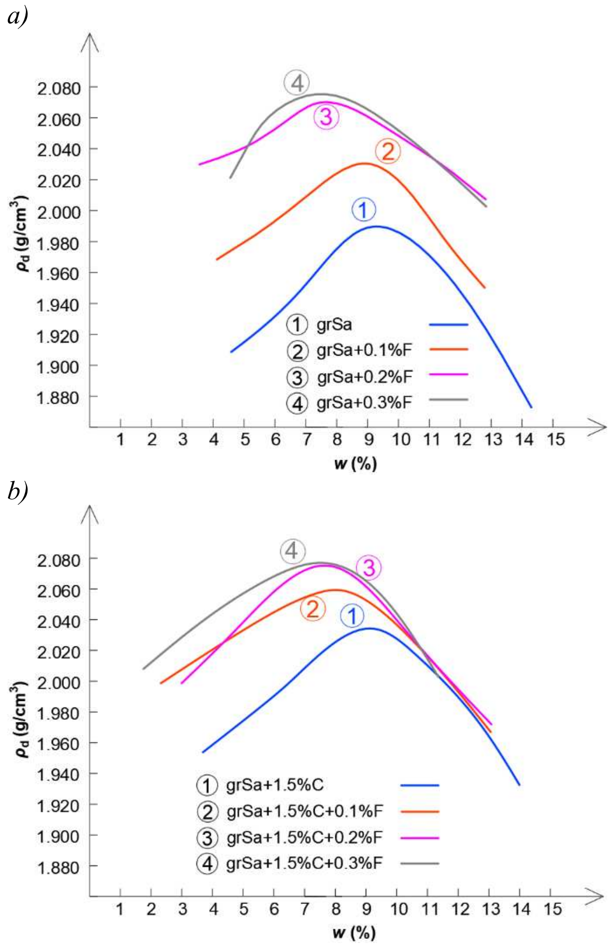

Figure 2. Compaction curves of tested materials with fibres: a) gravelly sand, b) sand and 1.5% of cement.

3.2 Triaxial test results

Test results for uncemented (Figure 3a) and lightly bound samples (Figure 3b) show that 1.5% cement addition increases twice the strength of tested samples that rises with the increase in confining pressure for each soil. The samples exhibit a gentle peak behaviour. The test results, presented in Figs. 3c-d, show the behaviour of the uncemented and cemented gravelly sand is changed by fibre addition. The peak strength and ultimate strength have increased whereas the initial strength is unchanged. The addition of fibres proportionally changed the sample behaviour on more plastic and the maximum shear strength was obtained at greater relative strains.

Stiffness assessed by the E_{50} module decreases with fibre content (Tab. 1), both for uncemented and cemented samples. The addition of 1.5% cement practically does not improve it, which was also stated for greater cement addition (Du et al., 2020).

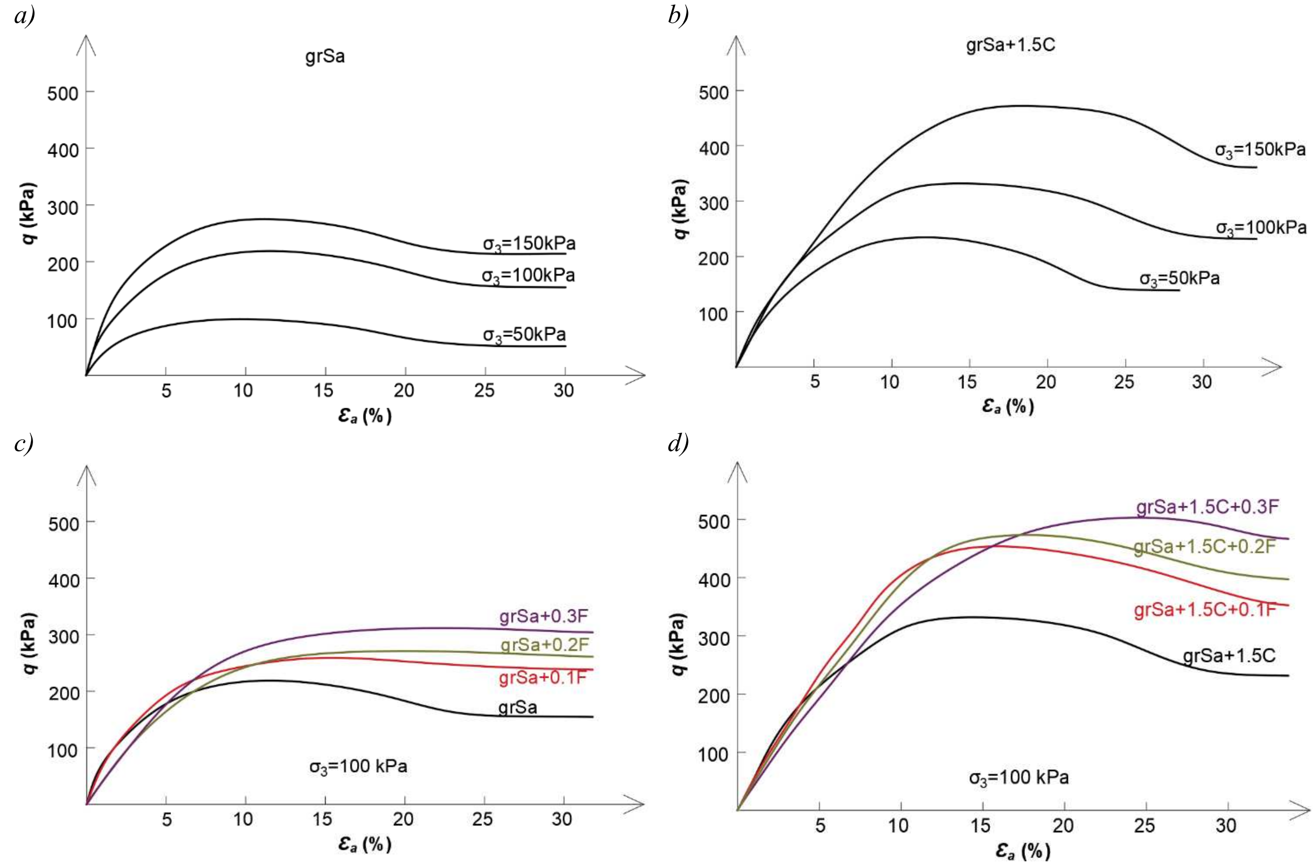

Figure 3. Results of CD triaxial tests shown as half of the deviator stress-strain curves for $\sigma_3' = 50$, 100 and 150 kPa for gravelly sand (a) and sand with 1.5% of cement addition (b), and 100 kPa for sand mix (c) and sand/cement with 0.1, 0.2 and 0.3% of fibres.

Table 1. Mechanical parameters of materials, where C – cement, and F – fibre content.

C	F	E_{50}	Shear strength parameters			
			Peak		Residual	
			ϕ'	c'	ϕ'	c'
%	%	MPa	°	kPa	°	kPa
0	0	10.39	40.3	1.3	38.5	0
	0.1	10.08	42.3	6.8	41.7	0
	0.2	7.84	43.5	8.8	43.2	5.1
	0.3	7.23	44.5	12.9	44.4	6.2
1.5	0	10.73	44.7	49.3	43.3	13.1
	0.1	9.33	45.0	82.6	45.7	45.9
	0.2	8.43	45.6	87.2	45.9	50.2
	0.3	7.51	45.8	88.2	46.5	60.6

The addition of cement and fibre improves shear strength parameters, both peak and residual (Tab. 1). Fibre content (0.1−0.3%) influences an increase of the effective angle of internal friction of natural grSa from 40.3° to 44.5°. In the case of stabilized soil, this increase is not so large and equals only 1.1°. Cohesion resistance grows significantly with the addition of fibres, both for natural and bounded materials. 1.5% of cement improves values of the angle of internal friction, but first of all – cohesion resistance.

Figure 4 shows various failure modes of samples damaged during the compression triaxial test. The sheared gravelly sand sample is characterized by the barrelling mode with a diagonal failure plane. The cement-bound soil failure mode is a typical single failure plane, obtained for semi-brittle material, whereas the plane of destruction in the uncemented and cemented samples improved with cement and fibre addition is close to horizontal. The horizontal failure plane signifies that fibre-reinforced material entered its plastic zone. In earlier research (Zabielska-Adamska et al., 2023b) carried out on grSa+1.5C with larger density (compacted by modified method) the failure mode was vertical through failure plane as in the case of brittle material.

grSa *grSa+1.5C_28 days*
grSa+0.3F *grSa+1.5C+0.3F_28 days*

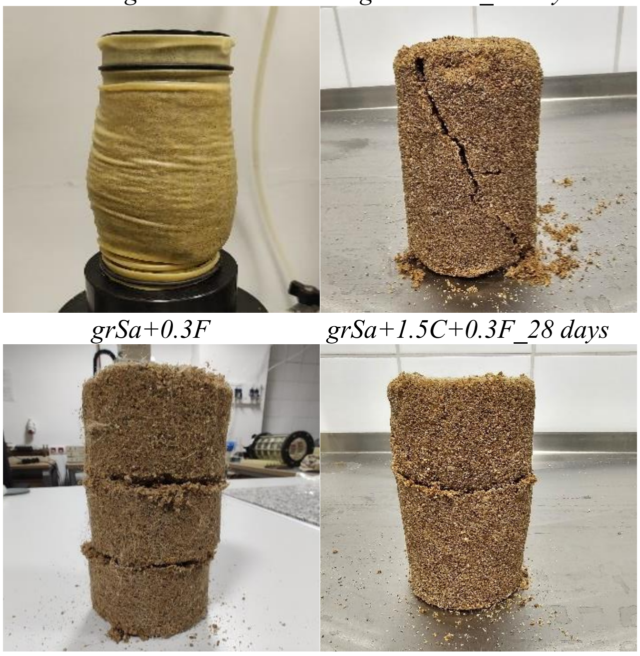

Figure 4. Views of sheared samples under $\sigma_3' = 100$ kPa.

4 CONCLUSIONS

1. The addition of 1.5% cement to gravelly sand increases peak and residual shear strength parameters, but practically does not impact on stiffness estimated by the E_{50} module.
2. Fibre reinforcement changes the behaviour of uncemented and slightly cemented gravelly sand. The peak and ultimate shear strength increased while the initial strength was the same. The peak and residual parameters increase, but the E_{50} module decreases.
3. The addition of 0−0.3% fibres regularly changed the behaviour of gravelly sand and its mix with cement on more plastic and where the peak strength was obtained at greater relative strain.

ACKNOWLEDGEMENTS

The investigations were conducted at Bialystok University of Technology in Poland under grant No.: WZ/WB-IIL/8/2023 and WI/WB-IIL/10/2023.

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