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Experimental Investigation on Geosynthetic-Reinforced Soil Sections via California Bearing Ratio Test

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***Abstract*—**Loose soils normally are of weak bearing capacity due to their structural nature. Being exposed to heavy traffic loads, they would fail in most cases. To tackle the aforementioned issue, geotechnical engineers have come up with different approaches; one of which is making use of geosynthetic-reinforced soil-aggregate systems. As these polymeric reinforcements have highlighted economic and environmentally-friendly features, they have become widespread in practice during the last decades. The present research investigates the efficiency of four different types of these reinforcements in increasing the bearing capacity of two-layered soil sections using a series California Bearing Ratio (CBR) test. The studied sections are comprised of a 10 cm-thick layer of no. 161 Firouzkooh sand (weak subgrade) and a 10 cm-thick layer of compacted aggregate materials (base course) classified as SP and GW according to the United Soil Classification System (USCS), respectively. The aggregate layer was compacted to the relative density (Dr) of 95% at the optimum water content (Wopt) of 6.5%. The applied reinforcements were including two kinds of geocomposites (type A and B), a geotextile, and a geogrid that were embedded at the interface of the lower and the upper layers of the soil-aggregate system. As the standard CBR mold was not appropriate in height for this study, the mold used for soaked CBR tests were utilized. To make a comparison between the results of stress-settlement behavior in the studied specimens, CBR values pertinent to the penetrations of 2.5 mm and 5 mm were considered. The obtained results demonstrated 21% and 24.5% increments in the amount of CBR value in the presence of geocomposite type A and geogrid, respectively. On the other hand, the effect of both geotextile and geocomposite type B on CBR values was generally insignificant in this research.

***Keywords*—**Geosynthetics, geogrid, geotextile, CBR test, increasing bearing capacity.

I. Introduction

In most of the civil projects in which the natural soil is exposed to heavy traffic loading such as railways, airport lanes, and container ports, to name but a few, geotechnical engineers are faced with two or more layered soil sections. The dominant characteristic of such sections is that they have a weak bearing capacity, and they cannot bear the imposed traffic loading alone. These layers (subgrades), in most cases, are of a great depth, and as a result, they would not seem to be economical to be removed. One practical method applying on such problematic soils is making use of geosynthetics, which are a topic of geotechnical engineers' interest today due to their easy operation, high durability, and both interlocking and separation functionality.

Abu-Farsakh et al. investigated the behavior of footing placed on geosynthetic-reinforced sandy soil. Their model tests were conducted in a large-scale test box (1.5 m long × 0.91 m wide × 0.91 m deep). Test results indicated that in case of reinforcement, the applied footing stress can redistribute to a more uniform pattern, hence reducing the stress concentration [1]. Asha and Latha studied reinforcing granular soils using geosynthetics by CBR test. They used three types of geosynthetics and two different molds. The results showed improvement of bearing capacity performance in the soils in the presence of reinforcements. On the other hand, it was found that by doubling the diameter of the specimens the bearing capacity was reduced by 50% [2].

Bergado et al. made a comparison between reinforced and unreinforced sandy layer placed over a weak clayey subgrade using a series of modified CBR tests in cylindrical mold with diameter of 300 mm and a height of 230 mm to minimize the boundary effect of standard CBR mold. The results of the tests showed an improvement of bearing capacity of sand-clay system when a layer of geotextile placed at the interface of two soils [3]. Miranda et al. studied the impact of geosynthetics on the strength parameters of well –graded soils. This study used Tri-axial and CBR test. The results showed 43% increase in CBR value in reinforced samples [4].

Montanelli et al. placed geogrid between gravel base course and sand subgrade. Their research showed that by increase in CBR value of subgrade, the amount of vertical settlement under loading decreases. They also demonstrated that the difference of settlement between the reinforced and unreinforced specimens in CBR value less than 3% is much higher than those of more than 3%. Moreover, the amount of settlement in reinforced specimen with 300 mm base course was less than unreinforced specimen with 400 mm base course [5]. Subaida et al. conducted some experiments to investigate the advantage of using coir geotextiles as a reinforcing material in a two-layer pavement section. The effects of placement position and thickness of geotextiles on the performance of reinforced sections were studied using two different base course thicknesses and two types of woven coir geotextiles. The test results indicate 45% enhancement in the bearing capacity of thin sections [6].

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In present study, a series of CBR tests have been conducted to investigate the effect of different geosynthetics on increasing the bearing capacity of two-layer soil sections.

II. Materials

A. Subgrade

In this study, no.161 Firouzkooh crushed silica sand was used as the subgrade layer. This soil is defined as fine angular standard sand classifying as SP according to Unified Soil Classification System (USCS). The grain size distribution of this sand is shown in Fig. 1. The sandy subgrade has a mean particle size (D_{50}) 0.27 mm, a uniformity coefficient (Cu) of 1.87 and a coefficient of curvature (C_c) 0.88. The magnified illustration of the sand is shown in Fig. 2.

To determine the shear strength parameters of sandy subgrade, a series of large-scale direct shear tests were conducted according to ASTM D3080-11[7]. To simulate the field conditions in large-scale direct shear box, the subgrade layer was compacted to 50% in dry condition (see Fig. 3).

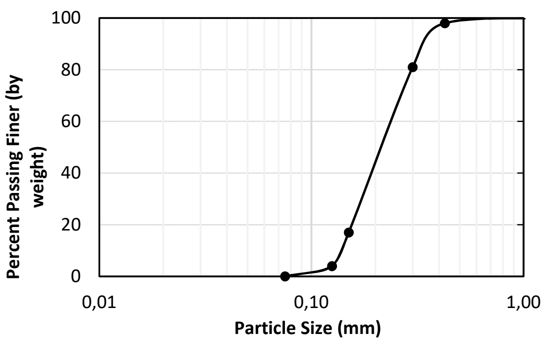

Fig. 1 Grain size distribution of silica sand

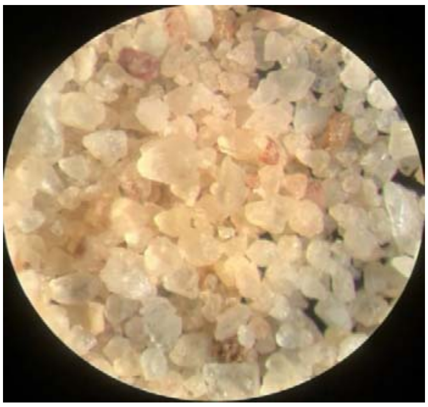

Fig. 2 Magnified illustration of silica sand grains

The samples were sheared at a constant rate of 1 mm/min recommended by ASTM D3080-11. Tests were done under three various normal stresses of 50 kPa, 100 kPa, and 200 kPa. Fig. 4 demonstrates the results of these tests in different applied normal stress values. The peak shear strengths of sandy subgrade in different normal stress are also shown in Fig. 5. Based on the results, the internal friction angle (ϕ) of the sandy subgrade and its cohesion are about 35° and 3 kPa, respectively.

Fig. 3 Large scale direct shear tests on sandy soil

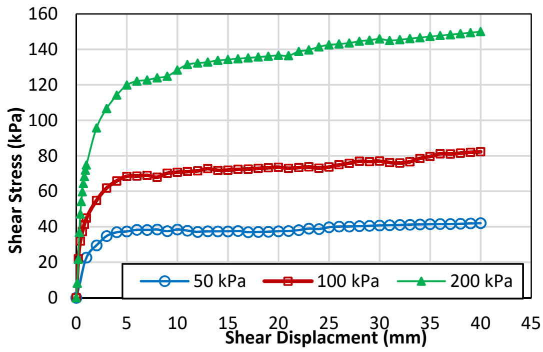

Fig. 4 Stress-strain behavior of sandy subgrade under different normal stress

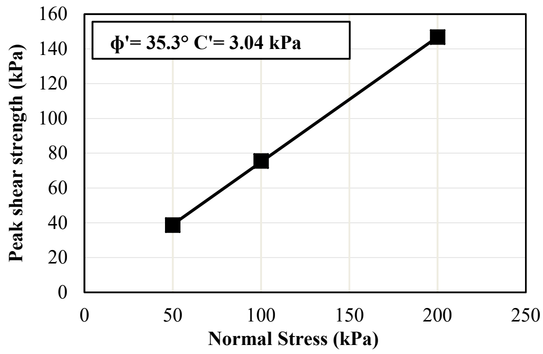

Fig. 5 Peak shear strength versus normal stress for sandy subgrade

B. Base Material

The base material used for all test sections was prepared based on the grading requirements for soil-aggregate material according to ASTM D1241-15 [8]. These features are presented in Table I.

The aggregate materials used as the base course in this study had a 100% passing 25-mm opening sieve, 52% passing 9.5-mm opening sieve, 41.5% passing no.4 opening sieve, 20.8% passing no. 10 opening sieve, 10.7% passing no. 40

opening sieve, and 2.6% passing no. 200 opening sieve with an effective particle size (D_{10}) of 0.4 mm, a mean particle size (D_{50}) of 9 mm, a uniformity coefficient (C_u) of 25.25 and a coefficient of curvature (C_c) of 3.96. The results of grading analysis indicated that the base material used in this study classified as "A" gradation of ASTM D1241-15. Both the upper and lower limitations of this standard code regarding the base course gradation are presented in Fig. 6.

The maximum dry density and the optimum moisture content of the base material were determined by the modified Proctor test according to ASTM D1557-12 [9]. Based on the results, the maximum dry density of base material is 2.08 gr/cm^3 at the optimum moisture content of 6.5%. This material is classified as GW and A-1-a according to USCS and the American Association of State Highway & Transportation Officials (AASHTO) classification systems, respectively. Fig. 7 shows the modified compaction curve of the base course material.

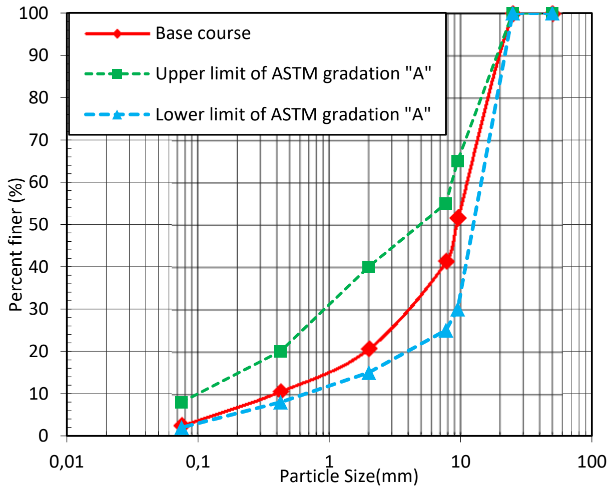

Fig. 6 Grain size distribution of base course material

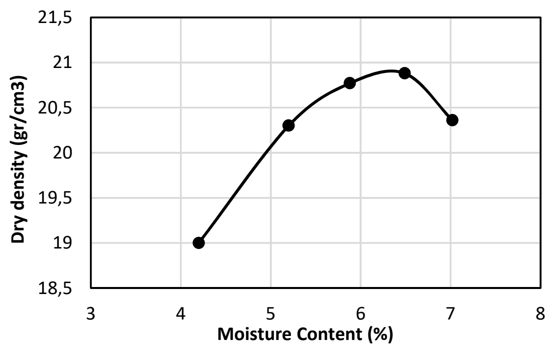

Fig. 7 Compaction curve of base course material

C. Geosynthetics

To reinforce soil sections, four kinds of geosynthetics were utilized in the tests including two types of geocomposite (Gc-A and Gc-B), a geogrid, and a geotextile. An illustration of these reinforcing materials is represented in Fig. 8. The geocomposite type A was comprised of a layer of non-woven geotextile and a layer of geogrid, and the geocomposite type B was a combination of a layer of non-woven geotextile and a polysteric geogrid layer. The mechanical properties of the aforementioned materials are depicted in Table II.

TABLE I
GRADING REQUIREMENT FOR SOIL-AGGREGATE MATERIALS (ASTM D1241)

Sieve Size	Mass Percent Passing Square Mesh Sieves			
	Gradation A	Gradation B	Gradation C	Gradation D
2-in	100	100	…	…
1-in	…	75 to 95	100	100
3/8-in	30 to 65	40 to 75	50 to 85	60 to 100
No. 4	25 to 55	30 to 60	35 to 65	50 to 85
No. 10	15 to 40	20 to 45	20 to 50	40 to 70
No. 40	8 to 20	15 to 30	15 to 30	25 to 45
No. 200	2 to 8	5 to 15	5 to 15	8 to 15

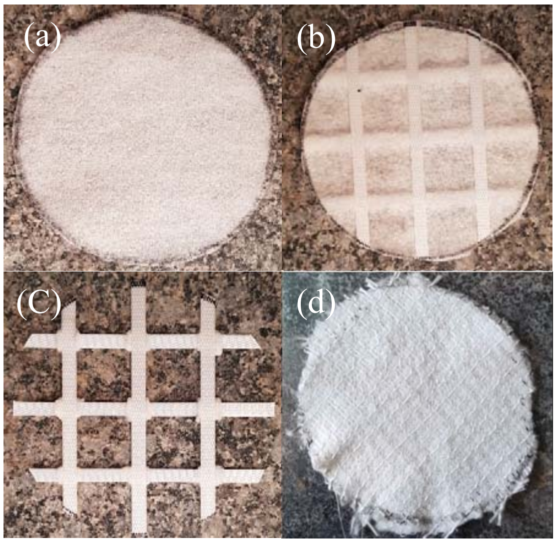

Fig. 8 Geosynthetics used in the experiments: (a) Geocomposite type A (b) Geocomposite type B (c) Geogrid (d) Geotextile

TABLE II
PROPERTIES OF DIFFERENT GEOSYNTHETICS USED AS REPORTED BY THE MANUFACTURER

Property	Gc-A[1]	Gc-B[2]	Geogrid	Geotextile
Aperture size (mm)	30*30	-	30*30	-
Tensile strength (kN/m) (MD)[3]	35.8	30	30	11.7
Tensile strength (kN/m) (CMD)[4]	41.5	30	30	14.9
Elongation at nominal strength (%) (MD)	5.8	12	8	51
Elongation at nominal strength (%) (CMD)	5.8	12	8	61
Mass per unit area (g/m^2)	367	438	203	164

[1] Geocomposite type A, [2] Geocomposite type B, [3]machine direction, [4]cross machine direction.

III. EXPERIMENTAL PROGRAM

A. Testing Procedure

The experimental study involved a series of standard CBR tests conducted in a metal cylindrical mold which was 15.2 cm in diameter, and 22.8c m in height as shown in Fig. 9. To

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prepare each section, a layer of subgrade by thickness of 10 cm was first implemented and compacted to a relative density of 50%. Having this step been taken, the reinforcement was placed at the top of the subgrade layer in the reinforced specimens. Then, a layer of 10cm-thick base course was applied at the density of 95% in four equal lifts of 2.5 cm at the moisture content of some 6%. A surcharge of 4.54 kg was applied by two annular metal weights on each specimen as recommended by ASTMD1883-16 [10] in order to produce the intensity of the pavement in field condition. Eventually, the studied sections were loaded by a penetration piston which was 5 cm in diameter (see Fig. 9 as a schematic demonstration). In this research, the load amount was recorded by a digital load cell the accuracy of which was 0.1 kg. Furthermore, the settlement of soil sections was recorded by an LVDT with the accuracy of 0.01 mm. Details of the testing apparatus could be seen in Fig. 10. During conducting each test, the rate of loading applied by this piston was 1.27 mm/min. The load amount in different penetration values of 0.5 mm, 1 mm, 1.5 mm, 2 mm, 2.5 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, and 10 mm was recorded in order to produce load-settlement graph for each specimen. The CBR values in all tests were calculated in both penetrations of 2.5 mm and 5 mm. Table III shows the details of the tests carried out.

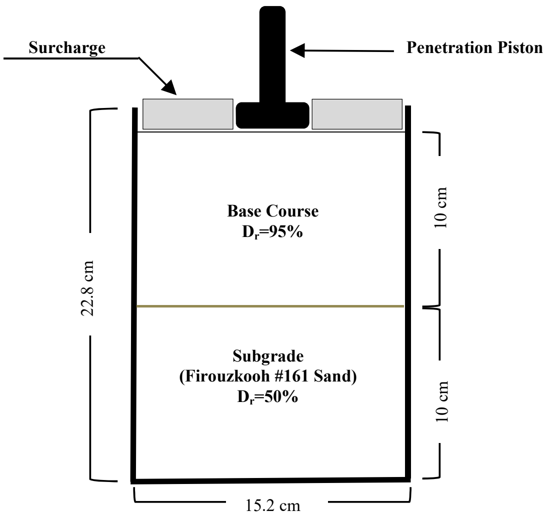

Fig. 9 Schematic representation of testing apparatus

TABLE III
DETAILS OF THE CONDUCTED TESTS

Test No.	Details of the test	Designation
1	Subgrade alone	S
2	Subgrade-aggregate system	SA
3	Subgrade-aggregate system reinforced with geocomposite Type A	SA-GcA
4	Subgrade-aggregate system reinforced with geocomposite Type B	SA-GcB
5	Subgrade-aggregate system reinforced with Geogrid	SA-G
6	Subgrade-aggregate system reinforced with Geotextile	SA-GT

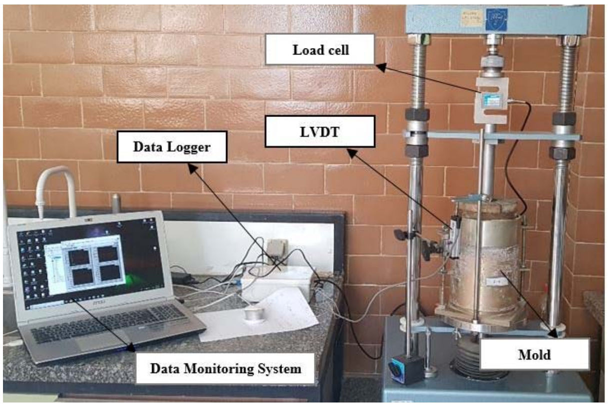

Fig. 10 Overview of the testing apparatus

IV. Results and Discussion

To determine the effect of geosynthetics type, five series of CBR tests carried out. The results of these tests would be elaborated as follows:

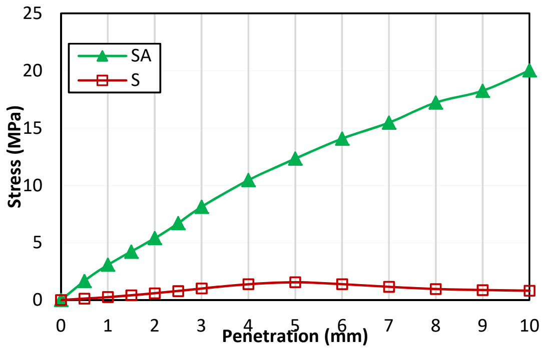

Fig. 11 Stress-settlement behavior of single layer and unreinforced soil sections

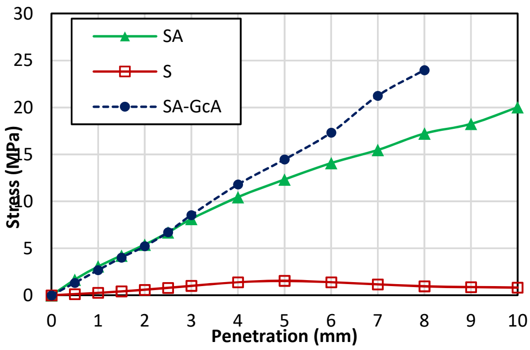

Fig. 12 Comparison of the stress-settlement behavior of geocomposite type A with unreinforced condition

The first series of the tests was conducted to evaluate the CBR value related to single-layer section (subgrade alone) and unreinforced soil-aggregate system, resulting in CBR amounts of somehow 15 and 121% in 5 mm penetration, respectively. Fig. 11 represents the stress-settlement behavior of these sections. The second series of the tests was applied in the presence of geocomposite type A (Gc-A) placed at the interface of the upper and the lower layer (see Fig. 12). In this set of the tests, an increment of 21% was witnessed in comparison to the unreinforced (SA) specimen. A glance at Fig. 12 reveals that the efficiency of Gc-A was more remarkable in the settlements greater than 3 mm. It can also be seen that the more settlement occurs, the more efficiency of this reinforcement is observed. It should be mentioned that loading application, in all tests, was extended to the maximum capacity of the testing apparatus, i.e. 20 MPa, for a better investigation of the reinforcements' efficiency at larger settlements. Considering as the third set of the experimental tests demonstrated in Fig. 13, geocomposite type B (Gc-B) did not have a considerable effect on the CBR of the soil-aggregate system in the penetration of 5 mm, although efficient in increasing this value at the settlements of 9 to 10 mm to some extent. The geogrid reinforcement functionality was studied as the fourth series of the tests, depicting 24.5% increase in CBR in comparison to the unreinforced soil-aggregate (SA) system. Fig. 14 shows the stress-settlement of this set of the experiments. The last series of the tests was conducted in the presence of geotextile. This kind of reinforcement was led to approximately 3% decrease in the CBR amount due to its merely separation function (see Fig. 15).

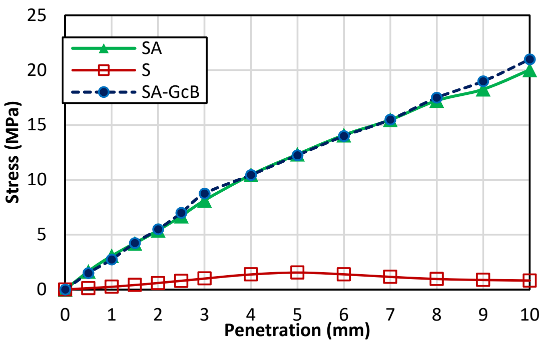

Fig. 13 Comparison of the stress-settlement behavior of geocomposite type B versus unreinforced and single-layer sections

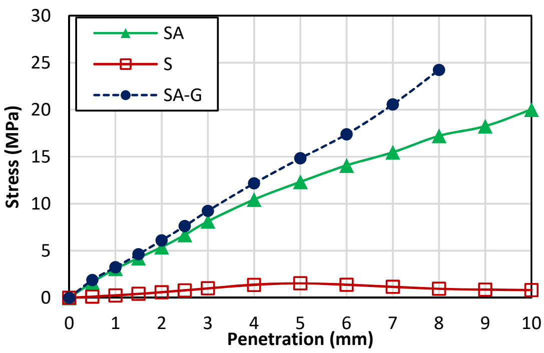

Fig. 14 Comparison of the stress-settlement behavior of geogrid versus unreinforced and single-layer sections

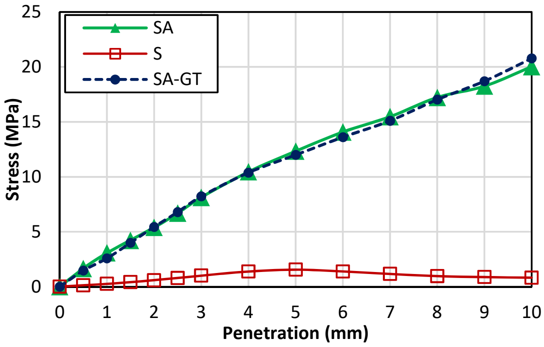

Fig. 15 Comparison of the stress-settlement behavior of geotextile versus unreinforced and single-layer sections

V. Conclusions

The results of the experimental tests to examine the improvement of CBR value and also the stress-settlement characteristics of sandy subgrade due to the application of four various types of geosynthetic reinforcements embedded between this layer and the base course material have been reported. Fig. 16 demonstrates an overall comparison among the obtained CBR values in this research. As can be seen from this figure, both geogrid and geocomposite type A are by far the most efficient reinforcements among the others. On the other hand, the effects of geocomposite type B and geotextile were negligible on CBR value. The point worth mentioning is that in all reinforced tests, the functionality of the utilized geosynthetics was more highlighted at greater settlements.

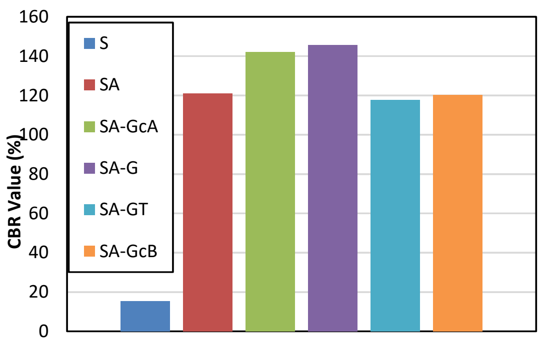

Fig. 16 Overview of the CBR values obtained from the tests

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