

Preloading Effect On The Strength of Cement Mass Mixing Treated Salty Sand

Rasoul Alipour (✉ civil.alipour@gmail.com)

Shahrekord University Faculty of Technology and Engineering <https://orcid.org/0000-0001-9425-1369>

Research Article

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Abstract

Existing problematic sub-layers in mixing technologies are a challenge, and for the first time, the effects of salt sub-layers in mass mixing technology have been investigated in this study for sandy salt in the southwest of Iran. This paper discusses the influence of adding various cement contents, A_w , and imposing different preloading values on the salty sand soil. First, salt and sand samples were dried, then, 90 % sand was mixed with 10% salt. After that, 30 % water was mixed thoroughly with the mixture of salty sand to obtain slurries. Cement slurry at a water-cement ratio (w/c) of 0.6 was then added to the sample and thoroughly mixed. The amount of cement in a slurry form that was added to the salty soil was 2, 4, 6, 8, and 10% by mass of dry soil. Each treated soil preloaded by 0, 9, and 45 kPa. After 120 days, the unconfined compressive strength of the sample was determined. Furthermore, by Scanning Electronic Microscope, SEM, the microstructures of treated samples were analyzed. At the end Unconfined Compression Strength, UCS, test results normalized to the non-preloaded treated soil. By increasing cement content, the effect of preloading in increasing UCS will decrease. In the SEM images for $A_w=2\%$, the effect of preloading indicates porous shape for non-preloaded samples. Vice versa by $A_w=8\%$, porous shape in the SEM images will disappear. In the end, treatability studies of pure salt in the thick layer have been investigated.

1. Introduction

Soil improvement techniques categorize due to their specific working principles, into replacement, densification, consolidation/dewatering, grouting, admixture stabilization, thermal stabilization, reinforcement, and various methods (M. Kitazume 2020, M. Kitazume, M.Terashi, 2013). The Deep Mixing Method (DMM) and mixing technologies are in situ soil treatment in which native soils or fills are blended with cementitious and/or other materials, typically referred to as binders. Compared to intrinsic soil or fills, the soil-binder composite material that is created has improved engineering properties such as increased strength, lower permeability, and reduced compressibility. The best-suited Soils to DMM include highly moisturized cohesive soils and loose, saturated, fine granular soil. This ground improvement method has also been used successfully in a wide range of less cohesive soils and fills, but it is typically not feasible in very dense materials or the ground with obstructions such as cobble or gravel (J. Chai, 2011, FHWA-HRT-13-046, 2013).

Two types of DMM: Dry Mixing and Wet Mixing are used (European Standard, EN 14679, 2005, Pakbaz MS and Alipour R, 2012). In situ soil mixing is used in diverse off-shore and onshore applications, mainly for soil stabilization and column-type reinforcement of soft soil, construction of excavation-support walls with inserted steel sections, gravity composite structures, mitigation of liquefaction potential, slope stabilization, environmental remediation, and in-place installation of cut-off barriers (Wang et al. 2019, S. Tokunaga et al. 2015, M. Topolnicki, 2014, Yamashita et al., 2011, R. Massarch, 2005, P. Raj. V. Siddharthan, 2004).

The mass mixing method is a technique to improve soft soil to the 8 m depth. Companies such as ALLU, Raito, Hayward baker Co., Bauer ... are among the most important companies for mass mixing soil improvement. In Iran, mass mixing methods have not been used (2020).

Both physicochemical and mechanical properties of improved ground are highly depend on the characteristics of the binders such as the ground to be treated, and mixing technologies, curing time, and loading condition (Terashi, 2015). Various studies depict that these parameters of DMM and mass mixing increase with increasing the cement content, mixing efficiency, curing time, curing temperature, and decreasing parameters such as water

content of the mixture, and the organic content of the intrinsic soil (G.M. Filz, 2015, Jacobson, 2005, Shiells, 2003, Bruce, 2000, Takenaka, 1995).

The reaction between soil and studied by various researchers. Van Lier et al. (1960) concluded that the solubility of silica is greatly increased in the presence of sodium chloride. The chloride ions react with the Ca_2^+ and Al_3^+ ions to form hydrocalumite $\text{Ca}_2\text{Al}(\text{OH})_6\text{Cl}(\text{H}_2\text{O})_2$. This mineral covers the surface of the clay, without enhancing the cohesion. Additionally, in cementitious materials, chloride ions react with C_3A to form Friedel's salt or calcium chloroaluminate and delay the development of the calcic compounds such as calcium aluminate hydrate CAH and calcium silicate hydrate CSH (Barberon et al., 2005; Lubelli et al., 2006; Saikia et al., 2006; Elakneswaran et al., 2009). Dingwen et al. (2013) found that sodium chloride salt in soil hurts the modulus of elasticity of cement-treated soil, and increasing salt concentration reduces the stiffness of cement-treated soil which is not good for engineering practices.

In this research for the first time laboratorial experiments for stabilizing soft soil in southwest of Iran for salt sub layers have been investigated. Major difference between mass mixing and DSM related to the surcharge load which applies to the treated soil (ALLU, 2015, Alipour et al., 2016, Herbst, 2008).

2. Research Objective

2.1. Effects of the Soil Mixing Installation Process, and Thickness of Salt Layer on Homogeneity

Homogeneity of the final soil mixture related to the thickness of the salt layer, H_s , and soil mixing execution method. Generally, dry and wet soil mixing, and mass mixing method used in soil mixing technologies. As depicted in Fig. 1b, in the mass mixing method if there is a salt sub-layer until the depth of 8 m, the salt sub layer will mix totally with above and lower soft soil. Due to the operation issues, using preloading embankment in the mass mixing method is essential.

On the other hand in deep soil mixing, due to the thickness of salt sub-layer, H_s , injection method (dry or wet), number of shafts, blade types, and installation process the homogeneity of mixing soft upper and lower soil with salt layer have been differentiated.

In the case of a very thick salt sub-layer the binder agent will mix only with salt and soft upper and bottom soil have not been mixed with salt layer (Fig. 2. a or c). In another word to attain a uniform mixture of soil-salt-binder in a very thick salt layer withdrawal by continuous upstroke by stepped or even full restroking is needed (Fig. 1 d, e).

In the thin salt layer, partial restroking (Fig. 1 b) has produced a more uniform mixture of soil-salt-binder.

The best installation method to attain optimum uniform soil-salt-binder is full depth restroking (Fig. 2 e) which produces more spoil (Topolnicki, 2004).

2.2. Experimental soil improvement base on mass mixing by preloading

In highly soft soil, mass mixing is a very well method for soil improvement, especially for road constructions. In Southwest of Iran, there are some problematic soils in which construction projects such as road and foundation

had encountered serious damages. Soil replacement for constructing these projects is very expensive, but the mass mixing method by improving existing soil is more cost-effective.

Currently, two primary mass stabilization methods can be chosen from, namely, stabilization in layers and stabilization by the blocks. The optimum method chosen depends on the soil type, and the application of the ground improvement project. With stabilization in layers, the soil is simultaneously mixed and moved towards the excavator as illustrated in Figure 1b. Once the mixture of soil-binder has been completed to the proper depth in front of the excavator, the excavator moves forward on top of the accomplished mass mix and the process is repeated. This method can only be used with soils that are strong enough to bear the weight of the excavator immediately after being mixed.

The general principle of the mass stabilization method is presented in Figure 1b. With the current equipment, the attachment of a mixing unit to an excavator allows for carrying out stabilization to the depth of 7-8 meters, providing the conditions are favorable (ALLU, 2015). A system of pressure feeder injects the binder(s) through the hose directly to the mixing drums of the mixing unit. The rotating drums mix the binder(s) into the ground, and consequently homogenize the soil. Mixing process is executed by moving the mixer unit vertically from the ground surface to the desired depth, as well as laterally.

Depending on the geometry of the site plan, the work area divides into blocks, or area, of equal size. Most of the time, work proceeds from block to block, with the size of a block between three to five meters square. A working platform is constructed after the completion of a block(s) to enable the excavator to move on to the site. The working platform also serves as a primary compaction embankment. After accomplishing the ground stabilization, an embankment as a preloading layer is also constructed. The allowable strength of the treated ground is usually attained over 1-3 months.

The main object of this research is experimental investigating feasibility use of treating loose sand with salt sub-layer in the southwest of Iran for road and foundation construction in mass mixing method with a preloading embankment. Due to loose soil, the mass mixing method is applicable just by block type. After conducting mass mixing, the salt layer will mix with loose sand, and uniform salty sand will produce. In loose sand stabilization with salt layer, block type of mass mixing with preloading embankment have been applied. Therefore, this embankment has the function of preloading for mass. In this research, the preloading value chose 9 kPa and 45 kPa which is equal to 0.5 m to 2.5 m embankment height with a specific gravity of 18 kN/m³. For applying surcharge load steel rods have been applied.

3. Experimental Studies

3.1. Geology and geomorphology

This area belongs to Zagros zone. There are some active faults such as Aghajari fault (in 70 km distance), Ahwaz fault (in 60 km distance), and white fault (in 80 km distance). This area is located in a low possibility zonation of occurring earthquake with 0.2 g, according to the Iranian earthquake code.

This area is located near the Persian Gulf and is categorizes as lowland regions. Also, this lowland area is filled with soil, and now it has an elevation in the range of 1.3-3.1 m. In addition, it has two major estuaries with the name of Zangi Estuary (800 m width) and Jafary Estuary (400 m width). The general profile of soil in this area

includes soft soil, sludge, and salt until 10 m depth, then medium-stiff soil to 20 m depth, and finally compacted sand.

NaCl Salt in this area exists in 2 forms. The first one is a mixture of salt and soil. The second one is a pure salt layer. The underground water table is in the range of 0.2 to 3.4 m in winter.

3.2. Field site investigation

For this study, 41 boreholes by drilling method and continuous coring with a depth of 11 to 25 m used for determining geotechnical site investigation in the Special Economic Petrochemical Zone, southwest of Iran. Boreholes describe as BH101 to BH141 are illustrated in Fig. 3.

3.2.1. Pressuremeter tests

This field test is very useful for determining the stress-strain behavior of soil. It is performed with a radial expandable probe inside the borehole. The type of pressuremeter used in this study is P.B.P. (Pre-Bored Pressuremeter) with the name of Ménard Pressuremeter. Table 1 illustrate the pressuremeter test results.

Table 1. Pressuremeter Results in Special Economic Petrochemical Zone, Iran

Borehole	Depth, m	Soil Type	α	E_m , kg/cm ²	E'_s , kg/cm ²	E_s , kg/cm ²	PL, kg/cm ²	E_m/P_L	G, kg/cm ²	Ks, kg/cm ³
BH-138	2-3.5	CL	0.67	66	98.5	61.4	1.25	5.26	2.34	3.84
	6-7.5	CL	0.67	63	94	58.6	1.27	4.97	2.25	3.69
	9-10.5	CL	0.67	60	89.6	55.8	1.14	5.21	2.13	3.48
BH-139	1-2.5	SM	0.34	66	194.1	121	1.47	4.5	2.45	3.87
	4-5.5	SM	0.34	71	208.8	130.1	1.48	4.87	2.62	4.14
	7-8.5	SM	0.34	54	158.8	99	1.73	3.11	1.96	3.14
	9-11	SM	0.34	60	176.5	110	1.7	3.54	2.23	3.52
BH-140	1-2.5	ML	0.5	94	188	117.1	2	4.71	3.36	5.51
	3.5-5	ML	0.5	74	148	92.2	1.7	4.38	2.56	4.34
	6.5-8	CL	0.67	64	95.5	59.5	1.72	3.7	2.26	3.71
	10-11.5	CL	0.67	82	122.4	76.3	1.74	4.71	2.93	4.8
BH-141	1-2.5	ML	0.5	82	164	102.2	1.67	4.9	2.92	4.87
	5-6.5	CL	0.67	75	111.9	69.7	1.67	4.51	2.69	4.4
	9.5-11	CL	0.67	66	98.5	61.4	1.73	3.81	2.35	3.85

3.2.2. Vane shear test

Vane shear test is an in situ tests for evaluating undrained shear strength. The Standard code of this test is ASTM D2573. This test has been used for site investigation in soft soils. The results of field vane shear tests are illustrated in Table 2.

Table 2. Vane shear test results

Borehole	Depth, m	Soil Type	S_u (Peak) (kg/cm ²)	S_u (Residual) (kg/cm ²)	Sensitivity	Remarks
BH-106	7	Silty Clay	0.11	0.08	1.37	Slightly sensitive
BH-110	9	Silty Clay	0.05	0.03	1.67	Slightly sensitive
BH-113	7	Sandy Silty Clay	0.11	0.05	2.20	Medium Sensitive
BH-113	11	Sand	0.27	0.17	1.59	Slightly sensitive
BH-114	11	Silty Clay	0.07	0.04	1.75	Slightly sensitive

3.2.3. Salt Sub Layers in PETZONE

From 41 boreholes, 6 number of them have salt sub layers. Table 3, depicted salt layers in various boreholes. The Standard Penetration value is between 4 to 10 until the depth of 11 m. Thickness of salt sub layers vary from 0.2 to 2.8 m.

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Table 3. Salt layers in various boreholes

Row	Borehole	Depth, m	Thickness, m	G.W.L.	Soil description	S.P.T.
1	BH 101	2.3-2.5	0.2	0.4	Salt with peat, wet, white	5
2	BH 102	2.1-2.5	0.4	0.9	Salt with peat, very hard, wet, white	61
3	BH 102	2.5-3	0.5	0.9	Salt with peat, wet, white	4
4	BH 105	2.7-3	0.3	1.5	Salt with ooze & peat, soft, wet, white	3
5	BH 110	2.7-4.3	1.6	0.8	Salt with ooze & peat, soft, wet, light gray	3
6	BH 110	4.3-5.0	0.7	0.8	Silty clay with salt, wet, light gray	2
7	BH 116	5.0-7.2	2.2	1.8	Silty clayey sand with ooze & salt, loose, wet, dark, gray	9
8	BH 122	5.3-5.6	0.3	1.5	Salt, very hard, wet, white	28
9	BH 122	11.0-12.2	1.2	1.5	Salt with ooze, firm, wet, gray	12
10	BH 122	12.2-15.0	2.8	1.5	Silty clay with salt and ooze, wet, dark gray	30
11	BH 122	15.0-17.0	2.0	1.5	Silty clay with salt and ooze, hard, wet, dark gray	32

3.3. Sand and Salt Properties for Experimental Tests

For conducting laboratory tests, sand materials were obtained from PETZONE, Mahshahr in the Southwest of Iran. Unit Weight of this soil is 26.29 kN/m³, and it categorizes as SM due to the Unified system of soil categorization. For soil stabilization and modeling liquefiable sand, water content is considered as 30 %. Figure 4 illustrates the salt layer in the depth 4-5 m below the ground. Also, figure 5 depict sieve analysis of sand material. In the mass mixing method this salty layer will mix with above, and below the soil and a combination of treated salty soil with cement will produce.

There are Interlayers of salt beneath the ground in the southwest of Iran. Shallow salt layers are not compact, but deeper salt converts to salt rock with a density in the range of 20-25 kN/m³ and compression strength of more than 15kPa. In this research for investigating the effects of salt on soil, treatability studies performed. As illustrated in the Scanning Electron Microscope images, Fig. 6, shallow salts are completely in the crystal form, which are soft soils, but deeper denser salts have less crystal shape.

In soil stabilization of various soil types in the southwest of Iran, type two Portland cement has been used. General properties of this type of Portland cement with a specific gravity of 31.5 kN/m³ are presented in Table 4.

Table 4. General properties of Portland cement used in this study

Oxides	Content, %
CaO	60-70
SiO ₂	17-25
Al ₂ O ₃	3-8
Fe ₂ O ₃	0.5-0.6
MgO	0.5-4
SO ₃	2-3.5
Na ₂ O	0.5-3

3.4. Sample Preparation

The sand and salt were collected from a site in PETZONE, Mahshahr petrochemical zone in the Southwest of Iran. The procedure of sample preparation was similar to that is described by Chew et al. (2004). First, salt, and sand samples were dried at 105 °C for 24 h. Then, 90 % of sand was mixed with 10% salt. After that, 30 % water was mixed thoroughly with the mixture of salty sand to obtain slurries. The higher water content samples were chosen to simulate the water content increase taking place in a mass mixing process in the field. Cement slurry at a water-cement ratio (w/c) of 0.6 was then added to the sample and thoroughly mixed. The amount of cement in a slurry form that was added to salty soil was 2, 4, 6, 8, and 10% by mass of dry soil. The mixture was then placed in 5 layers into PVC molds 35 mm in diameter and 70 mm in height for the unconfined compression test. To remove entrapped air bubbles, the placement of the samples into the molds was accompanied by a tapping action around the molds. Each treated salty sand preloaded by 0, 9, and 45 kPa. Steel rods were used for imposing preload to the salty sand. Curing periods of 120 days were chosen to determine the long-term effect. Unconfined compression tests were performed on the samples at an axial deformation rate of 1 mm/min. Figure 7, illustrates apparatuses used for preloading salty sand.

4. Results And Discussions

4.1. The Effect of Preloading on Salty Sand

Three types of salty sand with preloading values equal to 0, 9, and 45 kPa prepared for conducting UCS tests. As an interesting depiction in Fig. 8, at the top of the treated salty sand without preloading, salt crystals were composed. This phenomenon according to the capillary migration of water and salt (Jia et. al., 2020). When the preloading value is equal to zero, salty water comes up to the surface of the treated salty sand and bypassing time these salt crystals compose. On the other hand, by 9 and 45 kPa preloading value, these salt crystals were eliminated.

The crystal form of salt in Fig. 8 occurs on the surface of the ground, and it decreases the durability of the concrete foundation in real projects. This a good practical result that with a small amount of preloading in the real soil mixing project, the durability of the concrete foundation has been increased in salty soil.

Figures 9, 10, 11, 12, and 13 illustrate the UCS results of treated salty sand with 2, 4, 6, 8, and 10 % of cement content, respectively. Even at the lowest cement content of 2%, the increase in the strength and the stiffness is

evident (Fig. 9).

Table 5. The Unconfined Compressive Strength of Mass Mixing Samples

Row	Sample No	A_w , %	W, %	Curing, d	Preloading, kPa	UCS, kPa
1	100	2	30	120	45	498.53
2	101	2	30	120	9	483.87
3	102	2	30	120	0	234.6
4	103	4	30	120	45	845.15
5	104	4	30	120	9	834.43
6	105	4	30	120	0	757.88
7	106	6	30	120	45	1645.05
8	107	6	30	120	9	1212.14
9	108	6	30	120	0	836.95
10	109	8	30	120	45	1788.09
11	110	8	30	120	9	1713.59
12	111	8	30	120	0	1594.38
13	112	10	30	120	45	2174.8
14	113	10	30	120	9	1959.2
15	114	10	30	120	0	1602.98
16	Pure salt	20	20	120	0	1510.01

As depicted in Table 5, by increasing the preloading value, UCS results will increase. Furthermore, the UCS results with preloading are 483.87 to 2174.8 kPa by cement content is in the range of 2-10%. By normalizing UCS values for all samples to the UCS value of zero preloading ones, Fig. 14 will derive. This figure illustrates that by increasing A_w , the effect of preloading in increasing UCS will decrease.

In the SEM images for $A_w=2\%$, Fig.15-c, the effect of preloading indicates the existence of porous shape in the morphology of non-preloaded treated salty sand. The difference between Fig. 15-a-b and Fig. 15-c in producing more porosity by eliminating the preloading factor on the treated salty sand in the mass mixing method is obvious.

On the other hand, treated soil by $A_w=8\%$, Fig. 16, porous shape in the SEM images were disappeared. Also, by increasing cement content, the effect of preloading on increasing UCS will decrease.

4.2. The Effect of Cement on Pure Salt

When the thickness of the salt sub-layer is high, then the mixture is just salt-binder. Therefore, a higher amount of cement as a binder should be used. A mixture of salt with $A_w=20\%$ and 10 % water content makes a material with

higher mechanical properties. UCS test results depicted that by increasing curing time from 7

to 120 days the UCS will increase. It is interesting that using the high amount of Portland cement, $A_w=20\%$, causes to have salt-cement material which has UCS higher than 1500 kPa after 120 days. Therefore the big challenges for the treatability potential of pure salt and cement are positive. Figure 17 illustrates the UCS results of pure salt with Portland cement.

Interestingly, in the SEM images of salt mixture with cement after 28 curing days, salt crystal has been disappeared (Fig. 18).

5. Conclusions

This paper discusses the influence of adding various cement contents, A_w , and imposing different preloading values on salty sand soil in the mass mixing stabilization method. Salty sand prepared from Mahshahr petrochemical zone, Southwest of Iran. In the mass, mixing tests salty sand soil with 30 % water content in liquefiable potential condition has stabilized by 2, 4, 6, 8, and 10 % cement content. Each treated soil preloaded by 0, 9, and 45 kPa. After 120 days the unconfined compressive strength of the sample was determined. Furthermore, by the Scanning Electronic Microscope technique, the microstructures of treated samples were analyzed. At the end Unconfined Compression Strength, UCS, test results normalized to the non-preloaded treated soil. Due to the experimental investigations, the following conclusions were derived:

- By increasing preloading value and cement content, the unconfined compressive strength of treated salty soil in the southwest of Iran was increased.
- Salt crystals produce and cover the top surface of treated salty sand samples which are not preloaded. The reason for this phenomenon is the capillary effect of treated soil and accumulating salty water on the top surface of the treated soil sample. This phenomenon may produce a more severe corrosive environment for deep soil mixing columns that are connected to the concrete foundations.
- In loose ground for conducting mass mixing method, preloading is essential for preparing a suitable platform for construction equipment. Due to the surcharge load, and by preloading treated salty sand, salt crystals on top of soil samples were eliminated. It is the benefit of the mass mixing method on deep soil mixing columns in the soft ground with salt layers.
- SEM images revealed that in treated salty sand by 2% cement content, and without preloading, the morphology of treated soil has more porosity. On the other hand, by increasing cement content this porous shape has been disappeared.
- The big challenges for the treatability potential of pure salt and cement in the ground improvement methods for PETZONE are positive. Therefore mixing technologies such as deep soil mixing (dry or wet method) and mass mixing have good reliabilities even in the thick layers of salt sub-layers.

Declarations

Data Availability Statement

Some or all data including experimental results used during the study are available from the corresponding author by request.

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Figures

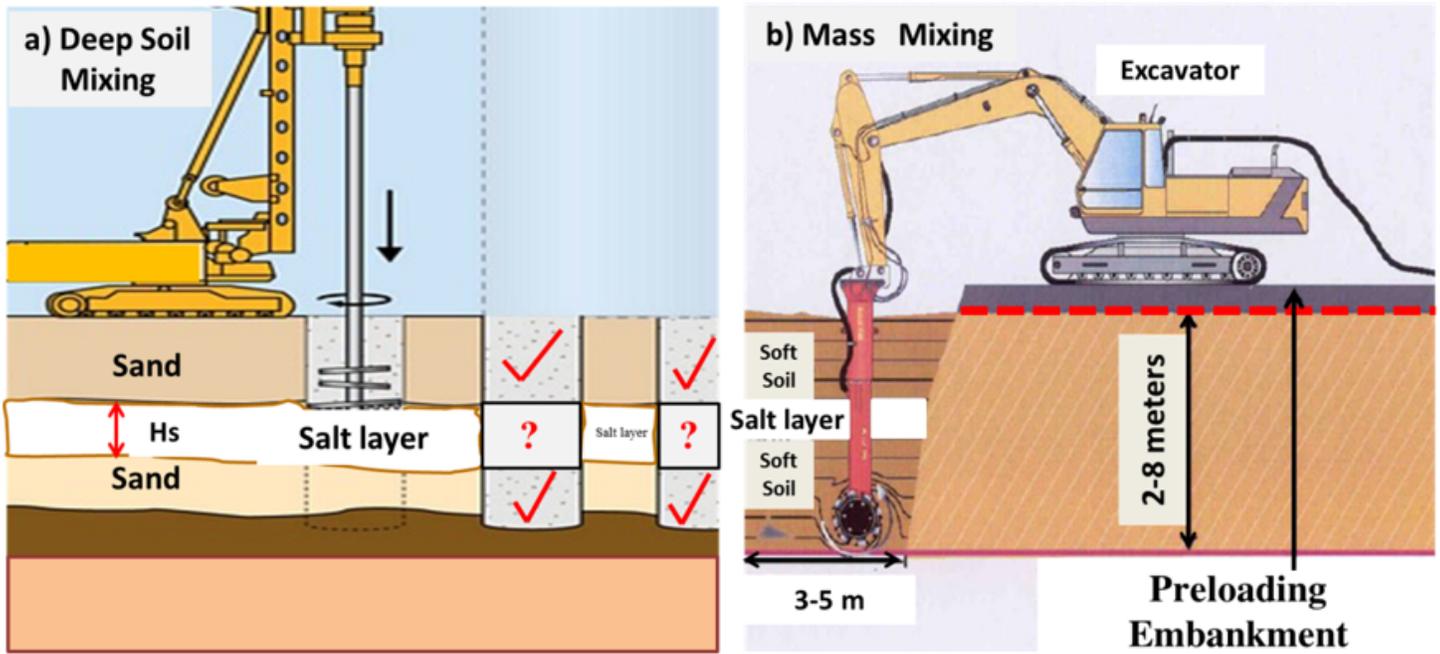


Figure 1

Principle of the soil mixing stabilization methods in salty soils: a) Deep Soil Mixing method (dry or wet method) without preloading; b) Mass Mixing in block stabilization with a preloading embankment

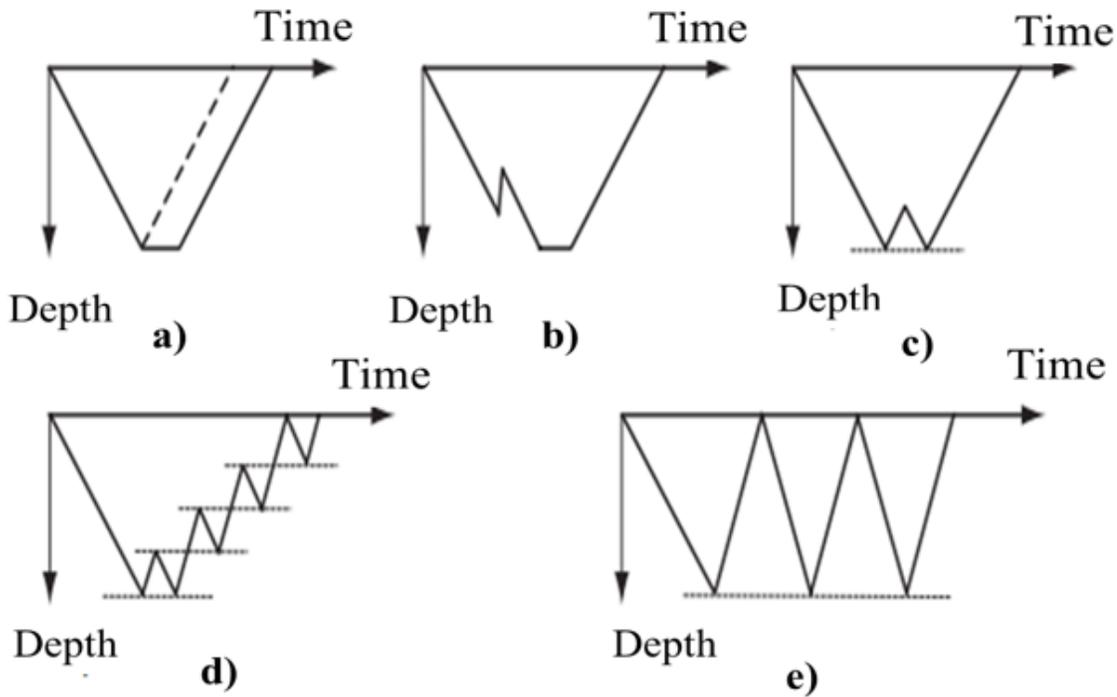


Figure 2

Execution of deep soil mixing: a) without or with bottoming; b) with reversal; c) with bottom restroking; d) with stepped restroking during withdrawal; e) with full depth restroking (Topolnicki, 2004)



Figure 3

Plan of boreholes in the Special Economic Petrochemical Zone, southwest of Iran, near Persian Gulf

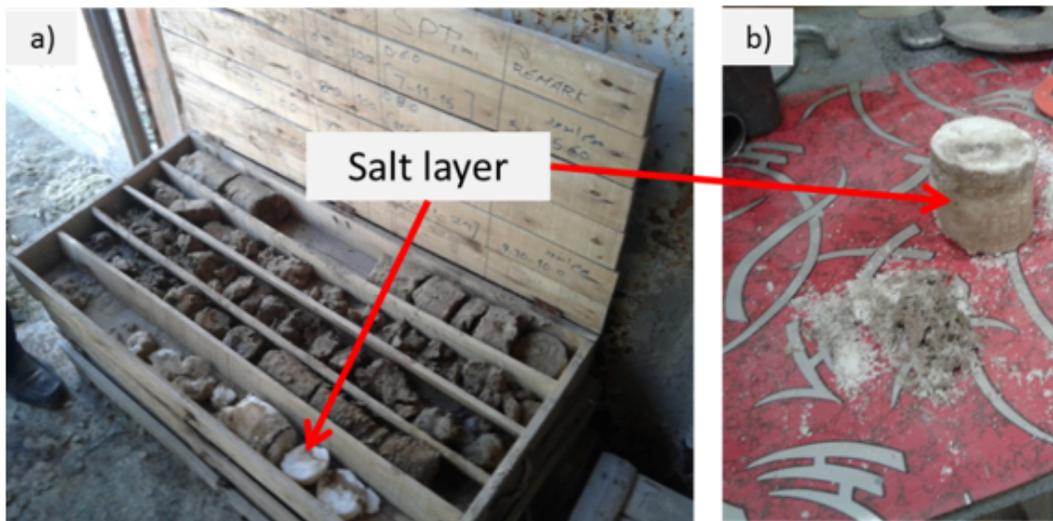
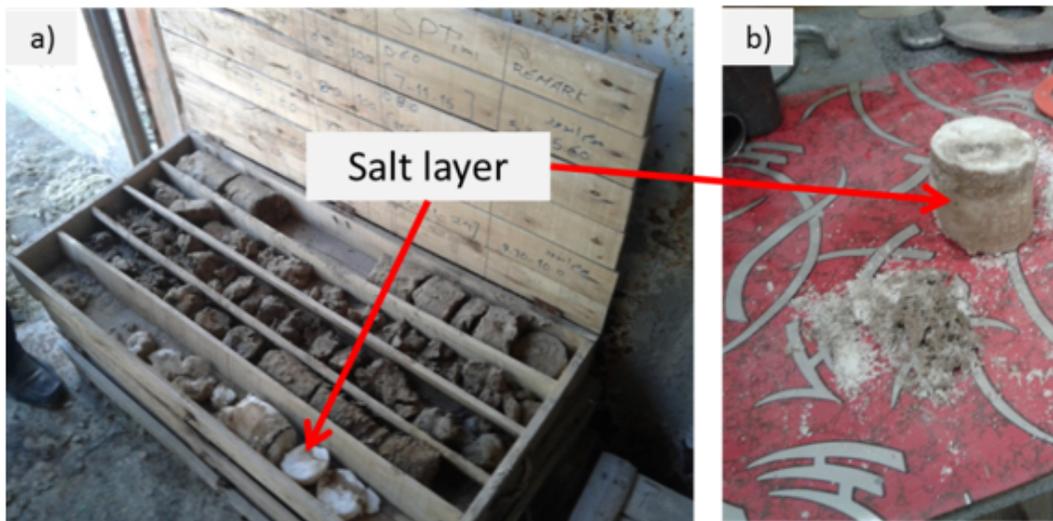


Figure 4

Salt layer at the 4.5-5 m depth beneath the ground, Mahshahr, Iran



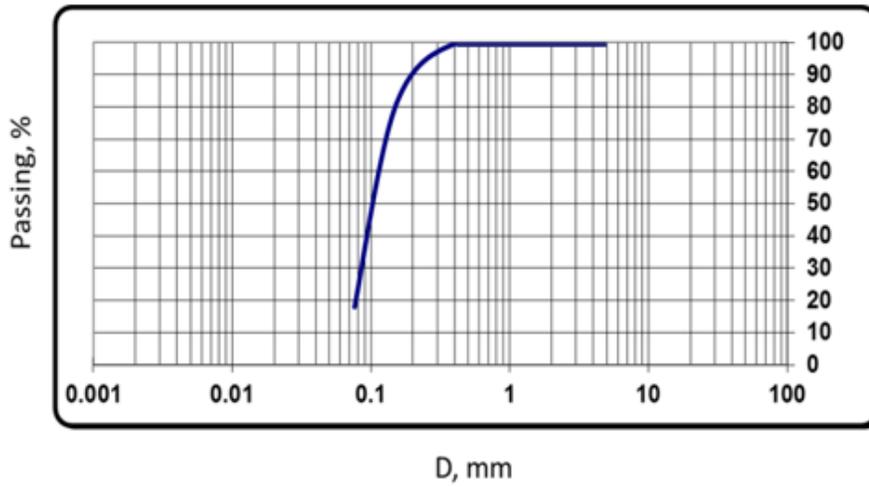


Figure 5

Sieve analyses of sand

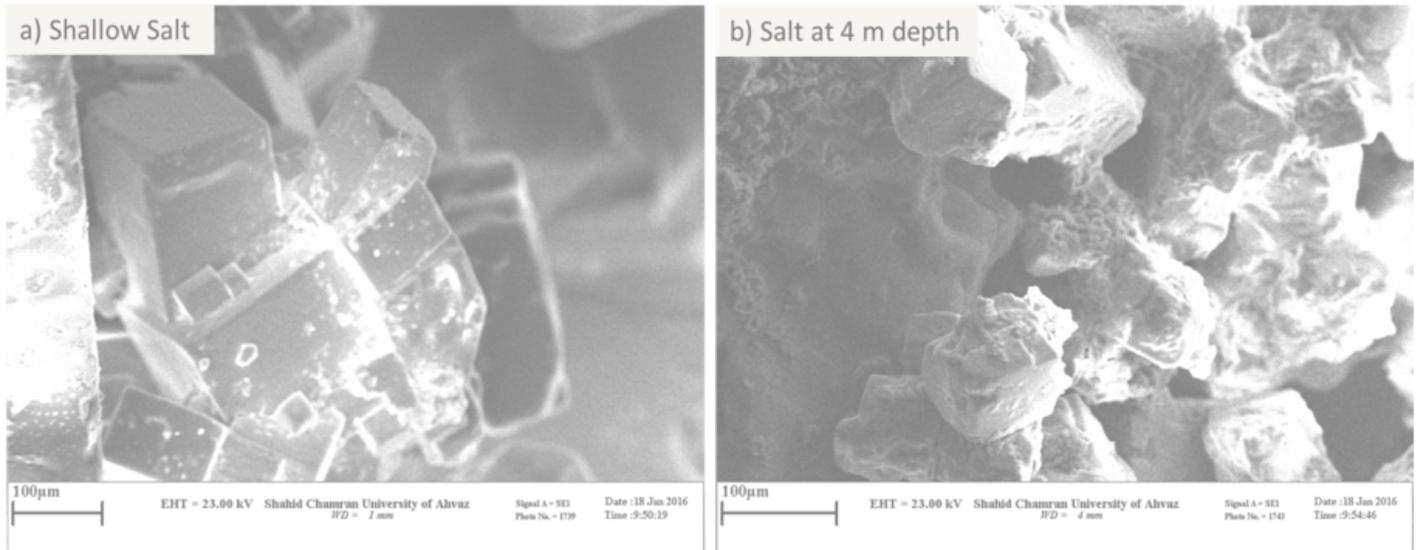


Figure 6

The SEM images of Salt sublayer: a) Shallow soft salt in crystal form, b) Dense Salt at the depth of 4 m

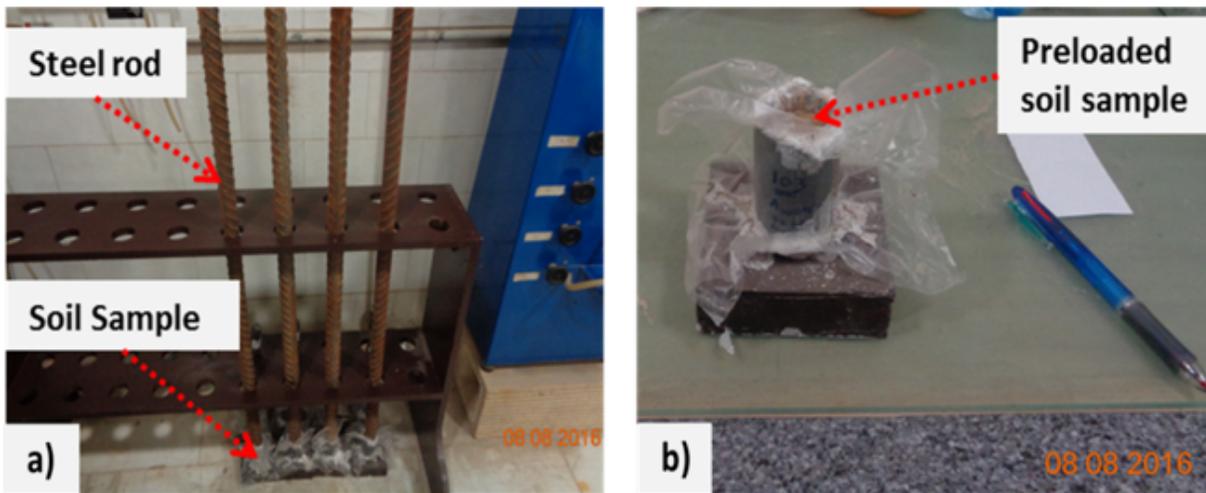


Figure 7

Laboratorial tests for mass mixing: a) Preloading salty sand with steel rods, and b) Preloaded sample after 120 day

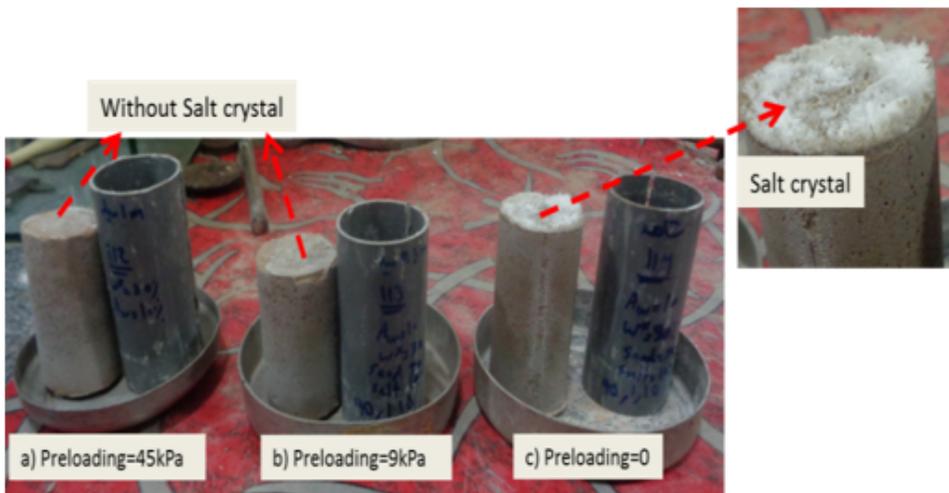


Figure 8

Treated salty sand samples before unconfined compressive strength test, Sand=90%, Salt=10%, $A_w=10\%$, $W=30\%$, 120d; a) Preloading=45kPa, b) Preloading=9kPa, c) Without preloading

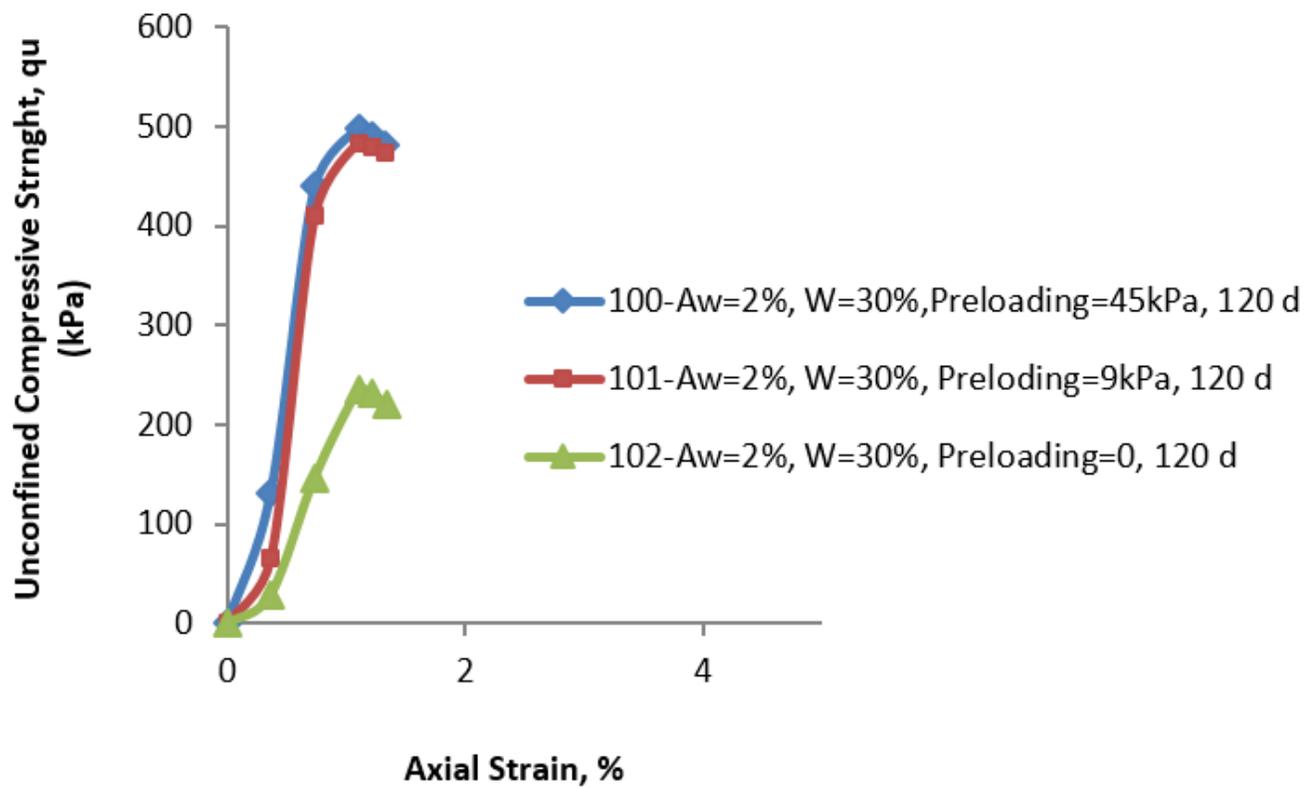


Figure 9

The stress–strain relationship for treated soils at different preloading values by 2% cement contents after 120 d of curing

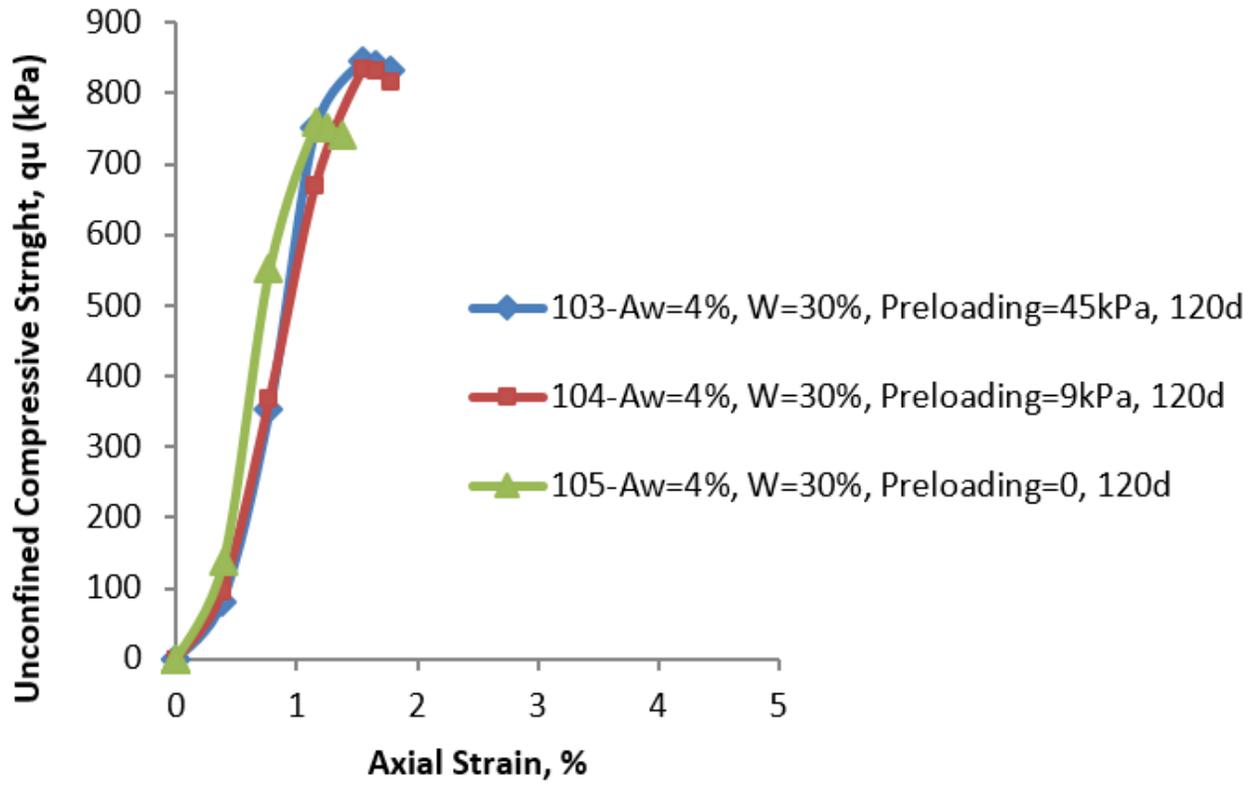


Figure 10

The stress–strain relationship for treated soils at different preloading values by 4% cement contents after 120 d of curing

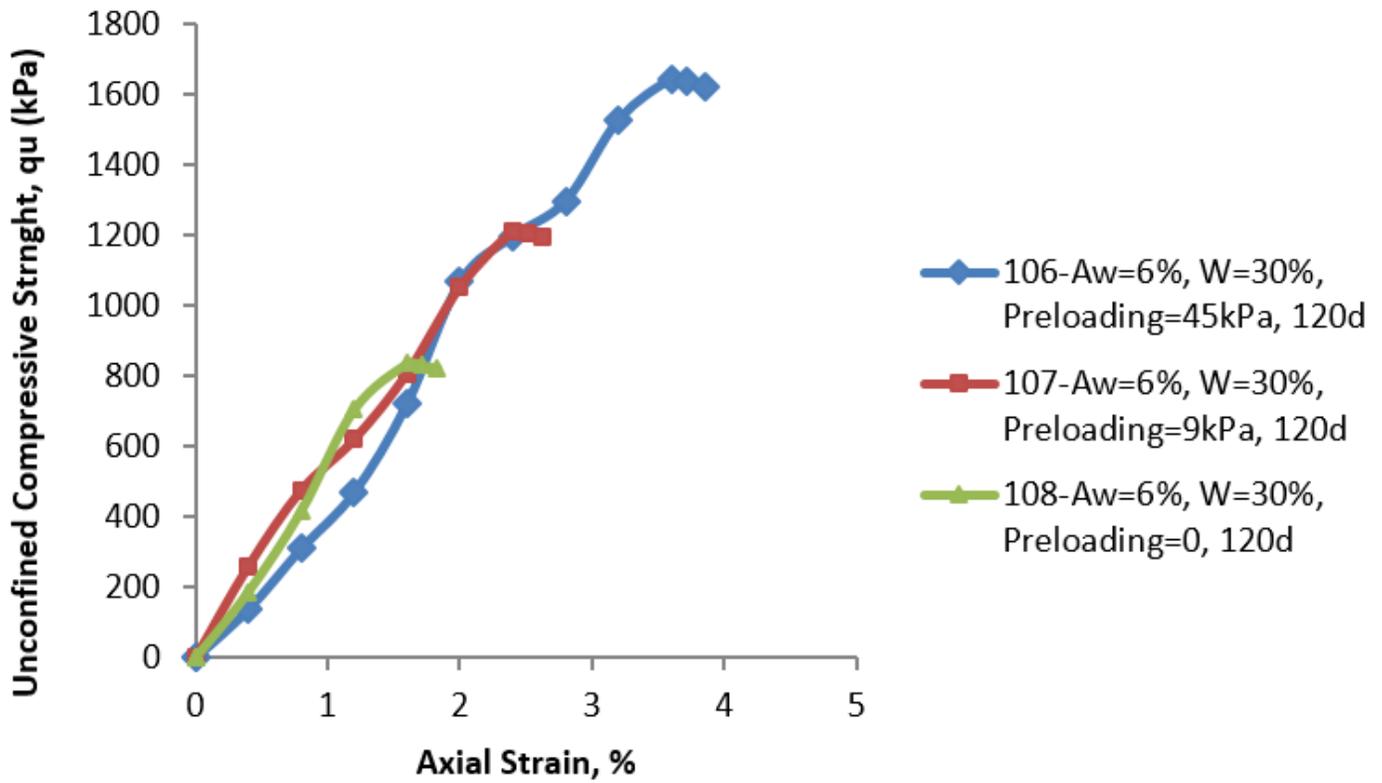


Figure 11

The stress-strain relationship for treated soils at different preloading values by 6% cement contents after 120 d of curing

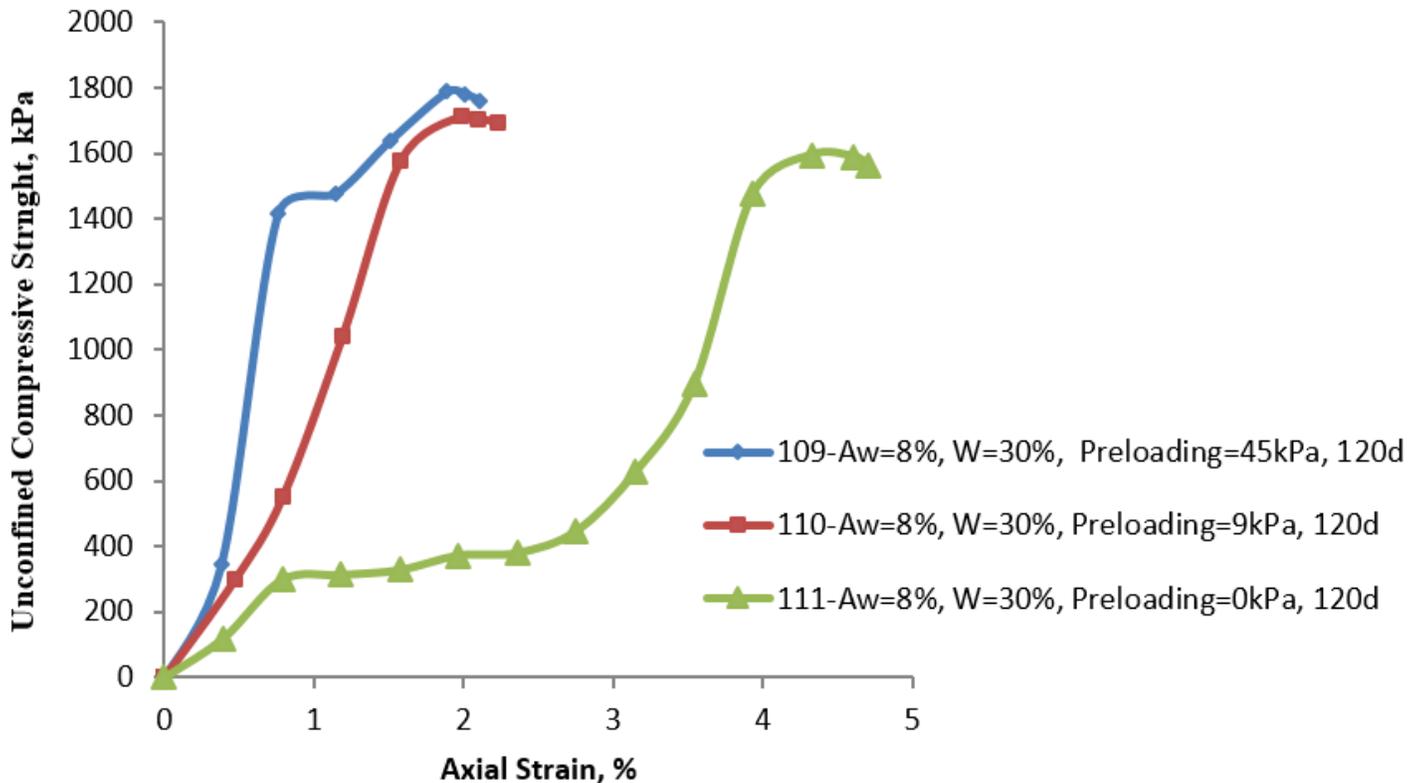


Figure 12

The stress–strain relationship for treated soils at different preloading values by 8% cement contents after 120 d of curing

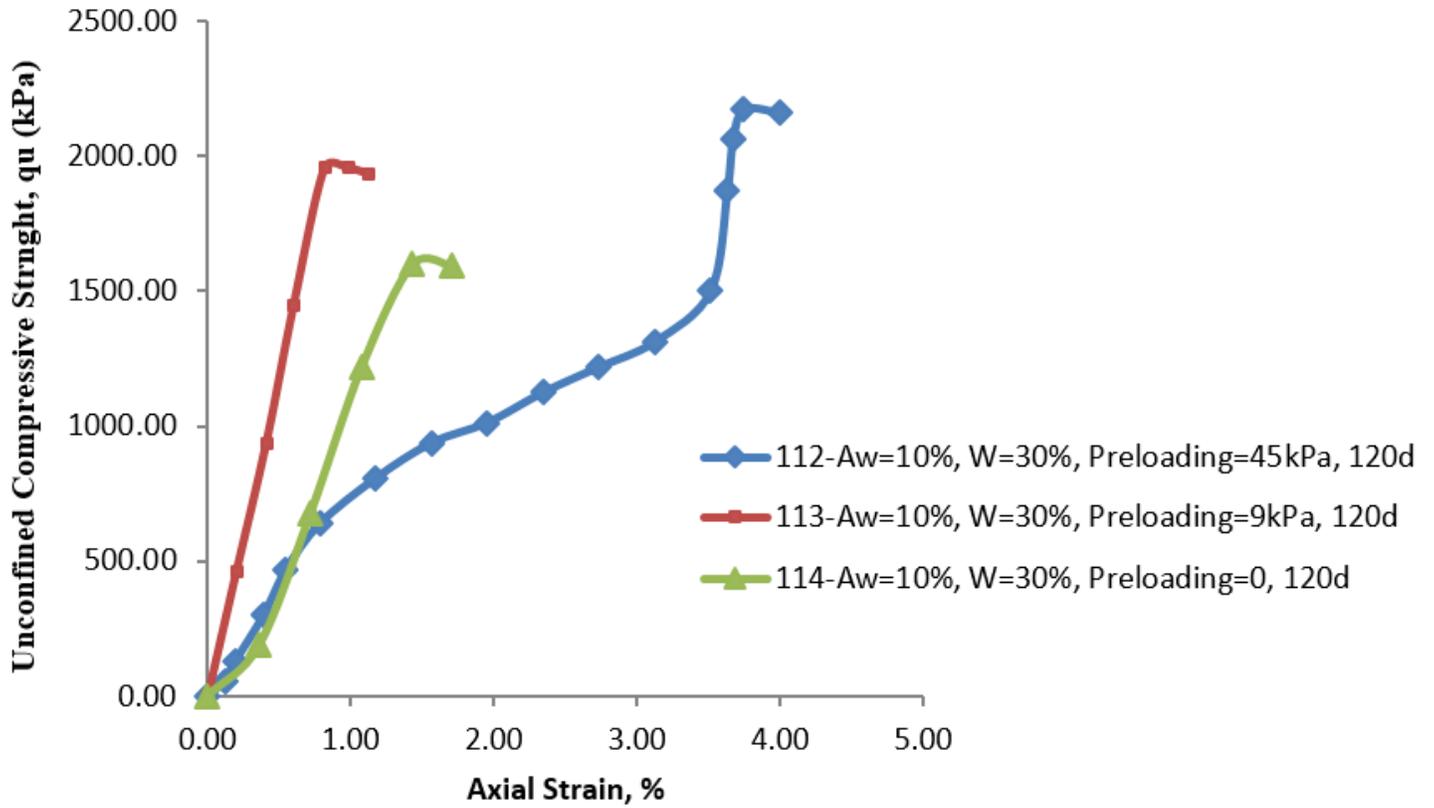


Figure 13

The stress–strain relationship for treated soils at different preloading values by 10% cement contents after 120 d of curing

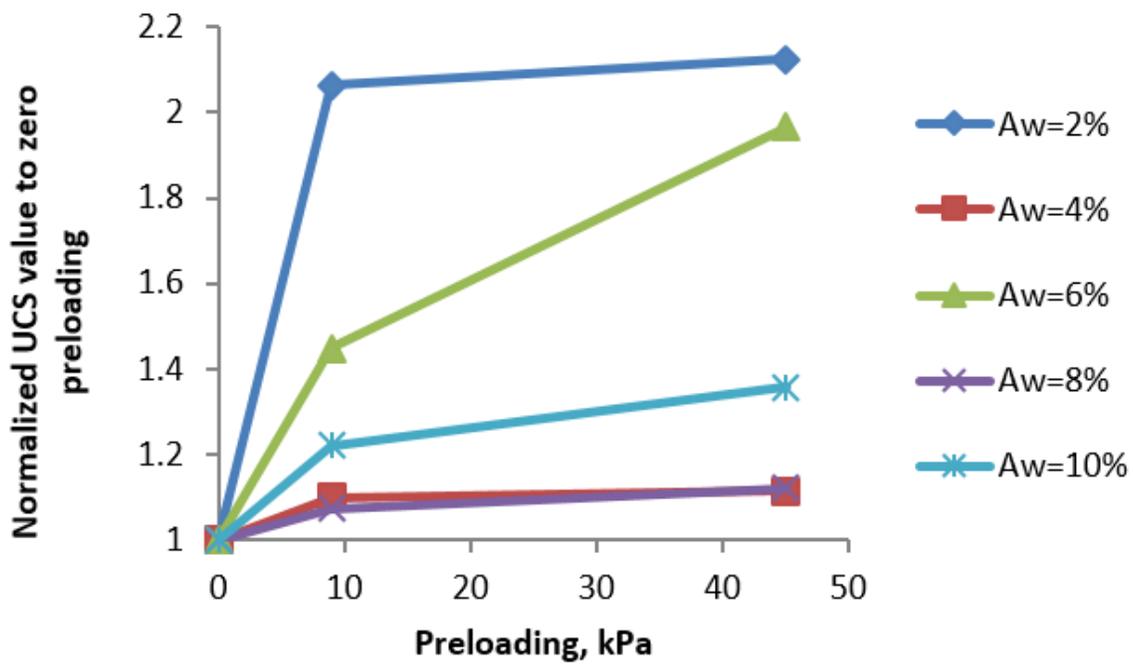


Figure 14

Normalized value of UCS for all samples to UCS of zero preloading one, Sand=90%, Salt=10%, W=30%, 120d

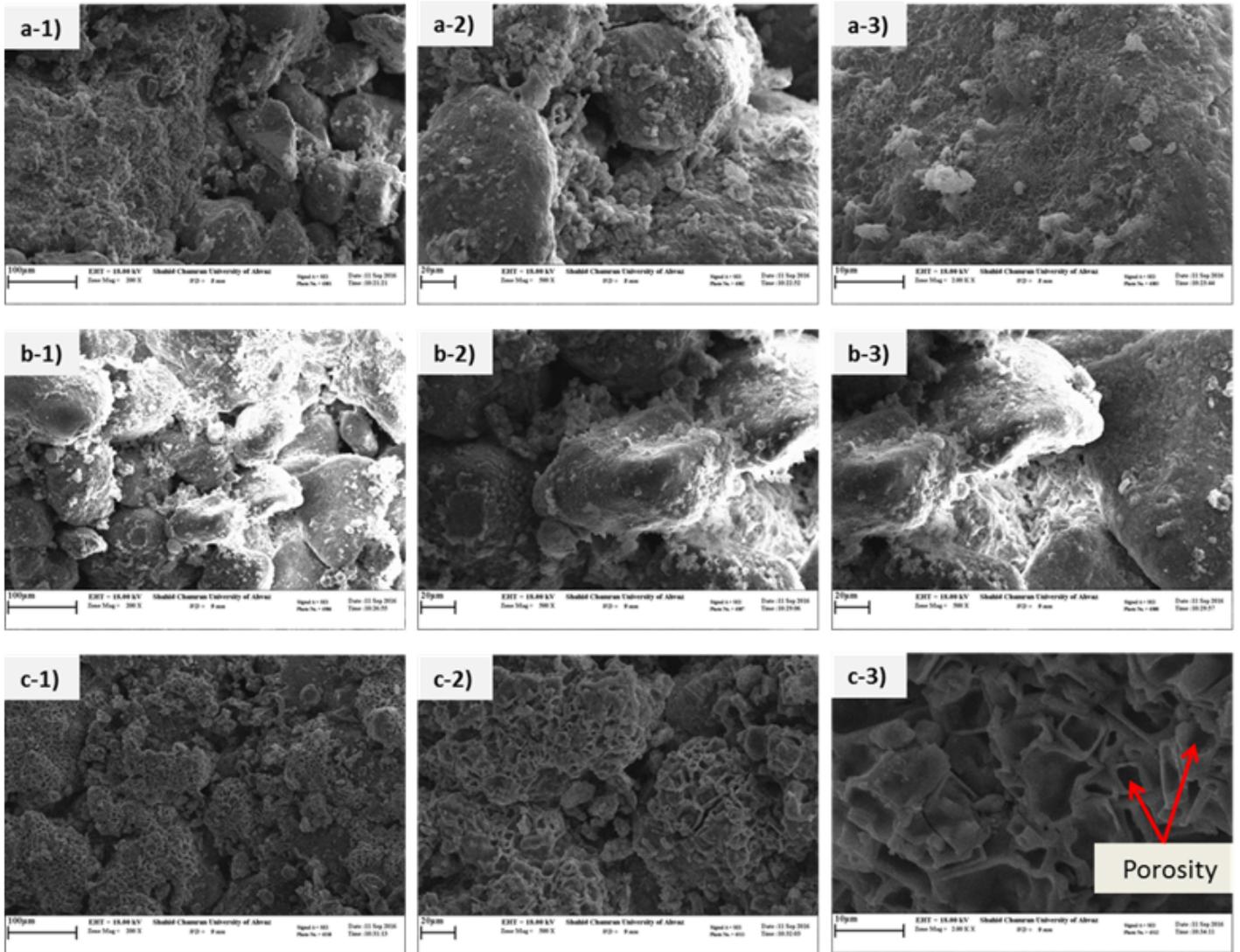


Figure 15

SEM images of soil cement samples in mass mixing, Sand=90%, Salt=10%, $A_w=2\%$, $W=30\%$, 120d; a) Preloading=45kPa, b) Preloading=9kPa, c) Without preloading

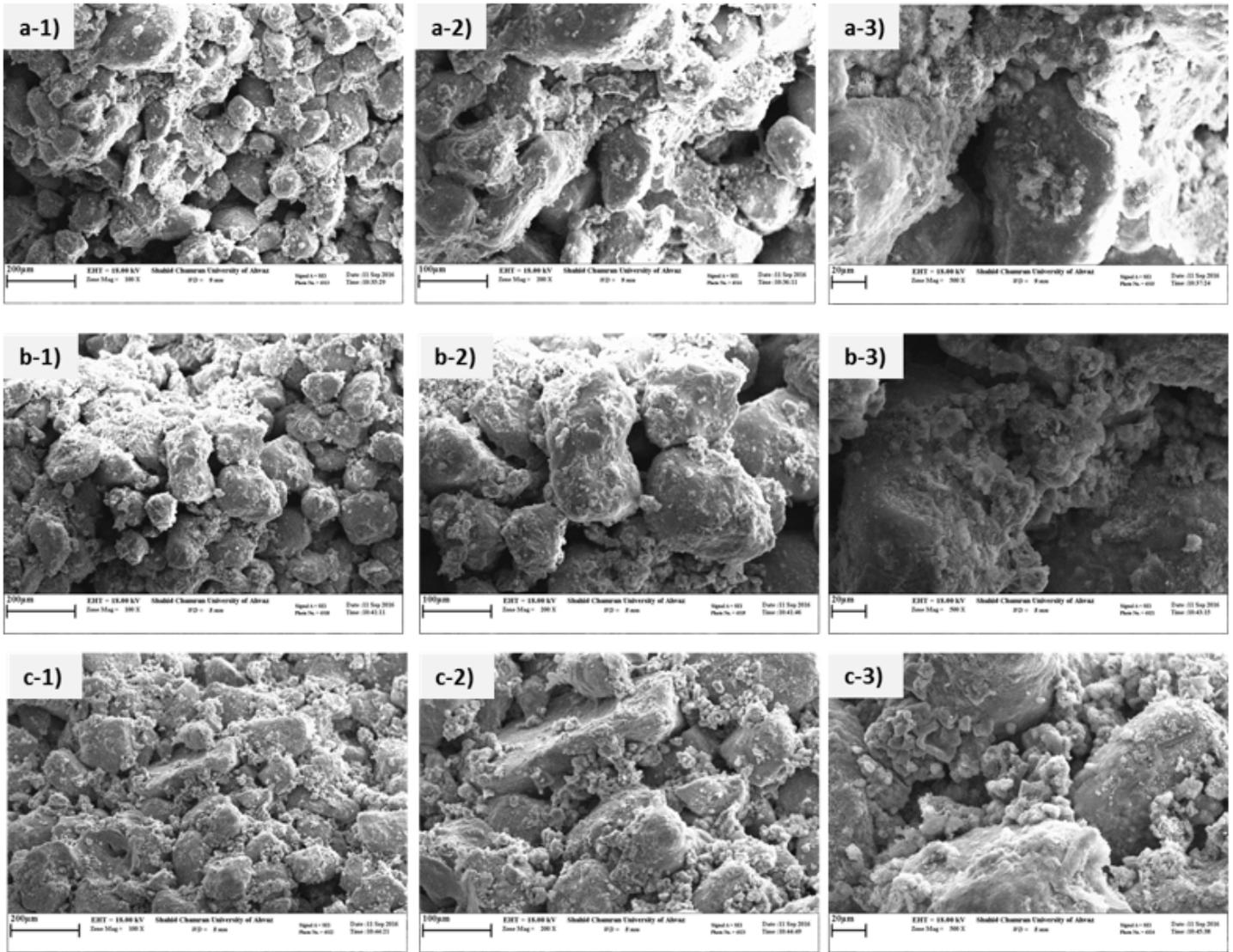


Figure 16

SEM images of soil cement samples in mass mixing, Sand=90%, Salt=10%, $A_w=8\%$, $W=30\%$, 120d; a) Preloading=45kPa, b) Preloading=9kPa, c) Without preloading

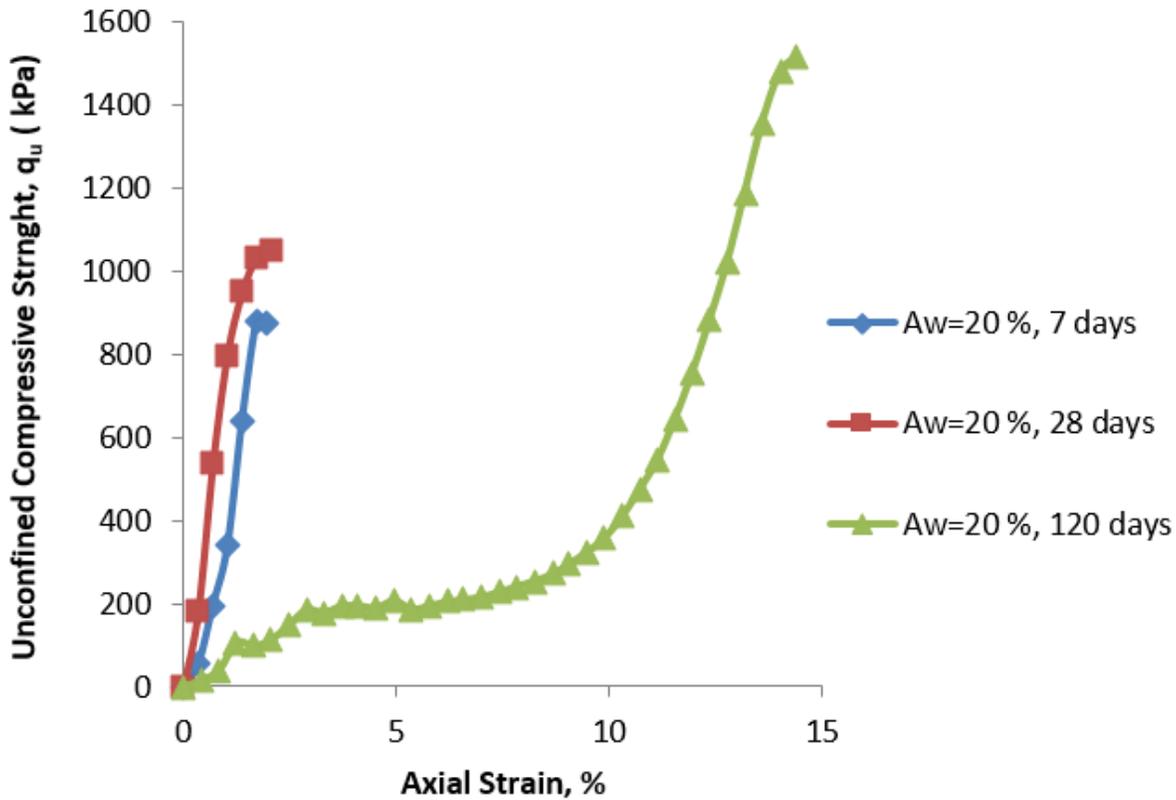


Figure 17

The Unconfined Compression Strength; Salt=100 %, Aw=20 %, W=10 %, w/c=0.6

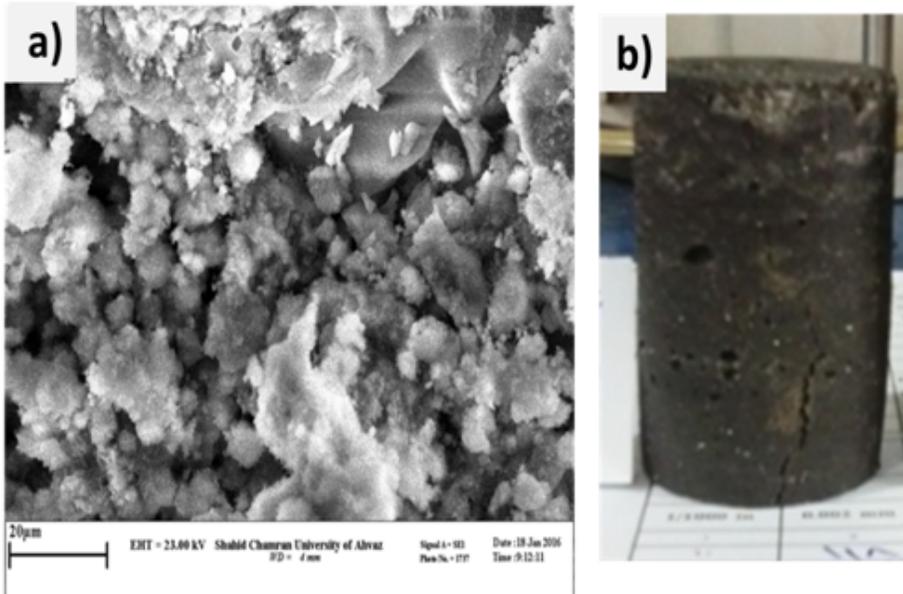


Figure 18

Pure salt-cement mixture; Salt=100 %, Aw=20 %, W=10 %, w/c=0.6, 28 days curing : a) The SEM images; b) UCS sample of treated salt with cement