# Impact of Composite Materials on Soil Durability

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***Abstract***—A number of studies have been conducted recently to investigate the influence of randomly oriented fibers on some engineering properties of cohesive and cohesionless soils. However, few studies have been carried out on freezing-thawing behavior of fine-grained soils modified with discrete fiber inclusions and additive materials. This experimental study was performed to investigate the effect of randomly distributed polypropylene fibers (PP) and some additive materials [e.g.., borogypsum (BG), fly ash (FA) and cement (C)] on freezing-thawing durability (mass losses) of a fine-grained soil for 6, 12, and 18 cycles. The Taguchi method was applied to the experiments and a standard L9 orthogonal array (OA) with four factors and three levels were chosen. A series of freezing-thawing tests were conducted on each specimen. 0-20% BG, 0-20% FA, 00.25% PP and 0-3% of C by total dry weight of mixture were used in the preparation of specimens. Experimental results showed that the most effective materials for the freezing-thawing durability (mass losses) of the samples were borogypsum and fly ash. The values of mass losses for 6, 12 and 18 cycles in optimum conditions were 16.1%, 5.1% and 3.6%, respectively.

***Keywords***—Additive materials, Freezing-thawing, Optimization, Reinforced soil.

## I. INTRODUCTION

THE cold regions are typically subdivided on the basis of whether the ground is only seasonally frozen, whether permafrost occurs everywhere (continuous), or whether permafrost occurs only in some areas (discontinuous) beneath the exposed land surface [1]. In seasonally frozen areas, soils are exposed to at least one freezing–thawing cycle every year. This has a significant effect on many engineering applications such as road, railroad, pipeline, and building constructions. Most of the engineering properties of soils are severely affected by freezing–thawing period. In the freezing period, ices in various sizes and shapes tend to segregate in soils resulting in the formation of characteristic structures in micro and macro scales [14]. The frozen layer begins to thaw from the top and the bottom at the same time during the thawing period. The effect of freezing–thawing on fine-grained soils can be more pronounced than that of the coarse-grained soils. Improvement of certain desired properties, like bearing capacity and shear strength of soil, can be undertaken by a variety of ground improvement techniques such as the use of randomly oriented fibers [2], [3], [7]-[9], [13], [15], [16], [20], [21], [24], [27]-[29], [31] or additive materials [6], [10]-[12], [26], [30].

Waste materials (e.g. fly ash, silica fume) can improve some engineering properties of the soil (e.g. bearing capacity, shear strength) but they are not enough to reach the desired level of some other characteristics of the soil (e.g. settlement, permeability) [18]. On the other hand, polypropylene fibers generally increase the shear strength but can also affect hydraulic conductivity negatively in impermeable liner systems. It is known that, some non-synthetic waste materials (e.g. borogypsym) can exhibit some raw material features in different industries. For this reason, the use of waste materials is important both for the environmental reasons and as they involve some raw materials.

This study aims at analyzing, the use of natural and synthetic waste materials for soil improvement, and establishing the optimum amount of additives needed to achieve the required soil properties. In this respect, the Taguchi method is used to determine optimum levels of each material in the study.

This experimental study was performed to investigate the effect of randomly distributed polypropylene fibers and additive materials (borogypsum (BG), fly ash (FA) and cement (C)) on freezing-thawing durability (mass losses) of a fine-grained soil for 6, 12, and 18 cycles.

## II. EXPERIMENTAL DESIGN

Soil used in this study was obtained from a fine-grained soil deposit of Konaklı–Erzurum in the Eastern Anatolia Region of Turkey. In this region, there is a long winter, and snow remains on the ground from November until the end of April. From the data obtained at a station in Erzurum between 2003 and 2013, the highest average temperature measured so far is 19.8°C and the lowest average temperature is -10.4°C (Erzurum 12th Regional Directorate of Meteorology) [12].This soil deposit resembles an area exposed to freezing–thawing and is used much in engineering work in Erzurum. The soil can be classified as “high plasticity silt (MH)” according to the Unified Soil Classification System. Some index properties of the soil are given in Table I. In addition, some properties of borogypsyum, fly ash, cement, and polypropylene fibers provided by the manufacturer are given in Tables II and III.

The Taguchi method employs standard tables known as the Orthogonal Arrays (OA) for construction the design of experiments. The orthogonal array (OA) experimental design method was chosen to determine the experimental plan, $L_9$, since it is the most suitable for the conditions being investigated, using four parameters with three levels each. The Taguchi method uses the S/N ratio (signal to noise) instead of the average value to interpret the trial result data into a value for the evaluation characteristics in the optimum setting analysis. This ratio expresses the scatter around a target value. If the S/N ratio is expressed in dB units, it can be defined by a logarithmic function based on the mean square deviation (MSD) around the target:

$$(S/N)_i = -10\log MSD_i = -10\log\left(\frac{1}{r}\sum_{j=1}^{r}\frac{1}{Y_{ij}^2}\right) \quad (1)$$

where i is the number of a trial; $MSD_i$ is the square of the standard deviation of a trial i; r is the number of repetitions for experimental combination; $Y_i$ is performance value of the $ij^{th}$ experiment. In the Taguchi method, the experiment corresponding to optimum working conditions might have not been done during the whole period of the experimentation. In this case, the performance value corresponding to optimum working conditions can be predicted by utilizing the balanced characteristic of the OA. The Taguchi method is explained as a summary in this study. More detailed information about the Taguchi method can be found in [17], [22], [23], [25]. BG, FA, PP and cement (C) were added at different levels by weight of the total solid materials. Experimental factors and their levels to be studied are given in Table IV. An L9 OA was chosen to evaluate the experimental results. Details of the experimental design and approach are given in Table V. The columns show the levels of factors and each row represents a trial condition.

TABLE I
ENGINEERING PROPERTIES OF SOIL USED IN THE STUDY

| | |
|---|---|
| Liquid limit, $w_L$ (%) | |
| Plastic limit, $w_P$ (%) | |
| Plasticity index, PI (%) | |
| Specific gravity, Gs | 2,5 |
| Maximum dry unit weight*, $\square_{dmax}$ (kN/m$^3$) | 15.4 |
| Optimum water content*, $w_{opt}$ (%) | |
| Electric conductivity (mmhos/cm) | 3.3 |
| pH | 6.9 |
| Dispersion | 1-2 |

* Obtained from standard proctor tests.

TABLE II
SOME PROPERTIES OF BOROGYPSYUM FLY ASH, CEMENT

| | Borogypsyum (%) | Fly ash (%) | Cement (%) |
|---|---|---|---|
| $B_2O_3$ | 1.62 | -- | -- |
| CaO | 27.8 | 6.6 | 59,61 |
| $SO_3$ | 44.2 | -- | 3,31 |
| MgO | 1.53 | 4.65 | 3,23 |
| $Na_2O$ | 1.32 | 15.95 | 0,4 |
| $Al_2O_3$ | 0.23 | 15.95 | 5,23 |
| $Fe_2O_3$ | 0.84 | 16.3 | 3,3 |
| $SiO_2$ | 20.95 | 47.5 | 21,02 |

TABLE III
PROPERTIES OF REINFORCEMENT MATERIALS USED IN THE STUDY

| | |
|---|---|
| Diameter, mm | 0.05 |
| Length, mm | |
| Density, kN/m³ | 9.1 |
| Tensile strength, N/mm² | 320-400 |
| Elastic modulus, N/mm² | |
| Specific surface, m$^2$/N | 20-30 |

TABLE IV
TEST FACTORS USED AND THEIR LEVELS

| Levels | Parameters | | | |
|---|---|---|---|---|
| | BG (%) | FA (%) | PP (%) | C(%) |
| | | | | |
| | | | 0.15 | |
| | | | 0.25 | |

TABLE V
CHOSEN $L_9$ EXPERIMENTAL PLAN (OA)

| Trial | Parameters and their levels | | | |
|---|---|---|---|---|
| | BG(%) | FA(%) | PP (%) | C (%) |
| | | | | |
| | | | 0.15 | |
| | | | 0.25 | |
| | | | 0.15 | |
| | | | 0.25 | |
| | | | | |
| | | | 0.25 | |
| | | | | |
| | | | 0.15 | |

The soil was dried in an oven at approximately 105°C. The required amounts of soil borogypsyum, fly ash, cement, and polypropylene fibers were blended together under dry conditions. 0-20% of BG, 0-20% of FA, 0-3% of C and 00,25% of PP by total dry weight of mixture were used in the preparation of specimens. Because the fibers tended to lump together, considerable care and time were spent to get a homogeneous distribution of the fibers in the mixtures. Then the soil–fiber-additive mixtures were mixed with the required amount of water according to the optimum water content. Water content (w) versus dry density ($\gamma_k$) relationship for soil and polypropylene fiber reinforced soil and additive material stabilized samples was determined by using standard compaction test according to [5]. The specimens were placed in a moist room having a temperature of 21°C and a relative humidity of 70% for a period of 7 days. At the end of the storage in the moist room, water-saturated felt pads were placed between the specimens and the carriers, and the assembly was placed in a freezing cabinet having a constant temperature not warmer than −23°C for 24 h. Then, the assembly was removed and placed in a moist room with a temperature of 21°C and a relative humidity of 100% for a period of 23 h. At the end of this period, the specimens were removed and firm strokes were applied to the full height and width of the specimen with a wire scratch brush as an experimental maneuver leading to the mass loss per [4]. This process was called 1 cycle. Again, the specimens were placed in the freezing cabinet and the same procedure was continued for 6, 12 and 18 cycles. After 6, 12 and 18 cycles, the test samples were dried in an oven at 110±5°C for 12 h.

Considering [4], the corrected oven-dry mass of specimen (CODM) was calculated as:

$$\text{CODM} = A / B \times 100 \qquad (2)$$

where: A= oven-dry mass after drying at 110 $^{O}$C, and B=percentage of water retained in specimen plus 100. Then, mass loss (ML) was calculated as:

$$\text{ML} (\%) = C / D \times 100 \qquad (3)$$

where: C = original calculated oven-dry mass minus final corrected oven-dry mass (i.e., C=D−CODM), and D = original (i.e., before freezing–thawing cycles) calculated oven-dry mass. Following the 6, 12 and 18 freezing-thawing cycles, the mass losses were calculated for both the unreinforced and the reinforced soil. Each test was repeated at least three times to assure their accuracy.

## III. RESULT AND DISCUSSION

The results of the freezing–thawing test are shown in (Fig. 1). Taguchi analyses were performed in order to determine the minimum mass loss (maximum freezing-thawing durability) for three different freezing-thawing cycles (6, 12 and 18 cycles). S/N analysis was carried out in order to determine the effect of parameters on the freezing-thawing durability of 6, 12 and 18 cycles results. Calculated S/N ratios were given (Table VI) using the test results (Fig. 1).

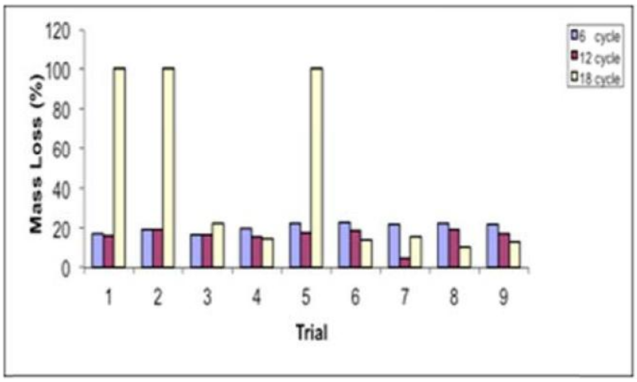

Fig. 1 Test results for each trial

were obtained on the level 1 of BG and level 3 of BG respectively. For the freezing-thawing durability of 12 cycles the highest value of average S/N was obtained on the level 1

TABLE VI
S/N RATIOS FOR TRIALS

| Trial | Parameters and their levels | | | | Cycles | | |
|---|---|---|---|---|---|---|---|
| | BG | FA | PP | C | | | |
| | mean S/N ratio | | | | 15.381 | 15.906 | -0.029 |
| | | | | | 14.416 | 14.416 | -0.029 |
| | | | | | 15.381 | 15.906 | 13.145 |
| | | | | | 13.972 | 16.465 | 17.062 |
| | | | | | 12.759 | 14.885 | -0.029 |
| | | | | | 12.759 | 14.416 | 17.062 |
| | | | | | 13.145 | 25.906 | 16.465 |
| | | | | | 13.145 | 14.416 | 19.148 |
| | | | | | 13.145 | 15.381 | 17.704 |
| | | | | | 13.789 | 16.411 | 11.166 |

AVERAGE EFFECTS OF FACTORS

| | Parameters | S/N ratio | | |
|---|---|---|---|---|
| | | 1. Level | 2. Level | 3. Level |
| 6 cycles | BG | 15.059 | 13.164 | 13.145 |
| | FA | 14.166 | 13.44 | 13.762 |
| | PP | 13.762 | 13.844 | 13.762 |
| | C | 13.762 | 13.44 | 14.166 |
| 12 cycles | BG | 15.409 | 15.255 | 18.568 |
| | FA | 19.425 | 14.573 | 15.234 |
| | PP | 14.913 | 15.421 | 18.399 |
| | C | 15.39 | 18.246 | 15.596 |
| 18 cycles | BG | 4.362 | 11.365 | 17.772 |
| | FA | 11.166 | 6.363 | 15.97 |
| | PP | 12.06 | 11.579 | 9.36 |
| | C | 5.882 | 11.166 | 16.452 |

In order to determine the effects of borogypsyum, fly ash, polypropylene fibers and cement on the freezing-thawing durability at 6, 12 and 18 days, analysis of variance (ANOVA) was performed. The results of variance analyses (ANOVA) are given in Table VIII.

TABLE VIII
RESULTS OF VARIANCE ANALYSES (ANOVA)

| | Parameter | DOF | (SS) | (V) | (S’) | P (%) |
|---|---|---|---|---|---|---|
| 6 cycles | BG | 2 | 7.257 | 3.628 | 7.257 | 81.942 |
| | FA | 2 | 0.792 | 0.396 | 0.792 | 8.951 |
| | PP | 2 | 0.013 | 0.006 | 0.013 | 0.153 |
| | C | 2 | 0.792 | 0.396 | 0.792 | 8.951 |
| 12 cycles | BG | 2 | 20.968 | 10.484 | 20.968 | 19.783 |
| | FA | 2 | 41.554 | 20.777 | 41.554 | 39.205 |
| | PP | 2 | 28.245 | 14.122 | 28.245 | 26.648 |
| | C | 2 | 15.222 | 7.611 | 15.222 | 14.362 |
| | BG | 2 | 269.916 | 134.958 | 269.916 | 46.22 |
| | FA | 2 | 138.448 | 69.224 | 138.448 | 23.707 |
| | PP | 2 | 8.025 | 4.012 | 8.025 | 1.374 |
| | C | 2 | 167.589 | 83.794 | 167.589 | 28.697 |

DOF: Degree of freedom; SS: Sum of square deviation; V: Variance; S’: Pure Sum; P: Percent contribution

TABLE VII

For the freezing-thawing durability of 6, 12 and 18 cycles, calculated average effects at each level of parameters are shown in Table VII. It is seen that the highest values of 18 average S/N for freezing-thawing durability at 6 and 18 cycles cycles

of

FA. According to these results the most effective parameter

It is seen from Table VIII that the most effective parameter on the freezing-thawing durability at 6,18 and 12 cycles are on the freezing-thawing durability at 6, 12 and 18 cycles are BG, BG and FA respectively.

BG, FA and BG, respectively. The graphics showing the

effects of parameters on the freezing-thawing durability at 6, 12 and 18 cycles are given in Figs. 2-4.

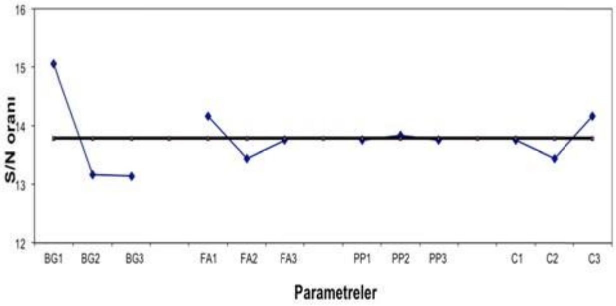

Fig. 2 Response graphs of main effects for freezing-thawing

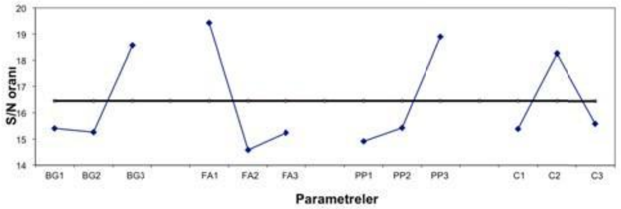

Fig. 3 Response graphs of main effects for freezing-thawing durability (12 cycles)

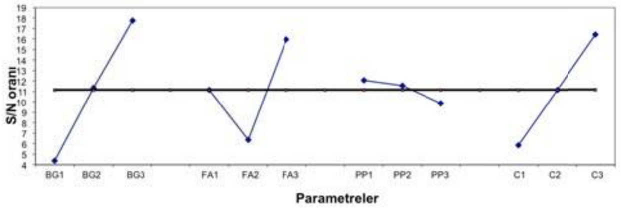

Fig. 4 Response graphs of main effects for freezing-thawing durability (18 cycles)

Fig. 2 shows that with the decrease of the borogypsyum (BG), there is an important increase in the freezing-thawing durability (6 cycles). With the increase of cement (C) ratio, there is a decrease in the freezing-thawing durability at 6 cycles. The effect of PP on the freezing-thawing durability at 6 is insignificant.

In Fig. 3, the decrease of the fly ash (FA), there is an important increase in the freezing-thawing durability (12 cycles). With the increase of BG and PP ratio, there is a decrease in the freezing-thawing durability at 12 cycles. 1% C ratio decreases the freezing-thawing durability (12 cycles), while 10% FA ratio increases the freezing-thawing durability (1 cycles).

Fig. 4 shows that with the increase of the BG and C, there is an important decrease in the freezing-thawing durability (18 cycles). This decrease in the freezing-thawing durability at 18 is attributed to the fact that addition of BG into the mixture results in set retarder properties [7]. With the decrease of PP ratio, there is an increase in the freezing-thawing durability at cycles.

durability (6 cycles)

The increase of the fly ash (FA), there is an important decrease in the freezing-thawing durability (6, 12 and 18 cycles). This decrease in the freezing-thawing durability at 6, 12 and 18 cycles is attributed to the fact that addition of FA into the mixture results in slow pozzolanic activity of fly ash and decrease in the concentration of cement [19].

The optimum conditions correspond to maximum freezingthawing durability (minimum mass less). In these figures, the levels corresponding to the highest S/N ratios are chosen for each factor for which they indicate the best condition. It can be seen from Fig. 1 that BG1 (0%), FA1 (0%), PP3 (0.25%) and C3 (3%) are the optimum conditions for the freezingthawing durability (6 cycles). For the freezing-thawing durability (12 days), 20% BG (BG3), 0% FA (FA1), 0.25% PP (PP3) and 1% C (C2) are the optimum conditions. For the freezing-thawing durability (18 days), 20% BG (BG3), 20% FA (FA3), 0% PP (PP1) and 3% C (C3) are the optimum conditions.

## V. CONCLUSIONS

The effect of randomly distributed polypropylene fibers (PP) and additive materials borogypsum (BG), fly ash (FA) and cement (C) on freezing-thawing durability (6,12 and 18 cycles) were investigated and the optimum conditions were determined for three different freezing-thawing cycles (6,12 and 18 days). The conclusions drawn from this study are summarized as follows:

- Among the four factors and levels tested, borogypsum is the most effective parameter on the freezing-thawing durability of 6 and 18 cycles.
- For an increase of cement ratio, there occurs a decrease in the freezing-thawing durability at 6 and 18 cycles.
- Polypropylene fibers do not have an important effect on the freezing-thawing durability of 6 cycles.
- With increase of the cement, there is an important decrease in the freezing-thawing durability at 18 cycles.
- With increase of the Polypropylene fibers, there is an important decrease in the freezing-thawing durability at 12 cycles.
- Among the four factors and levels tested, Polypropylene fibers are the most effective parameter on the freezingthawing durability of 12 cycles.
- The experimental results indicated that the optimum conditions are BG1 (0%), FA1 (10%), PP2 (0.15%) and C3 (3%) for the freezing-thawing durability (6 cycles), while they are BG3 (20%), FA1 (0%), PP3 (0,25%) and C2 (1%) for the freezing-thawing durability 12 cycles and they are BG3 (20%), FA3 (20%), PP1 (0%) and C3 (3%) for the freezing-thawing durability 12 cycles.

This paper reveals that polypropylene fibers and additive materials can be used to improve the freezing-thawing durability (mass loss) of fine-grained soils for the geotechnical applications. However, it should be added that further studies on the different fine-grained soils and different additive materials are needed to make more reasonable judgments.

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