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STATISTICAL ANALYSIS OF FIBRE REINFORCED FROZEN SOIL

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ABSTRACT

Across the globe, cold region areas experience frequent freeze and thaw cycles. Sometimes these natural cycles become so impacteous that the engineering properties of soil get affected adversely and supported structures like pavements damage or collapse by the time. In the present study chicken eggshell powder, sodium chloride and polypropylene fibres were used to stabilise the soil. Strength properties of 21-day cured virgin and treated soil samples were determined after keeping under 3, 5 and 10 freeze–thaw cycles. For durability assessment, mass loss was also determined after the same number of freeze–thaw cycles. Finally, optimal conditions were determined through analysis of variance. Results showed that the natural additives and synthetic fibres promise as better provision against harsh weather conditions. Design of experiments was made by the Taguchi technique using a statistical software Minitab® 17. Further analysis was done to find out the probability distribution of the responses. Probability distribution showed a large variation in the responses that implies that although the results were found satisfactorily as per the engineering purposes, yet not suitable to make any relationship between strength and durability properties.

Key words: eggshell powder, polypropylene fibres, freeze–thaw, probability distribution

INTRODUCTION

India's northern and north-east regions contain mountains and are the coldest in the country. In these areas, –20°C temperature is common in winter season but during summer temperature may vary up to 35°C. This seasonal variation is responsible for the multiple changes in soil properties present there (Chaduvula, Desai & Solanki, 2014). The changes may be the occurrence of strength reduction, swell increase, loss in permeability, dynamic properties etc. (Kalkan, 2009; Liu, Wang & Tian, 2010; Yıldız and Soğancı, 2012). Primary investigations of these properties become more important when soil at site comes into direct freeze–thaw (FT) cycles and experience lose in strength properties. As a remedy for such problems, many researchers have used synthetic or natural fibres, chemical additives and natural minerals etc. on different soils since decades (Ghazavi & Roustaie, 2010; Güllü & Khudir, 2014; Brózda & Selejdak, 2019; Patel & Singh, 2019; Pietrzak & Ulewicz, 2019).

Present study focuses on the usage of waste eggshell powder (ESP), commercial sodium chloride (NaCl) and polypropylene fibres (PPF) in fine soil to curb the strength and durability related problems in cold regions. Histograms and probability plots for the responses are also encouraged to correlate the experimental results.

MATERIAL AND METHODS

Soil was taken from a construction site located at Jammu and Kashmir, India. Before adding the additives in the soil, virgin soil was tested for index properties accordance to Indian standards of soil testing for civil engineering purposes. Soil properties have been tabulated in Table 1. Dried and clean eggshells were grinded to fine enough to change in eggshell powder

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Table 1. Index properties of soil

Gravel content [%]	Sand content [%]	Clay + Silt content [%]	Shear modulus (*G*)	Liquid limit (*LL*) [%]	Plastic limit (*PL*) [%]	Plasticity index (I_p) [%]	Indian Soil Classification	Optimum moisture content (*OMC*)[a] [%]	Maximum dry density (*MDD*)[b] [g·cm^{-3}]	Optimum moisture content (*OMC*)[b] [%]	Maximum dry density (*MDD*)[b] [g·cm^{-3}]
0	0	100	2.6	34	29	05	low plasticity silt	19.33	1.72	14.40	1.84

[a]standard Proctor test; [b]modified Proctor test.

(ESP) and dosages were set as 3, 6 and 9% by dry weight of soil. Sodium chloride (NaCl) was purchased from the local market in crystalline form and used in the range of 2, 4 and 6%. Polypropylene fibres (PPF) of 12 mm size were supplied by the Reliance India Limited. Reinforcement was provided in percentages of 0.05, 0.10 and 0.15% using arbitrarily distribution system.

Soil samples were prepared at optimum moisture content (*OMC*) and were dimensioned for unconfined compressive strength (*UCS*) and mass loss tests as per Indian standards. Since evaluation of strength and durability properties under repetitive FT cycles was prime concern of the present study so, samples were kept under –25°C for freezing and 25°C for thawing in fully automatic freezer and thaw cabinets. Each FT cycle was lasted for 24 h and 12 h for mass loss and strength evaluation, respectively. Because 6 h is proportional time period for freezing and thawing of soil samples after that no dimensional variation is reported (Qi, Zhang & Zhu, 2004). Experiments were designed using software Minitab® 17. Standard L9 matrix was chosen as a design of experiments (DOE). Additives and their dosages are given in Table 2. Standard matrix based orthogonal array is shown in Table 3. Statistical evaluation of the results was also done by using the same software.

Table 2. Additives and their dosages

Level	Eggshell powder (ESP) [%]	Polypropylene fibres (PPF) [%]	Sodium chloride (NaCl) [%]
A	3	0.05	2
B	6	0.10	4
C	9	0.15	6

Table 3. Orthogonally oriented mix design

Trial	Eggshell powder (ESP) [%]	Polypropylene fibres (PPF) [%]	Sodium chloride (NaCl) [%]
R1	3	0.05	2
R2	3	0.10	4
R3	3	0.15	6
R4	6	0.05	4
R5	6	0.10	6
R6	6	0.15	2
R7	9	0.05	6
R8	9	0.10	2
R9	9	0.15	4

RESULTS AND DISCUSSION

Figure 1 shows the strength variation in soil under repetitive FT cycles after incorporating the additives. Mass loss of the soil due to frequent FT cycles has been shown in Figure 2.

After study Figure 1, it can be seen that there is a large variation in strength properties of the soil with incorporation of the additives. The probable reason behind this nature of the soil is the differences in the densities at different moisture contents. Other scientific reason for this can be the outset of exothermic reactions of the reactants namely calcium and chloride ions introduced by ESP and NaCl, respectively. The reactions were so much effective initially that the reactions produced kind a cementitious product that bonded the soil particles altogether. But, after the third FT cycle present ions possibly got consumed by the reaction itself. So, the strength property of the soil

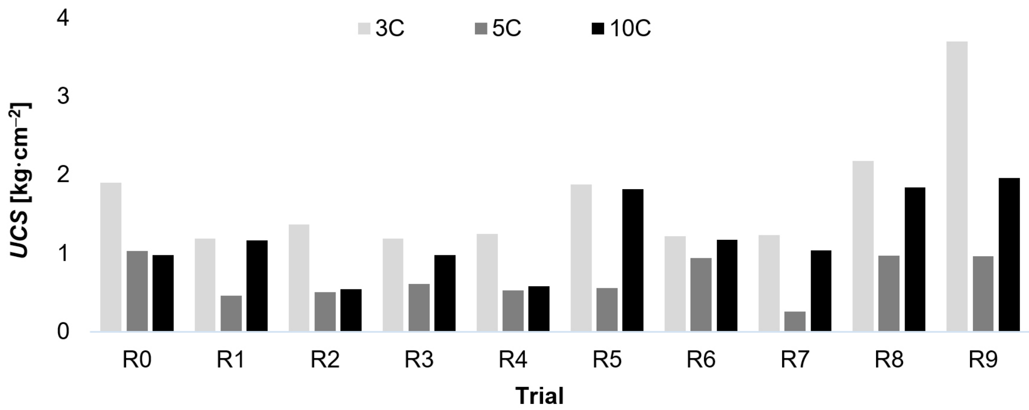
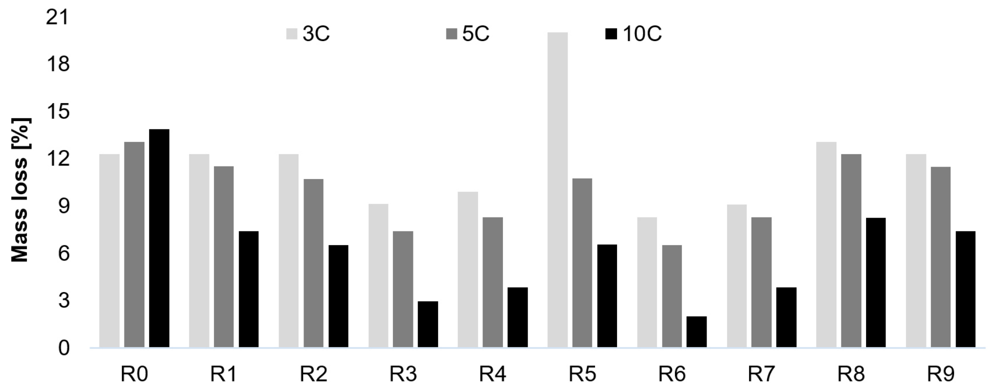


Fig. 1. Unconfined compressive strength test results of designed mixes



R_0 means parent soil sample

Fig. 2. Mass loss test results of designed mixes

affected adversely. Right after the tenth FT cycle additives again started to react and produced better results in strength (Al-Mukhtar, Khattab & Alcover, 2012).

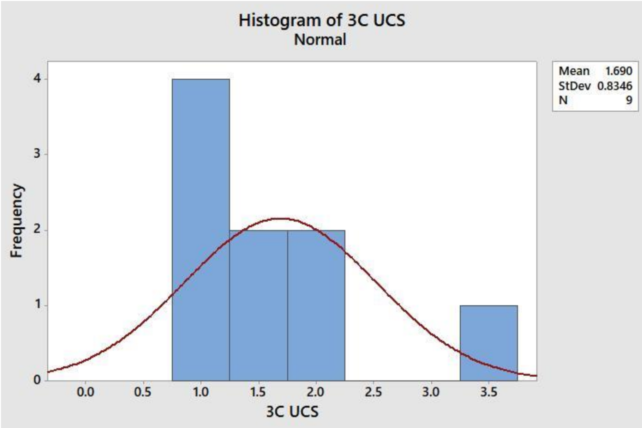
Figure 2 shows the durability characteristics of the soil-additive mixes against repetitive FT cycles. In this case, same phenomenon was also observed as during evaluating the strength properties but parent soil sample experienced highest mass loss by consequently FT cycles. After the third FT cycle some deleterious material, i.e. calcium hydrate was also produced during exothermic reactions. These materials are flaky in nature and are responsible for the losses in strength and binding properties of the soil. However, after the tenth FT cycle again binding booster were generated in the soil-additive matrix and produced satisfactory results against weathered conditions (Kumar, Dutta & Mohanty, 2015). Detailed reasons for the present study can be found in authors' previous works (Kumar & Soni, 2019a; 2019b).

Probability analysis was done using software Minitab® 17 itself. The histograms and probability curves for the strength properties have been shown in Figure 3 and Figure 4 for 3, 5 and 10 FT cycles, respectively.

Figures 3 and 4 show that there is a high frequency of events after soil conditioned to the 3 FT cycles than following FT cycles. This means the results after 3 FT cycles were in the range of more confidence level of approval. Probability curves showed lesser *p*-value for the test results obtained after 3 FT cycles which indicate the rejection of null hypothesis of the test responses.

Same statistical analysis was done for the test responses of the soil samples after mass loss tests. The histograms and probability plots for the durability tests have been shown in Figures 5 and 6, respectively.

a



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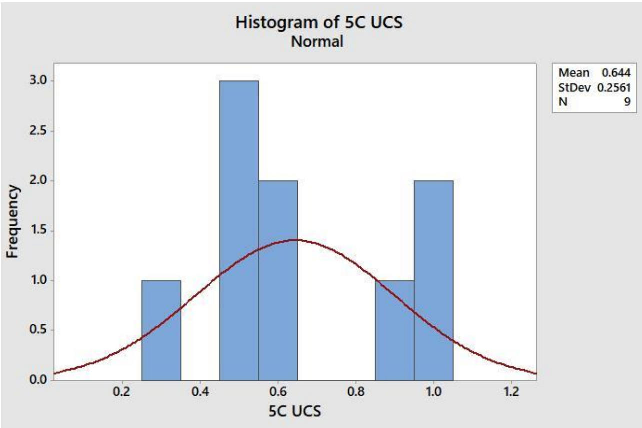

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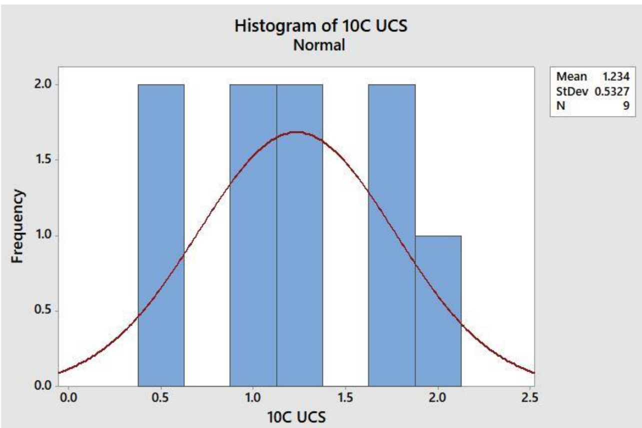
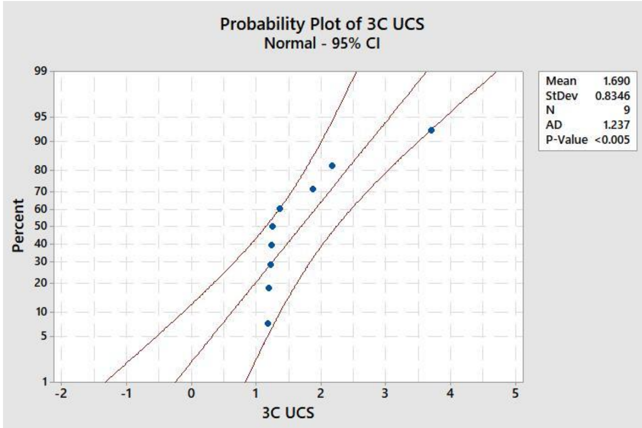


Fig. 3. Histograms of strength properties after (a) 3, (b) 5 and (c) 10 freeze–thaw cycles

a



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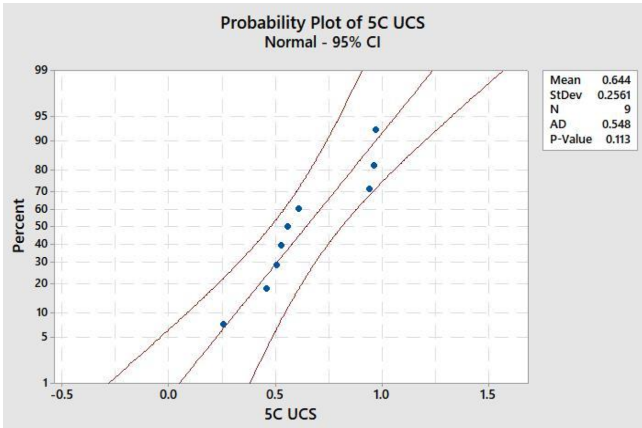

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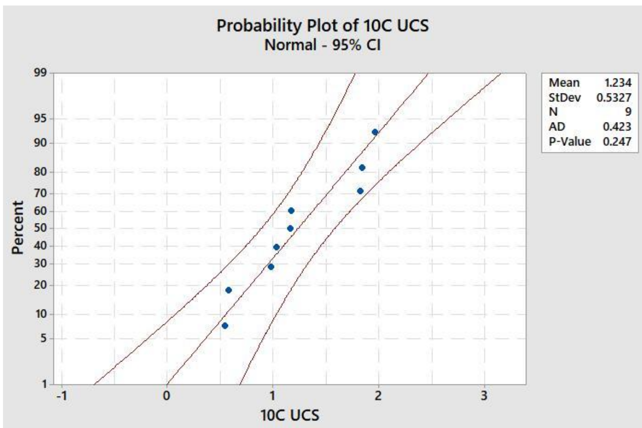

Fig. 4. Probability plots of strength properties after (a) 3, (b) 5 and (c) 10 freeze–thaw cycles

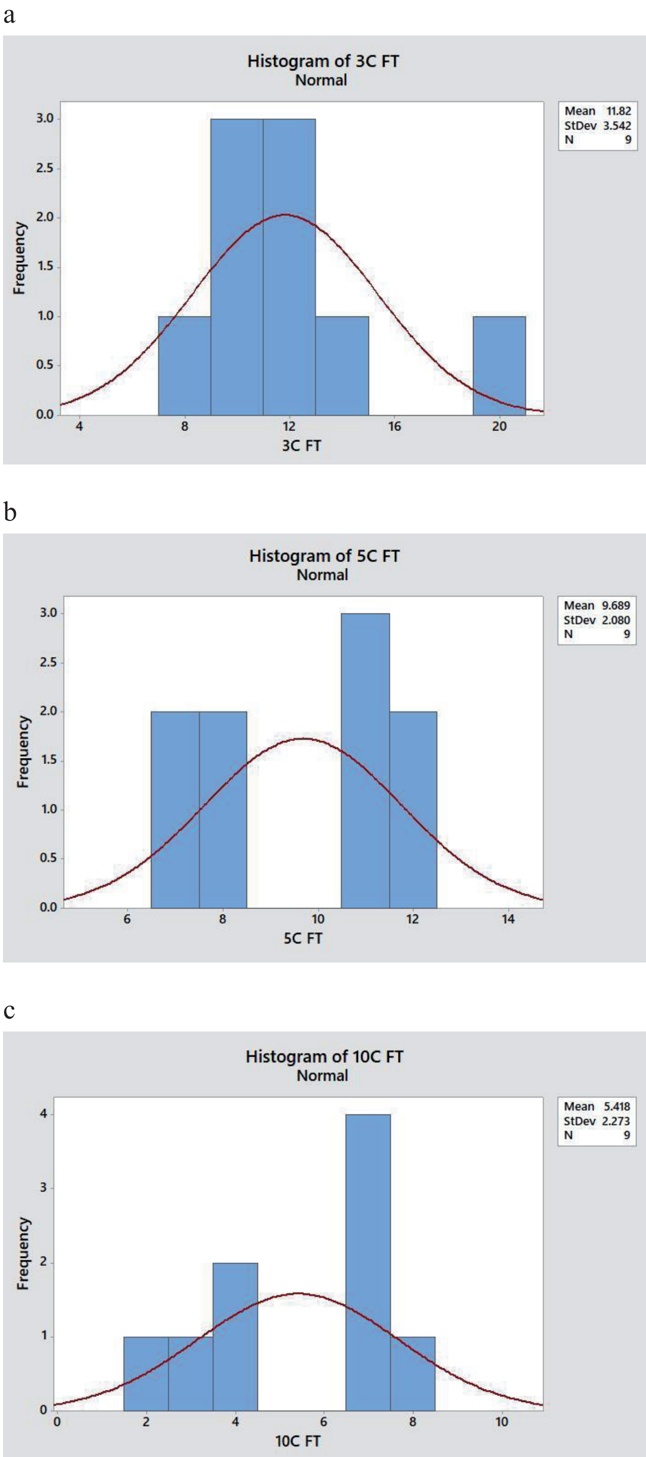

Fig. 5. Histograms of durability properties after (a) 3, (b) 5 and (c) 10 freeze–thaw cycles

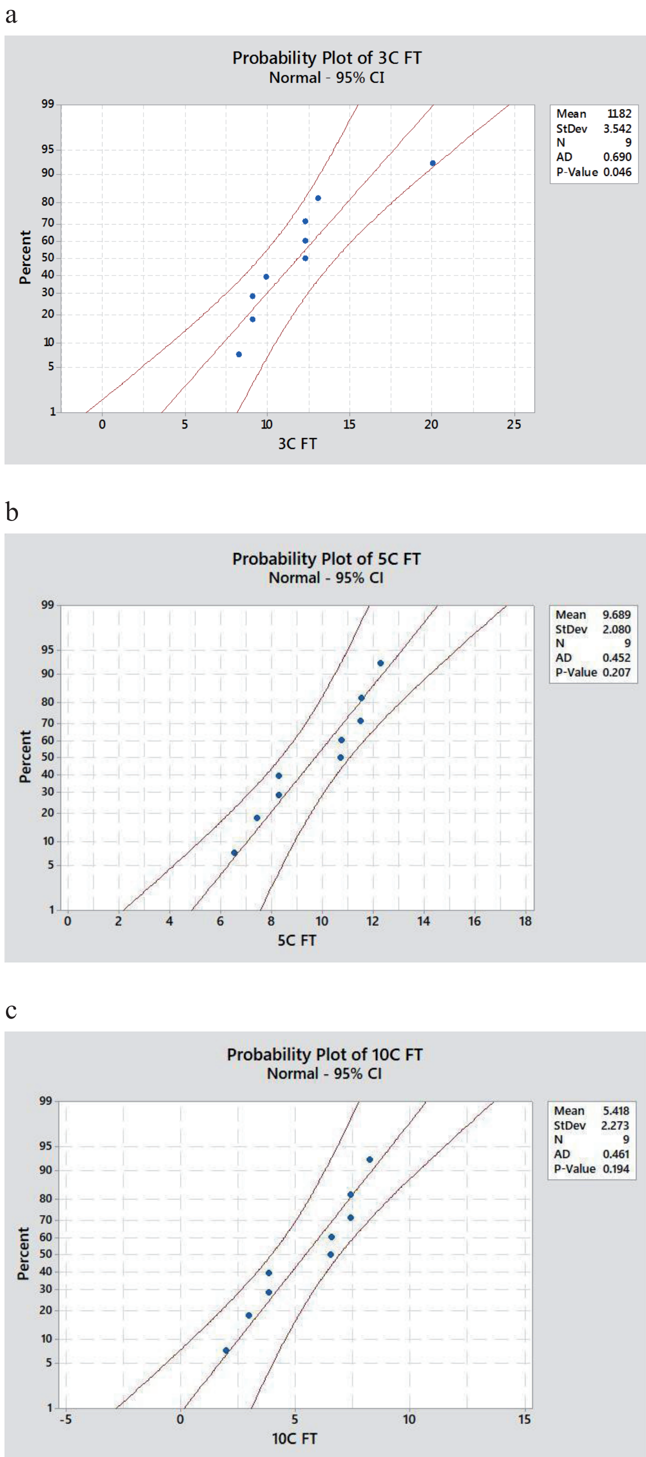

Fig. 6. Probability plots of durability properties after (a) 3, (b) 5 and (c) 10 freeze–thaw cycles

Similar pattern of responses has been observed after the evaluation of durability properties using mass loss method. Among all the responses 3 FT cycles results have been found in good shape of histogram with high gapping which shows the reliability of the responses. Lesser *p*-value again proved the little skewness of the results which is good symbol for the test results.

CONCLUSIONS

Present study depicts the efficacy of natural additives and polypropylene fibres against repetitive freeze–thaw cycles. After study the results following concrete conclusions can be drawn:

- Additives are found highly effective in resisting the strength and durability losses.
- Available calcium and chloride in the soil-additive matrix found responsible for the exothermic reactions and production of cementitious products.
- Fibres gripped the soil particles and make the soil more resistive against rupture and abrasion.
- Fibres produced the high strain in the soil due to their high ductile property.
- Since additives made the soil more resistive against weathered conditions but there is no direct correlation was found between them.

Although the present study gave an enormous idea against the worst weather conditions but for the more clarification on the concept authors encourage the researchers to do more with the different additives in different soil with intermediate percentages of dosages.

Authors' contributions

Conceptualisation: A.K.; methodology: A.K.; validation: A.K.; formal analysis: A.K.; investigation: A.K.; resources: A.K.; data curation: A.K.; writing – original draft preparation: A.K.; writing – review and editing: D.K.S.; visualisation: D.K.S.; supervision: D.K.S.; project administration: D.K.S.; funding acquisition: A.K.

All authors have read and agreed to the published version of the manuscript.

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ANALIZA STATYSTYCZNA ZMROŻONEJ GLEBY ZBROJONEJ WŁÓKNAMI

STRESZCZENIE

Na całym świecie w zimnych regionach występują często cykle zamrażania i rozmrażania. Czasami te naturalne cykle stają się tak intensywne, że niekorzystnie wpływają na właściwości inżynierskie gruntu, a podparte na nim konstrukcje, takie jak chodniki, z czasem zaczynają ulegać uszkodzeniu lub zawaleniu. W niniejszej pracy do stabilizacji gruntu zastosowano proszek ze skorupek jaj kurzych, chlorek sodu i włókna polipropylenowe. Własności wytrzymałościowe dojrzewających przez 21 dni, utwardzonych próbek gruntu pierwotnego i poddanego obróbce określono po przetrzymaniu w 3, 5 i 10 cyklach zamrażania–rozmrażania. Do oceny trwałości wyznaczono również ubytek masy po tej samej liczbie cykli zamrażania–rozmrażania. Optymalne warunki określono ostatecznie poprzez analizę wariancji. Wyniki pokazały, że naturalne dodatki i włókna syntetyczne zapewniają lepsze zabezpieczenie przed trudnymi warunkami pogodowymi. Projekty eksperymentów opracowano techniką Taguchiego przy użyciu oprogramowania statystycznego Minitab® 17. Przeprowadzono dalszą analizę w celu ustalenia rozkładu prawdopodobieństwa odpowiedzi. Rozkład prawdopodobieństwa wykazał duże zróżnicowanie odpowiedzi, co wskazuje na to, że chociaż wyniki uznano za zadowalające z punktu widzenia celów inżynierskich, to nie nadają się do wnioskowania na temat jakiegokolwiek związku między właściwościami dotyczącymi wytrzymałości i trwałości.

Słowa kluczowe: proszek ze skorupek jaj, włókna polipropylenowe, zamrażanie–rozmrażanie, rozkład prawdopodobieństwa