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EFFECTS OF CRUMB RUBBER ON COMPRESSIVE STRENGTH OF CEMENT-TREATED SOIL

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A study was undertaken to investigate the effects of crumb rubber on the strength and mechanical behaviour of Rubberized cement soil (RCS). In the present investigation, 26 groups of soil samples were prepared at five different percentages of crumb rubber content, four different percentages of cement content and two different finenesses of crumb rubber particle. Compressive strength tests were carried out at the curing age of 7 days, 14 days, 28 days and 90 days. The test results indicated that the inclusion of crumb rubber within cement soil leads to a decrease in the compressive strength and stiffness and improves the cement soil's brittle behaviour to a more ductile one. A reduction of up to 31% in the compressive strength happened in the 20% crumb content group. The compressive strength increases with the increase in the cement content. And the enlargement of cement content is more efficient at low cement content.

Keywords: Refuse reclamation, Crumb rubber, Compressive strength, Plasticity, Curing age

1. INTRODUCTION

Soil treatment with cement for the improvement of problematic soils has increased significantly in recent decades. A variety of selected additives have been mixed into artificially cemented soils

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by several investigators [1-5].However, it is worth noting that the additives sometimes lead to a high stiffness and brittle behavior [6]. With the increasing awareness of environmental protection and lack of resources, more and more researches are engaged in the recycling and reusing of industrial wastes. Used tires have become a big problem for the modern society due to the durability and huge volumes of discarded tires every year. They are disposed at a rate of 1.1 tires per person per year [7]. When the force reaches the ultimate strength of cement soil, which has the compressive strength greater than 2000kPa, the specimen experiences brittle fracture [8]. Using recycled tire rubber in cement-treated soil can provide an efficient way of utilizing rubber and a solution to the problem of high stiffness and brittle behavior of artificially cemented soils. Cement mixing pile will obtain better plasticity with rubber crumbs. The rubber crumbs mixed into the cement-treated soil may work similarly to that with rubberized concrete. Previously undertaken extensive research on rubberized concrete Ohemeng and Yalley [9] found that the compressive strength of rubberized concrete pavement blocks are affected differently depending on the rubber content and W/C ratio used. A systematic reduction in compressive strength takes place when the rubber content increases in the mixture which is consistent to the observations made by Neil and Ahmed [10]. Raimundo et al. [11] used a completely random experimental design to simultaneously optimize process variables and cementitious mixture components for rubberization. The optimum condition in the rubberized concrete, considering studied variables, is 2.4 mm size of rubber, 2.5% of rubber that replaced the aggregate, 16% of cement, 76% of aggregate and 8% of water. Fedroff et al. [12] have reported higher air content in rubberized concrete than control mixtures, and Guang-Cheng Long et al. [13] regard it as the cause of compressive strength reduction. Ri-Xin Liu et al. [14] found that crumb rubber mixed into concrete could improve the plasticity and ductility of concrete. In other words, all of the previous studies have shown that the addition of crumb rubber causes a significant reduction in the strength as well as a decrease in the stiffness of the concrete. Since stabilization by cement is a proven technique for improving of the properties of soil, significant amount of research has been focused on the impact factors of mechanical properties. Subramaniam and Banerjee [15] conducted a series of cyclic triaxial tests on artificially cement treated marine clay to study the factors affecting the shear modulus degradation. Research concluded that cement-treated clays exhibit stiffness degradation which depends on the mix ratio, curing time and loading condition. Study by Nilo et al. [16] investigated the strength controlling parameters of a fine grained soil molded at a different dosage ratio. A unique relationship was achieved linking the unconfined compressive strength of the studied fine grained soil with the molding water content, porosity and the volumetric cement content. Anggraini et al. [17] performed numbers of indirect tensile tests and unconfined compression tests focused on the effects of additives. The research has shown that both tensile and compressive strengths increased with the addition of lime, coir fiber and the increasing of the curing time. The objective of this paper is to determine the strength and mechanical behavior of rubberized cement soil. As reviewed above, the compressive strength of cement soil is greatly influenced by its constituents, the mixture design parameters and the curing time. Therefore, a series of compressive strength tests were carried out on the RCS specimens with different rubber particle size, different mixing amount of crumb rubber and cement and different curing period.

2. EXPERIMENTAL PROGRAM

2.1. MATERIALS

The soil used in the present research was obtained from Shenyang area, China. The basic properties of the soil such as specific gravity and Atterberg limits are shown in Table 1. To ensure the uniformity of particle size of soil, the soil has been sifted by a sifter with 2mm mesh size after tumble dry and pulverization. Ordinary Portland cement of grade 32.5 conforming to GB175-2007 was used in this study. Waste tire rubber was grinded into two kinds of crumb rubber, 30/40 mesh powder and 60/80 mesh powder. Tap water was used for molding specimens for the compressive strength tests.

Table 1. Physical properties of studied soil

Soil properties	Values
Liquid limit	35%
Plastic limit	21%
Plastic index	14%
Specific gravity	2.72
Void ratio	0.76

2.2. METHODS

2.2.1. MOLDING AND CURING OF SPECIMENS

Specimens used in the test are a mixture of water, cement, soil and rubber (if contained) prepared by hand-mixing. The content of cement, crumb rubber and water are defined as:

(2.1) $$m_c = m_s \times \alpha_c \times (1-\alpha_r)$$

(2.2) $$m_r = m_c \times \alpha_r$$

(2.3) $$m_w = (m_c + m_r + m_s) \times 20\%$$.

Where:

m_c–mass of the cement, m_r–mass of crumb rubber, m_s– mass of dried soil, m_w– mass of water

α_c –mass percentage of cement (expressed in relation to mass of dry soil), α_r –mass percentage of crumb rubber(expressed in relation to mass of cement)

The variables in this research were: cement content (7%, 15%, 20% and 25% by weight of dry soil), crumb rubber content (0%,5%,10%,15% and 20% by weight of cement, as a replacement of cement), particle size of crumb rubber(30/40mesh and 60/80 mesh). Twelve 70.7mm cubes were prepared from each mix, and they were divided equally into four groups. The four groups were used for compressive strength tests performed during the period of 7 days, 14 days, 28 days, and 90 days respectively. Table 2 provides the components of each mix and the Mixture code used in this paper.

Table 2. Composition mixtures

Mix code	**F**	**R/%**	**C/%**	**Mix code**	**F**	**R/%**	**C/%**
F1R5C7	1	5	7	F2R5C7	2	5	7
F1R5C20	1	5	20	F2R5C20	2	5	20
F1R10C7	1	10	7	F2R10C7	2	10	7
F1R10C15	1	10	15	F2R10C15	2	10	15
F1R10C20	1	10	20	F2R10C20	2	10	20
F1R10C25	1	10	25	F2R10C25	2	10	25
F1R15C7	1	15	7	F2R15C7	2	15	7

Mix code	**F**	**R/%**	**C/%**	**Mix code**	**F**	**R/%**	**C/%**
F1R15C20	1	15	20	F2R15C20	2	15	20
F1R20C7	1	20	7	F2R20C7	2	20	7
F1R20C15	1	20	15	F2R20C15	2	20	15
F1R20C20	1	20	20	F2R20C20	2	20	20
F1R20C25	1	20	25	F2R20C25	2	20	25
R0C7	-	0	7	R0C20	-	0	20

Notes: F=Fineness,F1stands for 30/40mesh group crumb rubber,F2 stands for 60/80mesh group crumb rubber; R=crumb rubber content; C=cement content.

After the necessary proportion of soil, cement and crumb rubber were weighed and fully mixed, and then a certain quantity of water was added to the mixture. The mixture was stirred before it turned into homogeneous paste. The specimen was then statically compacted in three layers inside a mould. The specimens were demoulded after 24h and cured in a moisture chamber until the compressive strength tests were carried out.

2.2.2. PROGRAM OF COMPRESSIVE STRENGTH TESTS

Compressive strength tests were performed on the cubic specimens at the curing age of 7 days, 14 days, 28 days, and 90 days. An automatic loading machine (SYE-2000A), with maximum capacity of 2000kN was used during the tests. All the data before the axial stress reached compressive strength were recorded by DH3816 programmable static strain gage. The increment of load level is 0.1MPa at the beginning of loading, and then it turned into 0.2MPa. The loading rate was 100N/s to 150N/s. The tests were repeated on three identical specimens, and the average value was used in the report.

3. RESULTS AND DISCUSSION

As mentioned above, the strength of cement soil depends on various factors such as cement content, curing time and additive. The following discusses the factors affecting the strength of Rubberized Cement Soil.

3.1. Effect of curing time on the compressive strength

The effect of the curing time on the compressive strength of the soil samples is shown in Fig.1. It can be observed that the compressive strength of the soil samples increased as curing age prolonged. The strength of 8 studied mixes developed in a similar manner. There was a much larger strength increase rate before the 28 days after casting than the curing period after it. As shown in Fig.1, 56% to 87.4% of late compressive strength developed during the 28 days after casting which is in correspondence with previous relevant work [18-20].

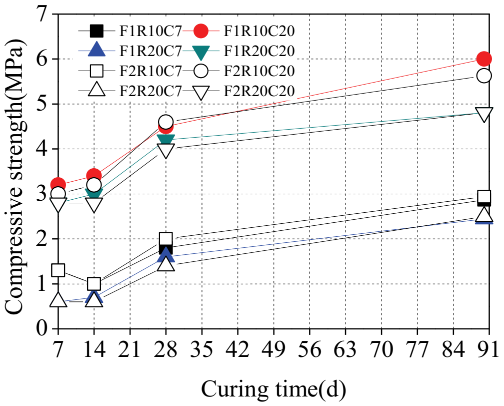

Fig. 1. Compressive strength vs. curing time for soil samples.

3.2. Effect of crumb rubber content on compressive strength

Figs.2-5 depicts the effect of addition of crumb rubber on the compressive strength of the cement-treated soil at different cement level (7%, 20%), different fineness of crumb rubber (30/40, 60/80mesh) and different curing age (7-, 14-, 28- and 90-day).As can be seen, when soil was 20% cemented and 30/40 mesh crumb rubber was used, compared to the cement soil without crumb rubber, a reduction of 4%, 10%, 14%, 17 % and 14%, 14%, 25%, 31 % occurred in specimens' strength at curing age of 28 days and 90 days for 5%, 10%, 15% and 20% crumb rubber content respectively. The above two sets of data indicate that the addition of crumb rubber resulted in a decrease in the compressive strength of soil samples. Furthermore, a higher percentage of strength reduction came into being at the curing age of 90 days than that of 28 days. On the one hand, according to Bing Wang et al. [21], cement soil obtained strength from the network of cement-hydrate. However, bad compatibility between polar rubber particle surface and non-polar cement matrix led to a bad connection between them. Furthermore, amount of void arose between rubber particles and cement matrix. The voids were the weak parts of the network of cement-hydrate where a stress concentration under compression was more likely to be created. And, the strength of soil samples reduced consequently. On the other hand, rubber particles in the cement soil failed to bear loads for its lower stiffness compared to the network of cement-hydrate. For the reasons elaborated above, along with the increase of crumb rubber content, the percentage of volume of crumb rubber and voids in the soil samples increased and the soil suffered a greater strength descent. The cement in the soil samples took a long period to react with water. So not all crumb rubber particles played a part in the descent of cement soil's strength at the beginning. A particle contributed to strength descent when the cement around it turned into cement-hydrate.

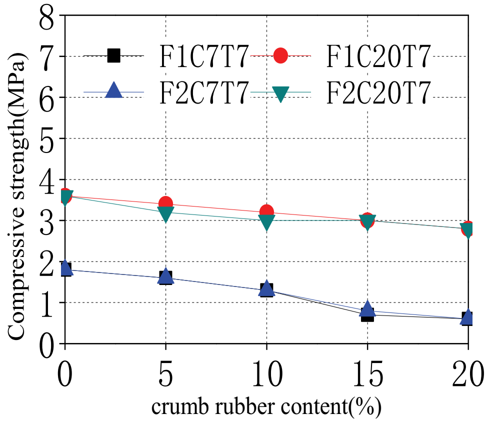

Fig. 2. Effect of rubber content on compressive strength at 7-day curing age

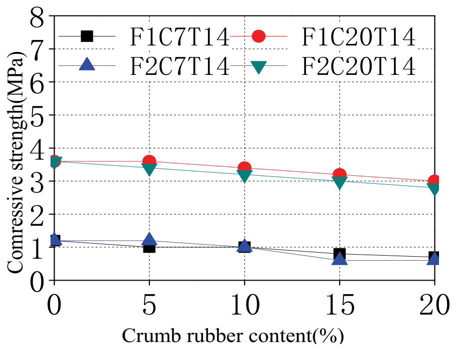

Fig. 3. Effect of rubber content on compressive strength at 14-day curing age

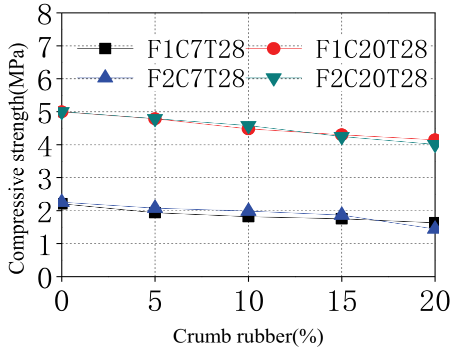

Fig. 4. Effect of rubber content on compressive strength at 28-day curing age

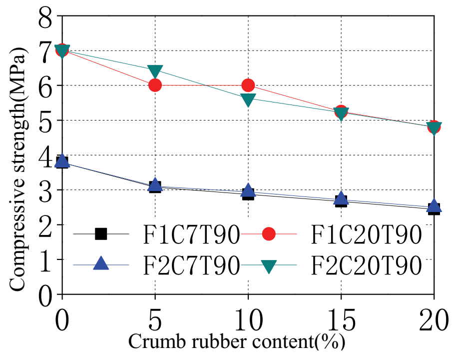

Fig. 5. Effect of crumb rubber content on compressive strength at 90-day curing age

3.3. EFFECT OF CEMENT CONTENT ON COMPRESSIVE STRENGTH

It can be seen from Figs.6-9 that compressive strength of rubberized cement soil increased with the addition of cement, and the higher the cement content, the greater the compressive strength.

It is illustrated by the increase of the volume of cement-hydrate network. The volume of network in the soil samples increased with the increase of cement content. And the bigger percentage of volume of network resulted in a more stable network of cement-hydrate and a bigger compressive strength. At the condition of cement soil containing 20% rubber (by weight of cement) whose fineness is 30/40 mesh, the strength increase rates were 132%, 9.5%, 17.3% (at the curing age of 28 days) and 76%, 11,9%, 23,4% (at curing age of 90 days) , while cement content (7%, 15%, 20% and 25%) changed from 7% to 25% one by one.

It is indicated that the enlargement of cement content is more efficient at low cement content.

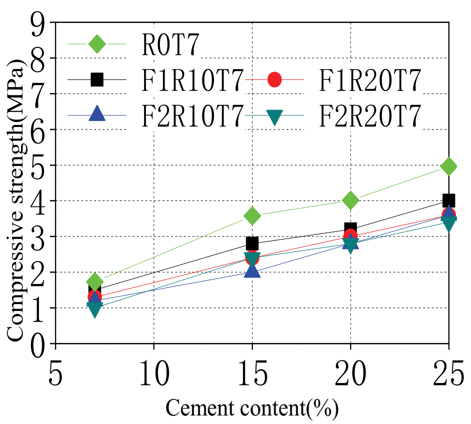

Fig. 6. Effect of cement content on compressive strength at curing age of 7-day

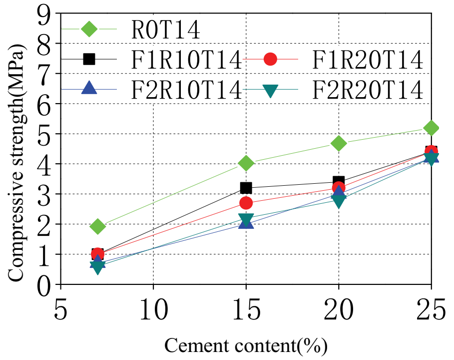

Fig. 7. Effect of cement content on compressive strength at curing age of 14-day

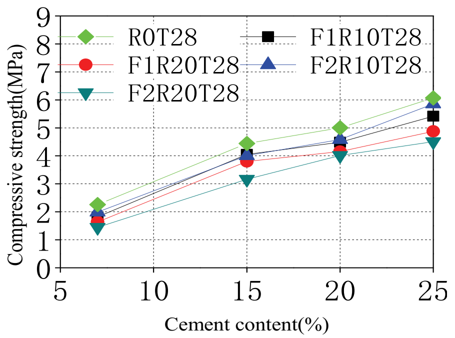

Fig. 8. Effect of cement content on compressive strength at curing age of 28-day

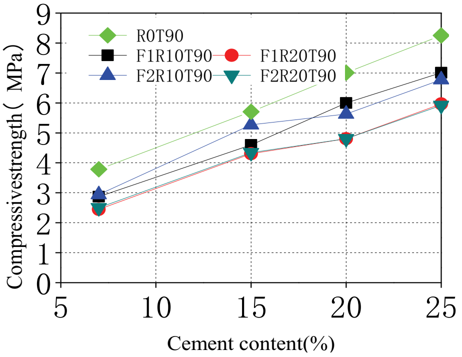

Fig. 9. Effect of cement content on compressive strength at curing age of 90-day

3.4. Effect of crumb rubber particle size on compressive strength

Table.3 shows the strength increase rate at the curing age of 28 days when rubber crumb fineness changed from 30/40 mesh to 60/80mesh. The values of strength increase rate range from - 16.79% to 9.64% in this study. It is obvious from Fig.1 that changing crumb rubber particle size didn't have much of an impact on the compressive strength of soil samples in the research. Maybe it is related to the limited differences in size between the two different groups of crumb rubber used in the study. According to F. C. Wang et al. [22], there is an optimizing crumb rubber particle size. A significant variation will take place if the size of the crumb rubber is distributed on a larger scale.

Table 3. Strength increase rate (%)

Crumb rubber content/%	Cement content/%			
	7	15	20	25
5	7.27	-	0.13	-
10	9.46	-1.21	2.09	8.12
15	6.31	-	-1.21	-
20	-11.55	-16.79	-4.42	-7.54

3.5. Effect of crumb rubber additive on stress-strain curve

Figs.10-17 show the stress-strain curves of the soil samples incorporated with 20% cement, which were obtained from the compressive strength tests on cubes. It can be seen from Fig.4 that the addition of crumb rubber resulted in a significant increase in peak strain of the stress-strain curve. The increase rates of peak strain at the curing age of 28 days were 3.49%, 27.71%, 57.12%, 64.06% for 5%, 10%, 15%, 20% crumb rubber content, respectively when the soil samples contained crumb rubber of 30/40 mesh. The increase rates of peak strain at the curing age of 28 days were 44.8%, 80.85%, 101.13% for 5%, 10%, 20% crumb rubber content, respectively when the soil samples contained crumb rubber of 60/80 mesh. It is indicated that the incorporation of crumb rubber increases the peak strain of stress-strain curve of soil sample and improves the plasticity of cement soil.

The peak strain of RCS specimens increased with the increase of crumb rubber content. 60/80 mesh crumb rubber is better than 30/40 mesh crumb rubber in improving the plasticity of cement soil.

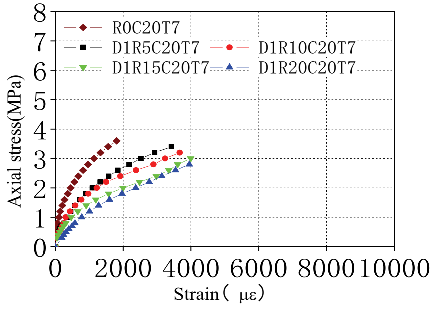

Fig. 10. Stress-strain curves considering C=20%, F=30/40 mesh, T=7d

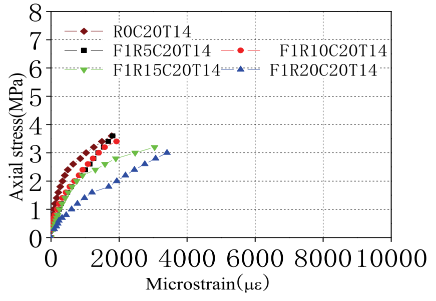

Fig. 11. Stress-strain curves considering C=20%, F=30/40 mesh, T=14d

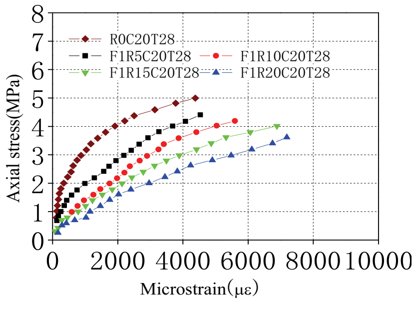

Fig. 12. Stress-strain curves considering C=20%, F=30/40 mesh, T=28d

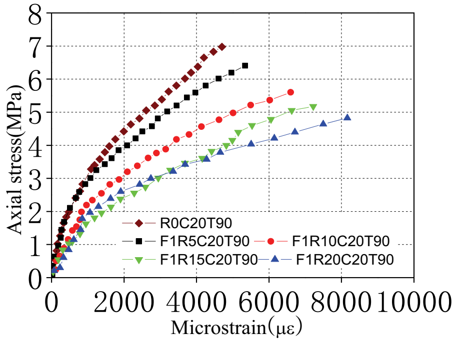

Fig. 13. Stress-strain curves considering C=20%, F=30/40 mesh, T=90d

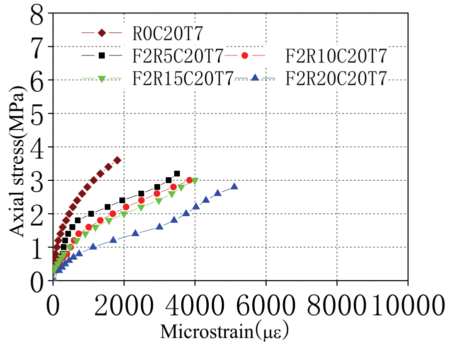

Fig. 14. Stress-strain curves considering C=20%, F=60/80 mesh, T=7d

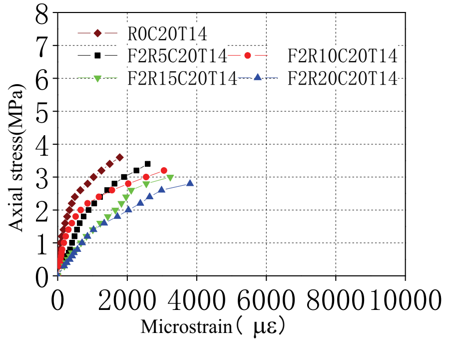

Fig. 15. Stress-strain curves considering C=20%, F=60/80 mesh, T=14d

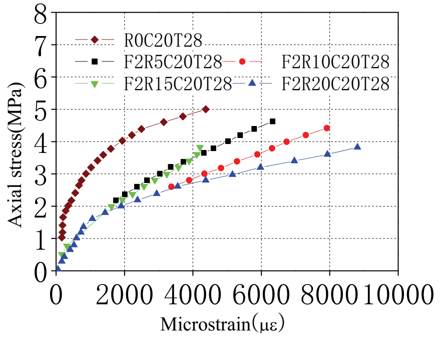

Fig. 16. Stress-strain curves considering C=20%, F=60/80 mesh, T=28d

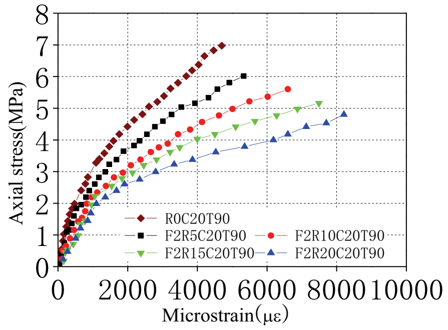

Fig. 17. Stress-strain curves considering C=20%, F=60/80 mesh, T=90d

4. SUMMARY AND CONCLUSIONS

This article investigated the influence of the amount of crumb rubber, the size of crumb rubber particle, and cement content on the compressive strength of RCS during different curing stages. From the data presented in this paper the following conclusions can be drawn:

1. Using crumb rubber in cement-treated soil can lead to a lower strength. From the results of the compressive strength tests, for cement content of 7%, 15%, 20% and 25%,the compressive strengths at 7-, 14-, 28- and 90-day curing age all show a decreasing trend when the crumb content increases. It is shown that utilizing 20% crumb rubber content can lead up to 17% and 31% reduction in the compressive strength at the curing age of 28 days and 90 days

respectively.

2. Addition of cement increases the unconfined compressive strength of samples dramatically. And the enlargement of cement content is more efficient at low cement content.
3. For the two 30/40 mesh and 60/80 mesh groups of crumb rubber that is used in the study, varying in the size of crumb rubber particle doesn't make a significant difference in unconfined compressive strength of rubberized cement soil.
4. It is noted that for the cement content 20%, the rubberized cement soil shows better plasticity than that of the control mix (without crumb rubber).

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LIST OF FIGURES AND TABLES:

Fig. 1. Compressive strength vs. curing time for soil samples.

Rys. 1. Wytrzymałość na ściskanie vs. czas utwardzania dla próbek gruntu

Fig. 2. Effect of rubber content on compressive strength at 7-day curing age

Rys. 2. Wpływ zawartości gumy na wytrzymałość na ściskanie po 7 dniach utwardzania

Fig. 3. Effect of rubber content on compressive strength at 14-day curing age

Rys. 3. Wpływ zawartości gumy na wytrzymałość na ściskanie po 14 dniach utwardzania

Fig. 4. Effect of rubber content on compressive strength at 28-day curing age

Rys. 4. Wpływ zawartości gumy na wytrzymałość na ściskanie po 28 dniach utwardzania

Fig. 5. Effect of crumb rubber content on compressive strength at 90-day curing age

Rys. 5. Wpływ zawartości granulowanych odpadów gumowych na wytrzymałość na ściskanie po 90 dniach utwardzania

Fig. 6. Effect of cement content on compressive strength at curing age of 7-day

Rys. 6. Wpływ zawartości cementu na wytrzymałość na ściskanie po 7 dniach utwardzania

Fig. 7. Effect of cement content on compressive strength at curing age of 14-day

Rys. 7. Wpływ zawartości cementu na wytrzymałość na ściskanie po 14 dniach utwardzania

Fig. 8. Effect of cement content on compressive strength at curing age of 28-day

Rys. 8. Wpływ zawartości cementu na wytrzymałość na ściskanie po 28 dniach utwardzania

Fig. 9. Effect of cement content on compressive strength at curing age of 90-day

Rys. 9. Wpływ zawartości cementu na wytrzymałość na ściskanie po 90 dniach utwardzania

Fig. 10． Stress-strain curves considering C=20%, F=30/40 mesh, T=7d

Rys. 10. Krzywe materiałowe przy C=20%, F= 30/40 Sito, T=7d

Fig. 11． Stress-strain curves considering C=20%, F=30/40 mesh, T=14d

Rys. 11. Krzywe materiałowe przy C=20%, F= 30/40 Sito, T=14d

Fig. 12. Stress-strain curves considering C=20%, F=30/40 mesh, T=28d

Rys. 12. Krzywe materiałowe przy C=20%, F= 30/40 Sito, T=28d

Fig. 13. Stress-strain curves considering C=20%, F=30/40 mesh, T=90d

Rys. 13. Krzywe materiałowe przy C=20%, F= 30/40 Sito, T=90d

Fig. 14. Stress-strain curves considering C=20%, F=60/80 mesh, T=7d

Rys. 14. Krzywe materiałowe przy C=20%, F= 60/80 Sito, T=7d

Fig. 15. Stress-strain curves considering C=20%, F=60/80 mesh, T=14d

Rys. 15. Krzywe materiałowe przy C=20%, F= 60/80 Sito, T=14d

Fig. 16. Stress-strain curves considering C=20%, F=60/80 mesh, T=28d

Rys. 16. Krzywe materiałowe przy C=20%, F= 60/80 Sito, T=28d

Fig. 17. Stress-strain curves considering C=20%, F=60/80 mesh, T=90d

Rys. 17. Krzywe materiałowe przy C=20%, F= 60/80 Sito, T=90d

Tab 1. Physical properties of studied soil

Tab. 1. Właściwości fizyczne badanego gruntu

Tab 2. Composition mixtures

Tab. 2. Skład mieszanek

Tab 3. Strength increase rate (%)

Tab. 3. Współczynnik wzrostu wytrzymałości (%)

WPŁYW GRANULOWANYCH ODPADÓW GUMOWYCH NA WYTRZYMAŁOŚĆ NA ŚCISKANIE GRUNTU STABILIZOWANEGO CEMENTEM

Słowa kluczowe: Odzysk odpadów, granulowane odpady gumowe, wytrzymałość na ściskanie, plastyczność, czas utwardzania

STRESZCZENIE:

Celem raportu jest przedstawienie wpływu granulowanych odpadów gumowych na wytrzymałość i mechaniczne zachowanie gumowanej mieszanki cementu i gruntu (*Rubberized Cement Soil*, RCS). W ostatnich dekadach wzrosło znaczenie obróbki gruntu z użyciem cementu w celu poprawy problematycznych gruntów. Kilku badaczy zmieszało różne wybrane dodatki z gruntami sztucznie cementowanymi. Ale warto zauważyć, że dodatki czasami prowadzą do wysokiej sztywności i kruchości. Ponadto problem związany z środowiskiem naturalnym jest coraz gorszy, a brak zasobów jest coraz bardziej dokuczliwy. Zastosowanie recyklingu opon gumowych w gruncie stabilizowanym cementem może być skutecznym sposobem wykorzystania gumy i rozwiązaniem problemu wysokiej sztywności i kruchości gruntów sztucznie cementowanych. Dodanie granulowanych odpadów gumowych powoduje znaczne zmniejszenie wytrzymałości oraz sztywności betonu.

W obecnym badaniu, przygotowano 26 grup próbek pod kątem pięciu różnych wartości procentowych zawartości granulowanych odpadów gumowych, czterech różnych wartości procentowych zawartości cementu i dwóch różnych stopni zmielenia cząstek granulowanych odpadów gumowych.

Grunt użyty w obecnym badaniu uzyskano z obszaru miasta Shenyang w Chinach. Podstawowe właściwości gruntu, takie jak masa właściwa, konsystencje oraz stany gruntów spoistych, przedstawiono w Tabeli 1. W celu zapewnienia jednorodności wielkości cząstek gruntu, grunt został przesiany za pomocą sita o rozmiarze oczek 2mm po osuszeniu w suszarce bębnowej i przemieleniu. W niniejszym badaniu użyto zwykłego cementu portlandzkiego klasy 32,5 zgodnego z chińską normą GB175-2007. Odpady opon gumowych zostały zmielone tak, aby otrzymać dwa rodzaje granulowanych odpadów gumowych – proszek 30/40 Mesh oraz proszek 60/80 Mesh. Do formowania próbek do badania wytrzymałości na ściskanie użyto wody bieżącej.

Badania wytrzymałości na ściskanie wykonano na sześciennych próbkach po 7, 14, 28 i 90 dniach utwardzania. Do badań użyto automatycznej maszyny ładującej (SYE-2000A) o maksymalnej wydajności 2000 kN. Zanim naprężenie osiowe osiągnęło wytrzymałość na ściskanie, wszystkie dane zostały zapisane za pomocą programowalnego przyrządu do pomiaru odkształceń statycznych DH3816. Na początku przyrost poziomu obciążenia wynosił 0.1MPa, a następnie uległ

zmianie i wyniósł 0.2MPa. Szybkość obciążania wynosiła od 100 N/s do 150 N/s. Badania powtórzono na trzech identycznych próbkach, a średnią wartość użyto w raporcie.

Wyniki badań wskazały, że przy użyciu granulowanych odpadów gumowych w gruncie stabilizowanym cementem może prowadzić do zmniejszenia wytrzymałości. Wyniki badań wytrzymałości na ściskanie, dla 7%, 15%, 20% i 25% zawartości cementu, pokazują, że wytrzymałość na ściskanie po 7, 14, 28 i 90 dniach utwardzania spada wraz ze wzrostem zawartości granulowanych odpadów. Wykazano, że wykorzystanie 20% zawartości granulowanych odpadów gumowych może prowadzić do 17% i 31% obniżenia wytrzymałości na ściskanie po odpowiednio 28 i 90 dniach utwardzania. Dodanie cementu znacznie zwiększa nieograniczoną wytrzymałość na ściskanie próbek. Ponadto zwiększenie zawartości cementu jest skuteczniejsze przy niskiej zawartości cementu. Dla dwóch grup granulowanych odpadów gumowych o wielkości 30/40 i 60/80 Mesh wykorzystanych w badaniu, różnica w wielkości granulowanych odpadów gumowych nie wnosi istotnej różnicy w przypadku wytrzymałości na ściskanie gumowanej mieszanki cementu i gruntu. Należy zauważyć, że dla 20% zawartości cementu gumowana mieszanka cementu i gruntu wykazuje lepszą plastyczność niż w przypadku mieszanki kontrolnej (bez granulowanych odpadów gumowych).