Kütahya Dumlupınar University
Institute of Graduate Studies

Journal of Scientific
Reports-A
E-ISSN: 2687-6167
Number 51, December 2022

RESEARCH ARTICLE

EVALUATION of GEOTECHNICAL BEHAVIOR of CLAY SOIL with CRUMB RUBBER ADDITION

Sadettin TOPÇU[1,*], Evren SEYREK[2]

[1*]Kütahya Dumlupınar University, Kütahya Vocational School of Technical Sciences, Department of Construction Technology, Kütahya, sadettin.topcu@dpu.edu.tr, ORCID: 0000-0003-1306-2502
[2]Kütahya Dumlupınar University, Faculty of Engineering, Department of Civil Engineering, Kütahya, evren.seyrek@dpu.edu.tr, ORCID: 0000-0003-4373-6723

Receive Date:30.09.2022 *Accepted Date: 24.10.2022*

ABSTRACT

The issue of investigating the usability of waste materials in many different applications of civil engineering has attracted the attention of researchers until today. The additive material used for stabiliser is waste material that causes positive effects on the environment, engineering and economy. Studies on the use of waste materials, especially in improving road and foundation filling materials, have recently attracted attention. In this study, compaction parameters, California Bearing Ratio (CBR) with the soaked and unsoaked condition and unconfined compressive strength values of soil-crumb rubber mixtures were evaluated. To investigate these effects, crumb rubber with various percentages (2.5%, 5.0%, 7.5%, 10.0% and 15.0%) was added to clay soil taken from Eskisehir city in Turkey. CBR and unconfined compressive test results show that a 5.0% crumb rubber level is optimum. For 5.0% additive level, soaked and unsoaked CBR values increased by approximately 18% and 25%, respectively. The highest increase was seen at same additive level as 8% compared to pure clay specimen for unconfined compressive strength.

Keywords: *Clay, Crumb rubber, CBR, Strength*

1. INTRODUCTION

Due to the rapid growth in vehicle production worldwide, approximately 1,5 billion tons of tires are wasted yearly [1]. About 3 million tons of tires are scrapped every year in Europe [2]. 180.000-200.000 tons of scrap tires are generated every year in Turkey [3]. Most waste tires are deposited in storage yards and landfills. Therefore, they occupy significant lands. In addition, many of them burn and cause toxic fumes (containing substances such as styrene, benzene, butadiene, CO, SO_2, etc.) to nature. These rubber-based wastes, which harm nature and human health, pose a significant problem.

Waste tires are used as a wedge in port structures, parking equipment in children's playgrounds, and fuel in power plants and cement factories [4]. There are three different specifications for waste tires to be used in the shredded form [5-7]. Besides Busic et al.[8] and Li et al. [9], there are also classifications based on the sizing suggested. In general, in these specifications and approaches, waste tire pieces are called chips, tire-derived aggregate, ground, crumb, fibre, granulate and powder rubber, depending on their size and shape. The performance of composite mixtures consisting of soil and waste tire depends on the type of soil and the size of the waste tire pieces.

Many types of research have been carried out in geotechnical engineering applications such as landfill, subgrade backfilling and retaining walls to obtain a benefit for the recycling of waste tires [10-13]. These materials, which are lightweight aggregates, can absorb vibrations while creating low stress in soil. Sandy soils are generally preferred for stabilization with the waste tire. The reason for this is the lack of cementing at the molecular level of the waste tire. Their interaction with the sand grains is also limited to friction, locking and filling the spaces between the grains. Use of waste rubber pieces on sand soils; compression and deformation [10,14,15], strength [15,16-18], dynamic properties [19-21], thermal properties [22,23], hydraulic properties [17,24] and microstructural properties [10,15,25]. In summary, waste rubber pieces mixed with sand reduce compressibility and vibrations, increase strength and hydraulic conductivity, and decrease thermal conductivity.

Studies carried out on clay soils were carried out under the headings of compression, strength, dynamic, thermal, hydraulic and microstructural characteristics like sand. Using different waste rubber particle diameter distributions, the variation of compaction parameters is also different. In general, the maximum dry density (M.D.D) and optimum moisture content (O.M.C) decrease depending on the size of the waste rubber [1,26,27]. Knowing the consolidation characteristics in determining the settlement behavior in fine-grained soils is necessary. There are also many studies on the consolidation characteristics of clay soil-waste rubber mixtures [28-30]. The effect of the waste rubber may also vary in the consolidation characteristics depending on the particle diameter distribution.

Strength parameters of soil-waste rubber mixtures in fine-grained soils are investigated by the Direct Shear Test [31,32], Triaxial Test [33-35], Unconfined Compressive Test [27,32,36-38] and California Bearing Ratio (CBR) Test) [26,27,35]. When these studies are evaluated in general, it can be said that waste rubber makes positive changes in the strength parameters of clay soils up to a certain percentage of contribution.

Clay-waste rubber mixture improves the seismic design parameters of slopes, embankments and retaining walls where it will be used as filling material. Waste rubber additive reduces the vibration of clay soils and provides high damping characteristics [19]. In waste rubber additives, clay soils' permeability coefficients and hydraulic conductivity are greatly reduced [36,39]. SEM analysis showed voids, gaps and micro-cavities at the crumb rubber-clay soil interfaces [27].

In this study, modification properties of soil-crumb rubber mixtures were assessed in term of compaction behavior, California Bearing Ratio (CBR) with the soaked and unsoaked condition and unconfined compressive strength. To investigate these effects, crumb rubber varying from 0.4 to 5.0 mm with various percentages (2.5%, 5.0%, 7.5%, 10.0% and 15.0%) was added to clay soil taken from Eskişehir city in Turkey.

JSR A
Journal of Scientific Reports

2. MATERIAL AND METHOD

2.1. Soil

The clay soil was taken from Eskisehir city in Turkey. The physical parameters including sieve and hydrometer test, water content, consistency limits and specific gravity values were obtained based on ASTM methods [40]. The particle size distribution of the clay soil is given in Figure 1. As seen in Figure 1, the soil contains 56% fines.

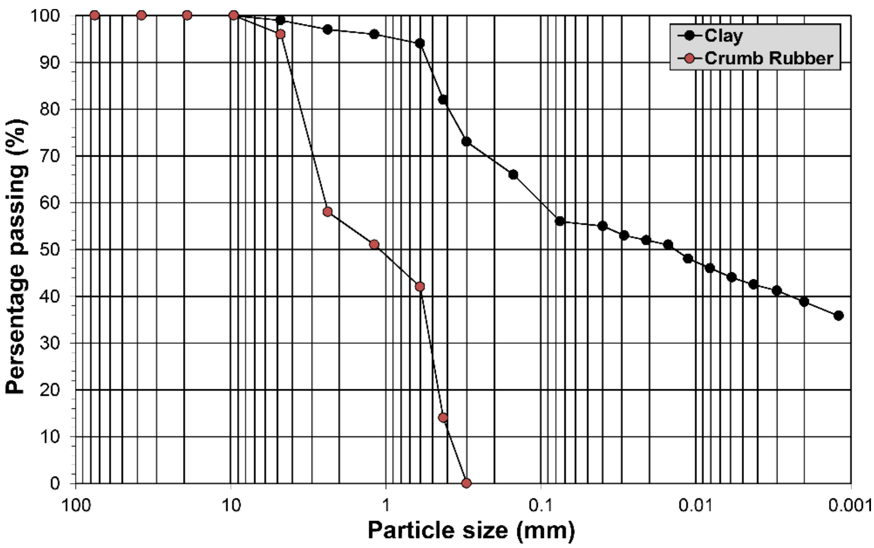

Figure 1. Particle size distribution of clay and crumb rubber.

The geotechnical features of the soil are summarised in Table 1. According to Table 1, the soil was classified as low plasticity (CL) clay under the Unified Soil Classification System (USCS). The clay soil sample with an activity value of 0.49 was described as inactive. The specific gravity of clay soil is 2.72. Liquidity limit value is calculated as a ratio of the difference between natural water content, plastic limit and liquid limit, and consistency is semi-solid. The compaction parameters maximum unit weight and optimum water content were determined with Standard Proctor Test [41] as 18.2 kN/m^3 and 14.2%, respectively.

Table 1. Geotechnical properties of clay soil.

Property	Clay
<4.75 mm (%)	99.0
<0.075 mm (%)	56.0
<0.002 mm (%)	38.8
Water content, w (%)	12.0

Liquid Limit, LL (%)	34.0
Plastic Limit, PL (%)	15.0
Plasticity Index, PI (%)	19.0
Specific Gravity, G_s	2.72
Classification (USCS)	CL
Activity, A	0.49
γ_{dmax} (kN/m^3)	18.2
w_{opt} (%)	14.2

2.2. Crumb Rubber

The crumb rubber adopted as an additive in this investigation was gained from a private company in Istanbul, Turkey. The particle size distribution of crumb rubber is given in Figure 1. It can be seen that most of the particles ranged from 0.4 to 5.0 mm. Busic et al. [8] classified waste rubber with a size of between 0.425mm and 4.75mm as crumb rubber. Effective size (D_{10}), coefficient of uniformity and curvature was determined as 0.38 mm, 6.32 and 0.30, respectively. The gradation of crumb rubber is similar to poorly graded sand (SP) when evaluated based on the USCS classification system. The specific gravity value is 1.09 (Table 2). It is stated that specific values of crumb rubber are between 1.02 and 1.27 [2].

Table 2. Geotechnical properties of crumb rubber.

Property	**Crumb Rubber**
<4.75 mm (%)	96.0
<0.075 mm (%)	0.0
<0.002 mm (%)	0.0
D_{10} (mm)	0.38
D_{30} (mm)	0.52
D_{50} (mm)	1.05
D_{60} (mm)	2.4
Coefficient of uniformity, C_u	6.32
Coefficient of curvature, C_c	0.30
Specific Gravity, G_s	1.09

2.3. Experimental Program

In the literature, different studies are performed to research the impact of crumb rubber on the geotechnical engineering behavior of clay soils with different rubber content. Compaction and strength behavior of kaolin clay was investigated by Priyadarshee et al. [42] with different ratios of tire crumbles such as 1.0%, 2.0%, 5.0%, 10.0% and 20.0%. Yadav and Tiwari [27] used 2.5%, 5.0%, 7.5% and 10.0% rubber content to treat soft clay soil. Vijay [43] studied stress-strain and penetration characteristics of clay with crumb rubber addition varying from 10% to 50%. Li and Li [44] used three scrap tire crumbs contents,10.0%, 20.0% and 30.0%, to investigate the mechanical properties of mixtures. The most striking point in these studies is that the crumb rubber content is considered at different ratios. The results of these researches have shown that the selection of the most effective content of waste rubber material is closely related to the gradation of rubber material. For this reason, in this study, the crumb rubber material was added to clay soil in different amounts (2.5%, 5.0%, 7.5%, 10% and 15% of the dry soil weight).

The experimental studies carried out to determine compaction parameters, California Bearing Ratio (CBR%) and strength values of the clay soil-crumb rubber mixtures. According to Table 3, the designations used for clay soil are S and R for crumb rubber. For example, 5SR represents a mixture having 95% soil and 5% crumb rubber. Compaction Test, CBR Test and Unconfined Compressive Tests are performed for all of the selected mixture ratios.

Table 3. Experimental program.

Crumb Rubber (%)	Mixture Designation	Atterberg Limits	Compaction Test	CBR Test		Unconfined Compressive Test
				Soaked	Unsoaked	
0.0	0SR	□	□	□	□	□
2.5	2.5SR		□	□	□	□
5.0	5SR		□	□	□	□
7.5	7.5SR		□	□	□	□
10.0	10SR		□	□	□	□
15.0	15SR		□	□	□	□

2.3.1. Preparation of clay soil-crumb rubber

Clay soil obtained from the field was dried for 24 hours in an oven, and then it was sieved from #4. Dry crumb rubbers were added to dry clay soil with different ratios (2.5%, 5.0%, 7.5%, 10.0% and 15.0%) and mixed (Figure 2). Special attention was paid to attaining a homogenous mixture during the mixture preparation stage. Proctor tests at the standard Proctor energy level were carried out on these prepared soil-crumb-rubber mixtures [41]. Maximum dry unit weight and optimum water content values of the mixtures were determined. CBR and unconfined compressive tests (UCT) were performed on the compacted samples having a optimum water content.

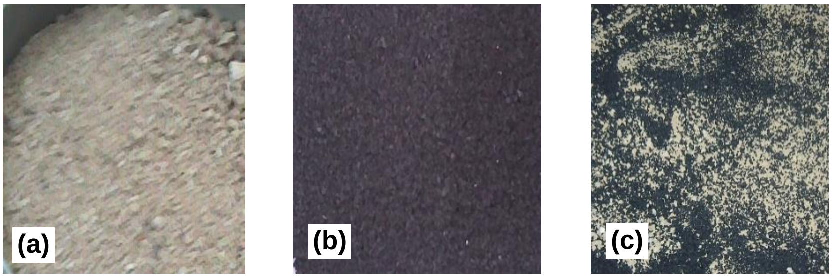

Figure 2. Test materials (a) clay soil (b) Crumb rubber (c) Clay-crumb rubber mixture.

2.3.2. Compaction test

The water content and dry unit weight relationship are necessary for the geotechnical behavior of soil subjected to static and dynamic loading. The specimens were compacted in three layers and an energy degree of 600 kN-m/m3 was applied as suggested in ASTM D698–12 [41]. The dry crumb rubber and clay were mixed until obtaining a homogenous mixture before the compaction. A view of the compaction process for additive-free soil and soil with 5.0% crumb addition is given in Figure 3.

Figure 3. Compacted test materials (a) clay soil (b) Clay-crumb rubber mixture (%5 rubber).

2.3.3. California Bearing Ratio (CBR) test

CBR test results evaluate the subgrade strength of roads and pavements. The CBR test is performed to find a load-penetration relation by pushing a cylindrical piston with a cross-sectional area of 19.35 cm^2 into the ground at a certain speed. For any penetration value, CBR, defined as the ratio of the measured load to a standard load, is usually given for 2.5 mm and 5.0 mm penetration. In this study, CBR tests of pure clay and clay-rubber mixtures for unsoaked and soaked conditions as described in ASTM D1883-21[45]. The samples were prepared at each mixture's maximum dry unit weight and optimum water content. Mixtures were soaked in water for 96 h before testing for soaked conditions.

2.3.4. Unconfined compressive test

The unconfined compressive test is widely used for determining the undrained shear strength value. This test is preferred due to be practical, easy and rapid evaluation. Unconfined compression tests of soil-crumb rubber mixtures compacted according to their compaction characteristics were carried out according to standard [46]. The samples were prepared in a mold designed with a ratio of height/diameter is 2.

3. RESULTS and DISCUSSION

3.1. Results of Compaction Tests

Results of compaction tests for various additive levels are given in Table 4. It can be said that including the crumb rubber to clay soil causes to decrease the maximum unit weight and optimum moisture content. The maximum dry unit weight value of pure clay soil was 18.2 $kN/m^{3.}$ The same value decreased to 15.2 kN/m^3 with 15.0% crumb rubber addition. When the optimum water content

JSR A
Journal of Scientific Reports

was 14.2% for pure clay soil, the optimum water content decreased to 12.4% after the same amount of crumb rubber addition.

Table 4. Compaction characteristics of soil-crumb rubber mixtures.

Mixture Designation	γ_{dmax} (kN/m^3)	w_{opt} (%)
0SR	18.2	14.2
2.5SR	17.4	13.9
5SR	17.0	13.6
7.5SR	16.2	13.1
10SR	15.8	12.9
15SR	15.2	12.4

With 5% crumb rubber addition to clay soil, the maximum dry unit weight decreases by 7% of pure clay soil. The same value decreases by approximately 17% with 15% crumb rubber.

Figure 4 was prepared to see the general trend of the relationship between the optimum moisture content and maximum dry unit weight of the mixtures. This figure shows a decrease in maximum dry unit weight and optimum water content with an increment in the rubber content. The specific gravity value of crumb is 1.09. Since specific gravity value of crumb rubber is too low compared to pure clay soil, the specific gravity of the mixture reduces with the rise in the crumb rubber amount. A decrease in the maximum dry unit weight can be explained with this situation. In addition, Cabalar et al. [26] expressed that the decrease in optimum moisture content of the clay-rubber mixtures could be explained with rubber's lower water absorption capacity. These results are similar with the other researches in the literature [27,44].

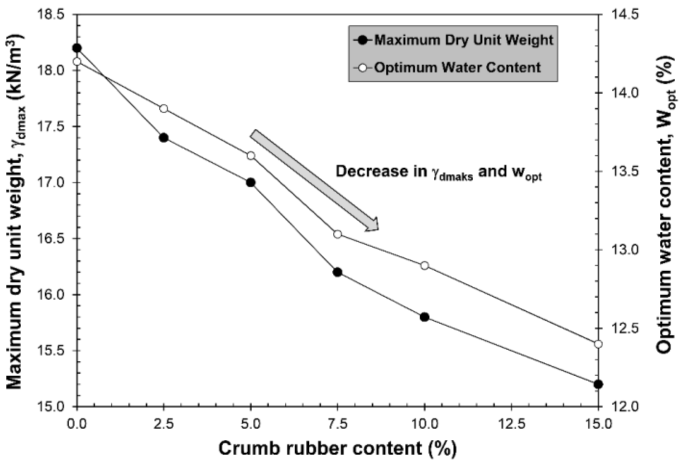

Figure 4. Compaction properties of clay-crumb rubber mixtures.

JSR A
Journal of Scientific Reports

Topçu, S. and Seyrek, E., Journal of Scientific Reports-A, Number 51, 136-148, December 2022.

3.2. Results of California Bearing Ratio (CBR) Tests

Results of the CBR test performed on clay soil stabilized using various percentages of crumb rubber are shown in Figures 5a for unsoaked conditions and 5b for soaked conditions.

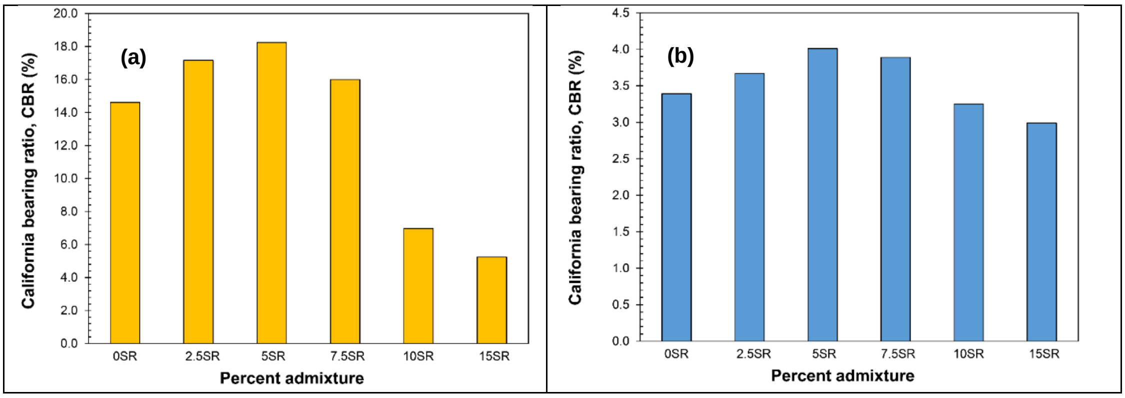

Figure 5. Variations of CBR value of pure clay and mixtures (a) soaked (b) unsoaked condition.

When both Figure 5a and Figure 5b are evaluated together, the CBR value of mixtures for the soaked condition is smaller than mixtures for the unsoaked condition. It should be noted that the CBR value of mixtures with 10.0% and 15.0% additive levels is much smaller than the CBR value of clay soil in a non-additive state for dry conditions. CBR value is 14.61% for specimen 0SR. The highest CBR value is 18.24%, corresponding to a 25% increase compared to specimen 0SR (Figure 5a).

CBR test results for soaked conditions show that the additive level giving the largest CBR value is 5.0% crumb rubber (Figure 5b). The CBR value for clay soil with 5.0% crumb rubber corresponds to approximately 1.18 times the CBR value of pure clay soil. Another remarkable point between Figure 5a and Figure 5b is that the CBR value for clay with 10.0% crumb rubber is very close to the CBR value of pure clay soil.

For both conditions, the CBR value increases to 5.0% crumb rubber and decreases. These results are in concord with other studies in the literature. According to Yadav and Tiwari, the reduction in CBR value with increasing the rubber content can be explained with the higher compressibility of rubber particles compared to soil particles [27].

3.3. Results of Unconfined Compressive Tests

Unconfined compressive strength (UCS) values for different proportions of Clay–crumb rubber mixtures compacted according to their compaction characteristics are given in Figure 6 as the UCS value of the treated soil to the UCS value of the untreated soil. UCS value of pure clay soil is determined as 140.1 kPa.

UCS values are 145.2 kPa and 151.2 kPa for 2.5% and 5.0% crumb rubber addition, respectively. Minimum UCS value is observed in clay soil with 15.0% crumb rubber additives as 119.6 kPa. The

JSR A
Journal of Scientific Reports

UCS value of the mixtures with a rubber ratio between 2.5% and 15% to the UCS value of the pure clay soil varies between 0.85 and 1.03. The highest rate value is seen at the 5.0% additive level.

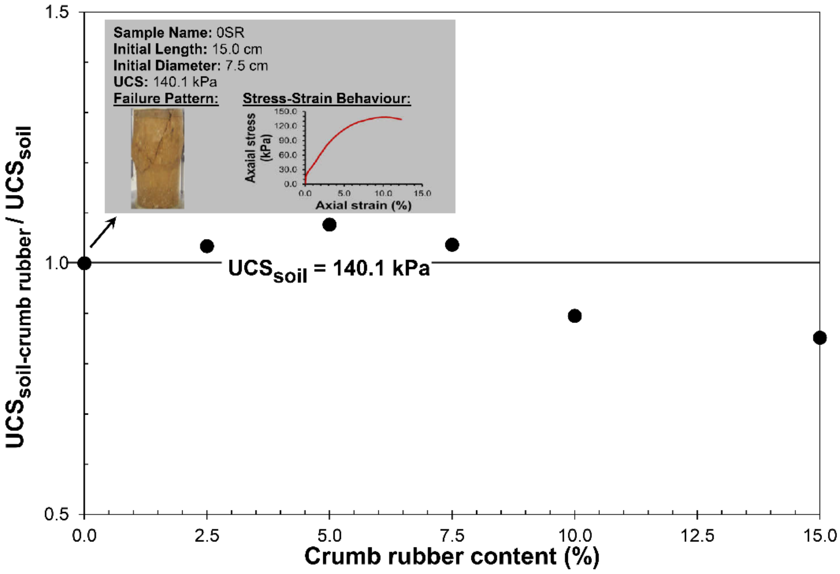

Figure 6. Effect of crumb rubber contents on unconfined compressive strength (UCS) of mixtures.

According to Figure 6, UCS value of mixtures increases with the crumb rubber content by up to 5%. Ajmera et al. [38] stated that this behavior could be related to the increase in the dry unit weight of the mixtures with crumb rubber addition until the threshold content. According to a different perspective by Kim and Kang [47], the friction and bonding loss between crumb rubber and clay particles could reduce unconfined compressive strength.

4. CONCLUSIONS

This study was carried out to investigate the influence of crumb rubber sizes varying from 0.4 to 5.0 mm on the compaction and strength behavior of clay soil taken from Eskisehir city in Turkey. Compaction, CBR and UCT experiments were performed on clay soil with different crumb rubber contents (2.5%, 5.0%, 7.5%, 10.0% and 15.0%), and the following results have been reached:

- Including the crumb rubber in clay soil reductions the maximum unit weight and optimum moisture content of the mixtures with all different additive ratios. It is thought that the lower water absorption capability of rubber causes to this behavior.
- For unsoaked and soaked conditions, CBR values increase to 5.0% crumb rubber and starts to decrease after this threshold value. This decrease in CBR values on increasing the rubber content may be ascribed to the higher compressibility of rubber particles.

- Addition of crumb rubber to the clay soil results in an initial increase in the UCS followed by a reduction in the unconfined compressive strength (UCS) after a peak value is achieved. The UCS value peak occurs when 5.0% crumb rubber is used. Therefore, 5.0% crumb rubber content can be accepted as optimum strength for this study.
- It should be noted that the results obtained within the scope of this study are not independent of rubber size.
- Experimental findings demonstrate that optimum crumb rubber content is 5.0% for effective solution. In this way, the unfavorable effects of this waste material on the environment will be reduced and contribute to the economy.

ACKNOWLEDGEMENT

The authors declare that there is no conflict of interest in the course of this study.

REFERENCES

[1] Yadav, J.S., Tiwari, S.K., (2016), Effect of inclusion of crumb rubber on the unconfined compressive strength and wet-dry durability of cement stabilized clayey soil, J Build Mater Struct, 3:68–84.

[2] Edinçliler, A., (2010), Atık lastiklerin geoteknik uygulamalarda hafif malzeme olarak kullanılması, Dördüncü Ulusal Geosentetikler Konferansı, İstanbul, Türkiye, 58-68.

[3] URL-1, Lastik Sanayicileri Derneği, https://www.lasder.org.tr/, Erişim 26.09.2022.

[4] Karabörk, F., Akdemir, A., (2013), Atık Taşıt Lastiklerinin Parçalanması ve Lastik Tozunun Karakterizasyonu, Erciyes Üniversitesi Fen Bilimleri Enstitüsü Fen Bilimleri Dergisi, 29(1): 29-40.

[5] ASTM D6270-08, (2008), Standard practice for use of scrap tires in civil engineering applications. West Conshohocken, Pa: ASTM standard D6270-08. ASTM International.

[6] ASTM D5681-18, (2018), Standard Terminology for waste and waste management. West Conshohocken, Pa: ASTM standard D5681-18. ASTM International.

[7] CEN Workshop agreement (CWA) 14243-2002. CWA; 2002.

[8] Busic, R, Milicevic, I., Sipos T. and Strukar, K., (2018), Recycled rubber as an aggregate replacement in self-compacting concrete—literature overview, Materials, 11:1729.

[9] Li, B., Huang, M. and Zeng, X., (2016), Dynamic behavior and liquefaction analysis of recycled-rubber sand mixture, J Mater Civ Eng, 28:04016122.

[10] Liu, L., Cai, G. and Liu, S., (2018), Compression properties and micro-mechanisms of rubber-sand particle mixtures considering grain breakage, Construct Build Mater, 187: 1061–1072.
[11] Morales, E., Filiatrault A. and Aref, A., (2018), Seismic floor isolation using recycled tires for essential buildings in developing countries, Bull Earthq Eng, 16:6299–6333.

[12] Neaz Sheikh, M,, Mashiri, M., Vinod, J. and Tsang, H-H., (2012), Shear and compressibility behavior of sand–tire crumb mixtures, J Mater Civ Eng, 25:1366–1374.

[13] Tafreshi, S.M., Mehrjardi, G.T. and Dawson, A.R., (2012), Buried pipes in rubber-soil backfilled trenches under cyclic loading, J Geotech Eng, 138:1346–1356.

[14] Guo, Y., Morgan, J.K., (2006), The frictional and micromechanical effects of grain comminution in fault gouge from distinct element simulations, J Geophys Res Solid Earth,111.

[15] Zhang, T., Cai, G. and Duan, W., (2018), Strength and microstructure characteristics of the recycled rubber tire-sand mixtures as lightweight backfill, Environ Sci Pollut Res, 25:3872–3883.

[16] Ahmed, I., (1993), Laboratory study on properties of rubber-soils.

[17] Edil, T.B., Bosscher, P.J., (1994), Engineering properties of tire chips and soil mixtures, Geotech Test J, 17:453–464.

[18] Foose, G.J, Benson, C.H. and Bosscher P.J., (1996), Sand reinforced with shredded waste tires, J Geotech Eng-ASCE, 122:760–767.

[19] Feng, Z-Y, Sutter, K.G., (2000), Dynamic properties of granulated rubber/sand mixtures, Geotech Test J, 23:338–344.

[20] Zornberg, J.G., Cabral, A.R. and Viratjandr, C., (2004), Behavior of tire shred-sand mixtures, Can Geotech J, 41:227–241.

[21] Senetakis, K., Anastasiadis, A. and Pitilakis, K., (2012), Dynamic properties of dry sand/rubber (SRM) and gravel/rubber (GRM) mixtures in a wide range of shearing strain amplitudes, Soil Dynam. Earthq. Eng., 33:38–53.

[22] Mounanga, P., Gbongbon, W., Poullain, P. and Turcry, P., (2008), Proportioning and characterization of lightweight concrete mixtures made with rigid polyurethane foam wastes, Cement Concr Compos, 30:806–814.

[23] Corinaldesi, V., Mazzoli, A. and Moriconi, G., (2011), Mechanical behavior and thermal conductivity of mortars containing waste rubber particles, Mater Des, 32: 1646–1650.

[24] Edil, T.B., Bosscher, P.J., (1992), Development of engineering of Criteria for shred waste tires in highway applications final report.

[25] Perez, J.L., Kwok, C. and Senetakis, K., (2017), Micromechanical analyses of the effect of rubber size and content on sand-rubber mixtures at the critical state, Geotext Geomembranes, 45:81–97.

[26] Cabalar, A.F., Karabash, Z. and Mustafa, W.S., (2014), Stabilising a clay using tyre buffings and lime. Road Mater. Pavement Des., 15, 872–891.

[27] Yadav., J., Tiwari, S., (2017), The impact of end-of-life tires on the mechanical properties of fine-grained soil: a review, Environ Dev Sustain,1–84.

[28] Cokca, E., Yilmaz, Z., (2004), Use of rubber and bentonite added fly ash as a liner material, Waste Manag, 24:153–164.

[29] Seda, J.H., Lee, J.C., Carraro, J.A.H., (2007), Beneficial use of waste tire rubber for swelling potential mitigation in expansive soils, ASCE Geotechnical Special Publication 172, 1–9.

[30] Srivastava, A., Pandey, S. and Rana, J., (2014), Use of shredded tyre waste in improving the geotechnical properties of expansive black cotton soil, Geomechanics Geoengin, 9:303–311.

[31] Tatlisoz, N., Benson, C.H. and Edil, T.B., (1997), Effect of fines on mechanical properties of soil- tire chip mixtures, Testing Soil Mixed with wWaste or Recycled Materials, ASTM International.

[32] Akbulut, S., Arasan, S., Kalkan, E., (2007), Modification of clayey soils using scrap tire rubber and synthetic fibers, Appl Clay Sci, 38:23–32.

[33] Ozkul, Z.H., Baykal, G., (2007), Shear behavior of compacted rubber fiber-clay composite in drained and undrained loading, J Geotech Geoenviron, 133:767–781.

[34] Asadzadeh, M., Ersizad, A., (2013), Effect of tire-chips on geotechnical properties of clayey soil, In: International Symposium on Advances in Science and Technology, p. 117–20.

[35] Tajdini, M., Nabizadeh, A., Taherkhani, H. and Zartaj, H., (2017), Effect of added waste rubber on the properties and failure mode of kaolinite clay, Int J Civ Eng, 15:949–958.

[36] Al-Tabbaa, A., Aravinthan, T., (1998), Natural clay-shredded tire mixtures as landfill barrier materials, Waste Manag, 18:9–16.

[37] Signes, C.H., Garzon-Roca, J., Fernandez, P.M., de la Torre, M.E.G. and Franco, R.I., (2016), Swelling potential reduction of Spanish argillaceous marlstone Facies Tap soil through the addition of crumb rubber particles from scrap tyres, Appl Clay Sci,132: 768–773.

JSR A
Journal of Scientific Reports

[38] Ajmera, B., Tiwari, B., Koirala, J. and Obaid, Z., (2017), Compaction Characteristics, Unconfined Compressive Strengths, and Coefficients of Permeability of FineGrained Soils Mixed with Crumb-Rubber Tire, Journal of Materials in Civil Engineering, 29 (9), 1-10.

[39] Al-Tabbaa, A., Blackwell, O., Porter, S., (1997), An investigation into the geotechnical properties of soil-tyre mixtures, Environ Technol, 18:855–860.

[40] ASTM, (1994), Annual Book of ASTM Standards, Soil and Rock. American Society for Testing and Materials, 04.08.

[41] ASTM D698–12, (2021), Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft3 (600 kN-m/m3)), ASTM International, West Conshohocken, PA USA.

[42] Priyadarshee, A., Gupta, D., Kumar, V. and Sharma, V., (2015), Comparative study on performance of tire crumbles with fly ash and kaolin clay, International Journal of Geosynthetics and Ground Engineering, 1:38, 7p.

[43] Vijay, S., (2018), Stress-strain and penetration characteristics of clay modified with crumb rubber, Revista Facultad de Ingenieria, vol. 27 (49), 65-75.

[44] Li, S., Li, D., (2018), Mechanical properties of scrap tire crumbs-clayey soil mixtures determined by laboratory tests, Advances in Materials Science and Engineering, Article ID 1742676, 10 pages.

[45] ASTM D1883-21, (2021), Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils, ASTM International: Philadelphia, PA, USA.

[46] ASTM, D2166-13/D2166M-16, (2016), Standard Test Method for Unconfined Compressive Strength of Cohesive Soil, ASTM International, West Conshohocken, PA USA.

[47] Kim, Y.T., Kang, H.S., (2013), Effects of rubber and bottom ash inclusion on geotechnical characteristics of composite geomaterial. Marine Georesources and Geotechnology, 31(1), 71–85.