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RESEARCH ARTICLE

ASSESSMENT OF TYRE RUBBER-SOIL INTERACTION THROUGH ADVANCED GEOTECHNICAL TESTING

Talal Ahmed[ab]*, Sajjad Ali[a], Muhammad Ali Bhatti[a], Masood Anwar[a], Tooba Nayab[b], Minahil Saeed[b], Munahil Tarique[b]

[a] Department of Earth and Environmental Sciences, Bahria University, Islamabad Pakistan
[b] Earthocity Science Hub, Earthocity, Islamabad, Pakistan
**Corresponding Author Email: ttalal.pg@gmail.com*

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ABSTRACT

The utilization of recycled waste materials in geotechnical and civil engineering presents an eco-friendly approach to waste management, with the potential to enhance soil properties. Scrap tyres, in particular, possess valuable characteristics that can be effectively harnessed for various engineering applications. This study conducted in sector H-12, Islamabad, Pakistan,examines the impact of incorporating crumb rubber, obtained from scrap tyres, as an additive in clayey soil. Soil specimens were statically compacted at optimum moisture content and maximum dry density, incorporating 3%, 5%, 7%, 10%, and 15% by weight of crumb rubber into the base soil. The experimental results indicate a reduction in optimum moisture content and maximum dry density. The California Bearing Ratio (CBR) strength demonstrated an initial increase with up to 7% rubber incorporation, followed by a subsequent decline. These findings suggest that waste crumb rubber can be effectively employed in various geotechnical applications up to a certain proportion, offering a sustainable solution for waste management and soil enhancement.

KEYWORDS

California bearing ratio, Maximum dry density, Optimum moisture content, Crumb rubber.

1. INTRODUCTION

The current era witnesses a significant surge in population growth, surpassing the capacity of available resources to adequately meet human needs. In response, researchers are diligently exploring optimal methodologies to utilize funds effectively. Enhancing the utilization of these funds is crucial, necessitating the incorporation of specialized approaches in geotechnical and civil engineering (Ayothiraman and Meena, 2011). The inception of modern soil stabilization dates back to the 1920s in the United States, a period marked by the implementation of regulations on various industries during the rapid industrial expansion (Ayothiraman and Meena, 2011).

Faced with the need to dispose of highly toxic liquid waste, paper mills, once discharging by-products into local rivers, sought innovative solutions (Tweedie et al., 1998). One such solution involved utilizing the waste as a dust palliative on dirt roads (Rokade, 2012). Surprisingly, some treated roads developed a durable surface, while others did not. It took several decades of extensive private and government research, coupled with technological advancements in the 1940s and 1960s, to comprehend that the change was due to a chemical reaction between the waste solution and the clay particles in the soil (Tweedie et al., 1998).

As a result, traditional soil stabilizers were established. In contemporary times, researchers are exploring various combinations of different waste materials to enhance the engineering properties of soil (Aryal and Kolay, 2020). Among these, substantial progress has been achieved by incorporating waste materials such as rubber tire chips, shredded tires, and crumb rubber in numerous investigative studies to improve soil properties (Otoko and Pedro, 2014).

Constructing on a property with clayey soil poses challenges due to its low strength and increased compressibility, particularly with rising water content, posing a threat to construction projects. Instead of seeking alternative land, a more practical approach is to modify the characteristics of the existing land. In engineering applications, techniques like compaction, drainage, and soil reinforcement can be employed to stabilize the soil. This involves the incorporation of various admixtures such as lime powder, cement, fly ash, industrial waste, etc. The utilization of waste materials for soil stabilization presents an attractive option, offering cost-effectiveness and aiding in waste management (Vergara and Tchnobanoglous, 2012).

The environmental and health issues resulting from waste produced through microbial processes or leaching methods can have significant global implications. The substantial volume of soil waste generated worldwide, stemming from discarded vehicle tires and pipes, is a consequence of escalating waste concerns (Munnoli et al., 2013). There are three primary methods for disposing of waste tires and tubes: stockpiling, land filling, and burning. Stockpiling not only creates an unsightly appearance but also poses potential health hazards.

The combination of rainwater, windblown debris, and trapped dust within discarded tires creates an environment conducive to the breeding of disease-carrying vermin and mosquitoes. Stockpiles also present a fire hazard, and once ignited, they are challenging to extinguish, releasing toxic smoke and contaminating groundwater. When disposed of in landfills alongside municipal solid waste, tyres resist compaction, reducing overall landfill capacity. Whole tyres may surface in landfills, causing damage to the final cover of a closed landfill. However, burying sliced tires in landfills is still an allowable practice, as slicing minimizes the potential for tires to

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resurface (Otoko and Pedro, 2014).

The open burning of tyres poses hazards related to air pollution, including particulates, odors, visual impacts, and contaminants associated with landfills, such as fumes, polycyclic aromatic hydrocarbons, furans, dioxins, and nitrogen oxides. To transform waste rubber tyres into a valuable resource, there is a need for a cost-effective and environmentally friendly alternative. Consequently, a study was conducted to explore the potential use of waste rubber tyres for energy recovery or their incorporation in flexible road pavements. Traditionally, tyres were either burned or sent to kilns, leading to serious issues like cancer. Therefore, an alternative approach is being explored, focusing on the use of crumb rubber tyres in sub-grade soil as a soil binder, aiming to repurpose them for a safe and beneficial purpose (Munnoli et al., 2013).

Pakistan, classified as a developing country, is experiencing a growing number of vehicles, leading to a daily increase in the quantity of waste tyres. Statistical research indicates that the tyre sector in Pakistan can only fulfill approximately 12-15% of the global demand for tyres. Although there is no precise statistic, the annual tyre consumption in the country is estimated to be around 2-3 million metric tons. In terms of waste tyre generation, Pakistan is ranked 89th globally, producing 109 million metric tons (MTY) (Jan et al., 2015).

The study conducted by according to them the study analyzed soil sample characteristics through various tests, including those conducted on soil samples mixed with different ratios of rubber (4%, 6%, 8%, 10%) and coir (0.25, 0.5, 0.75) (Deepiya et al., 2015). It was found that adding 4% crumb rubber to clayey soil resulted in optimal moisture content. Moreover, adding 6% rubber to the clayey soil effectively increased its bearing capacity and shear strength compared to normal soil. Similarly, the addition of 0.5% coir to clayey soil led to optimal moisture content and enhanced bearing capacity. Additionally, incorporating 0.5% coir increased the soil's shear strength compared to regular soil. Results from unconfined compression tests, Proctor compaction tests, and California bearing tests indicated that adding 6% rubber and 0.5% coir yielded superior outcomes compared to other ratios. In conclusion, the study suggests that adding 6% rubber and 0.5% coir significantly improves shear strength and overall soil performance (Deepiya et al., 2015).

In our study, the soil samples were retrieved from NUST Gate 10 in sector H-12, Islamabad, as our designated research site. Through the geotechnical index testing, it was revealed that the soil’s predominant clayey nature rendered it unsuitable for stabilization purposes. To counter this limitation, the strategic decision was made to introduce an admixture into the soil, specifically utilizing rubber waste sourced from tyres to bolster its stabilization properties. Employing the compaction method as the preferred soil stabilization technique, the research primarily aimed to evaluate the soil’s engineering characteristics, encompassing Optimum Moisture Content (OMC), Maximum Dry Density (MDD), California Bearing Ratio (CBR), and Plastic Limit Index (PI), across varying proportions of crumb rubber incorporation. Furthermore, the investigation sought to meticulously assess the efficacy of crumb Rubber in enhancing soil stabilization efforts.

2. STUDY AREA

The study area lies near the NUST Gate 10, in Sector H-12 Islamabad. The map given below displays the soil sampling sites from where the soil samples were collected for laboratory testing to determine various geotechnical parameters for enhancing the soil through our proposed methodology. Three sites wereselected for soil collection purpose, chosen from the same zone although with varying sampling locations.

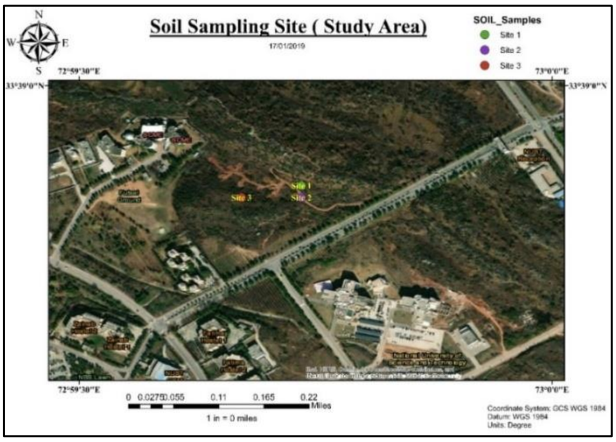

Figure 1: Map showing soil sampling sites.

3. METHODOLOGY

The study encompassed a comprehensive process, starting with material collection, followed by sampling methods, and a battery of tests conducted on the collected specimens. Various samples were meticulously prepared, each comprising different proportions of soil and crumb rubber. Through a meticulous series of tests, diligent efforts were made to ascertain the optimal composition for the mixed samples. This involved a systematic exploration aimed at determining the ideal balance between soil and crumb rubber content to enhance the desired properties of the materials under investigation.

In our research, a comprehensive array of geotechnical index tests were undertaken in the material laboratory. These included the sieve analysis, also known as the gradation test, the Atterberg limit test, the California Bearing Ratio (CBR) test (both soaked and unsoaked), and the Modified Proctor test. These tests were employed to investigate the influence of crumb rubber on the soil used in our experiments.

Various samples were meticulously prepared, each with different proportions of soil and crumb rubber. The sieve analysis, Atterberg limits, and Modified Proctor tests were meticulously conducted to ascertain the optimal composition for the mixed samples. This thorough examination allowed us to determine the most effective balance between soil and crumb rubber content, providing valuable insights into their combined properties.

3.1 Material Collection and Properties

3.1.1 Soil

The soil utilized in the experiments was sourced from Sector H-12, Islamabad, near NESPAK, NLC metro bus project. According to the AASHTO soil classification, this soil falls under the category of A-4 soil, characterized by a predominant composition of clay with some silt (CL-ML) (Rokade, 2012).

3.1.2 Crumb Rubber

The crumb rubber used for research was acquired from the rubber factory area Garhi Shahu, Lahore.

3.1.3 Sieve Analysis

The sieve analysis, also known as the gradation test, is a method used to determine the particle size distribution of a granular material. This involves passing the material through a series of sieves with progressively smaller mesh sizes and measuring the amount of material retained on each sieve as a fraction of the total mass (Jan et al., 2015).

In our sample preparation process, we initially took an 800g sample of oven-dried soil that passed through sieve #4. Subsequently, then varying percentages of rubber (3%, 5%, 7%, 10%, and 15%) were added to separate 800g samples of soil passing through sieve #4.

Further, samples were washed through sieve #200, followed by drying and weighing the samples. Next, the washed samples were passed through sieves #10, #40, and #200, and measured the mass of material retained on each sieve was measured. This meticulous approach allowed us to accurately assess the particle size distribution and composition of the soil-rubber mixtures, providing valuable insights into their characteristics and behaviour.

Figure 2: Soil sampling site.

Figure 3: (a) Soil sample (b) Crumbed rubber sample.

Figure 4: Sieve analysis test performed (Sieve no. 10, 40, and 200 were used).

3.1.4 Modified Proctor Test

To begin, 7kg of oven-dried soil was taken for each sample, and then 3%, 5%, 7%, 10%, and 15% of rubber were added accordingly. The samples were meticulously mixed on trays with different percentages of water (7%, 9%, 11%, and 13%) to achieve the OMC and MDD.

Following the standard procedure outlined in T-193, the prepared samples were compacted in a mould of 2135 cc capacity. Each layer was compacted with 56 blows using a 4.5 kg rammer with a free fall height of 450 mm. After five layers, the collar was removed, and excess soil was trimmed off. The weight of the mould with the soil was recorded.

This process was repeated for varying water content until a decline in the MDD value was observed. Moisture content determination was conducted for each trial. The apparatus used for the proctor test included a rammer, soft rubber hammer, proctor mould, collar, detachable base plate, oven, balance, sample mixing tray, graduated jar, and gloves. These tools ensured accurate and consistent testing throughout the experiment.

3.1.5 California Bearing Ratio Test

The California Bearing Ratio (CBR) test, developed by the California Department of Transportation, is a penetration test used to assess soil strength, particularly for road and pavement subgrades. The results obtained from these tests, along with empirical curves, helped to determine pavement thickness and its component layers.

During the sample preparation phase, 7000g of soil sample was taken for each mould and mixed thoroughly with the achieved optimum moisture content. The extension collar and base plate were fixed to the mould, and a spacer disc was inserted over the base plate. For soaked CBR samples, a filter paper was placed on top of the spacer disc. The soil mixture was then compacted into the mould using a heavy-weight compaction rammer in five equal layers, each layer being compacted with 10, 30, and 65 blows from the 450mm rammer. After compaction, the collar was removed, and excess soil was trimmed off. The mould was then inverted, and the sample was weighed. Subsequently, the moulded sample was immersed in water for 96 hours to ensure thorough soaking. After soaking, the sample was removed from the water, and excess water was drained off by placing the mould at an incline for 15 minutes.

Next, the load penetration test was performed on the CBR testing machine. The mould was placed on the lower plate of the machine, and annular weights were placed on the soil surface to prevent upheaval during penetration. The penetration plunger was then seated, and surcharge weights were added. The stress and strain gauges were set to zero, and readings were taken at penetrations of 0.64, 1.27, 1.90, 2.54, 3.81, 5.08, and 7.62. The piston area of the test machine was 19.35, and the correction factor was 4.41. The apparatus used for the California Bearing Ratio test included a rammer, soft rubber hammer, CBR mould, collar, spacer disc, surcharge weights, water tank, oven, balance, sample mixing tray, graduated jar, gloves, penetration plunger, loading machine, swell plate, and swell tripod. The utilization of these tools guaranteed precise and dependable testing protocols across the duration of the experiment.

Figure 5: (a) Mold preparations for proctor test (b) Prepared mold sample on weigh balance to perform further test calculations.

Figure 6: (a) Load vs penetration machine for CBR test (b) CBR mold with swell tripod.

3.1.6 Atterberg Limit Tests

The measurement of critical water contents, such as Plastic Limit (PL), Liquid Limit (LL), and Plastic Index (PI), in fine-grained soil is essential for understanding its behavior and consistency. Soil can exist in different states such as solid, semi-solid, plastic, and liquid state, each with distinct properties, which are crucial in soil mechanics. These states are defined by boundaries known as Atterberg limits, named after Swedish Agriculturist Albert Atterberg and later refined by Arthur Casagrande (Ghatge and Rakaraddi, 2014).

Soil typically expands when it absorbs water, a phenomenon related to its water retention capacity and atomic structural pattern. Atterberg limits, particularly relevant for clayey to silty soils, provide key parameters like plastic limit, plasticity index, and liquid limit (Ghatge and Rakaraddi, 2014).

The liquid limit represents the water content at which soil transitions from a plastic to a liquid state. The liquid limit test, often conducted using the Casagrande Cup method, evaluates this transition and helps determine soil behavior and moisture content (Jan et al., 2015). Apparatus for this test includes ASTM Sieve No. 40 with Pan, Casagrande Apparatus with cup, Wash bottle containing distilled water, Spatula, Groove Mark or Grooving Tool, Oven, and Balance. Standard methods like AASHTO T-89 and T-90 guide the liquid limit determination using the Casagrande Cup method. The process involves preparing a soil sample, mixing it with water, filling a brass cup, cutting the sample, vibrating the cup, and noting the groove closure.

The sample is then dried, and weighed, and the moisture content calculated. The Plastic Limit represents the water content at which soil changes from a semi-solid to a plastic state (Jan et al., 2015). This test, based on AASHTO (T-90), determines soil behavior changes from semi-solid to solid. Apparatus includes ASTM Sieve No. 40 with Pan, Porcelain Evaporating Dish, Balance, Oven, Watering Bottle, Glass Plate, Spatula, and 3mm Diameter Rod. The process involves taking a soil sample, adding rubber content, and mixing it with water to form a paste. The Casagrande cup method is applied, and the groove closure is determined by rotating the handle. Three trials are conducted, and the threads are made from the paste for each trial. The threads are dried, and the Plastic Limit is calculated. This thorough methodology guarantees a precise evaluation of soil properties and performance, crucial for engineering and construction purposes.

Figure 7: Casa-grande up and groove marker.

4. RESULTS

4.1 Sieve Analysis Test

The sieve analysis was conducted in accordance with the standard (T-27) (Jan et al., 2015), on a simple A-4 soil first to check its compatibility and then respectively on 3 percent, 5 percent, 7 percent, 10 percent and 15 percent for each addition of the rubber proportion results obtained shown in tables given below. In this procedure, we utilized 800 gm of sample along with the addition of rubber. The material was then sieved through meshes of sizes 4, 10, 40, and 200 to obtain the remaining sample weight on the sieve, maintaining the proportion and passing the material proportion from the sieve.

4.2 Modified Proctor Test

Modified Proctor Testing on A-4 soil was conducted in accordance with AASTHO standards (T-180 and 99) (Munnoli et al., 2013) showed a certain limit at which a peak dry density (MDD) of 1,965gm/cc at optimum moisture content (OMC) of 12.7% was achieved as shown in Fig 5. With the addition of 3 percent rubber, MDD decreased to 1,958gm/cc and OMC to 12.5 percent as shown in Fig 8. The observations were made at 3%, 5%, 7%, 10%, and 15% rubber and MDD added respectively at 1.958gm/cc, 1.955gm/cc, 1.950gm/cc, 1.914gm/cc and 1.850gm/cc shown in Fig 8, while the OMC was achieved at 12.5%, 12.2%, 12.0%, 11.8%, and 10.4% respectively refer in Fig 8. The MDD reduced to 1,850gm/cc with the addition of 15% rubber and the OMC decreased to 10.4% as shown in Fig 8. Increase in rubber content up to 7% shown increase in CBR value, but more the rubber content we add to the soil there will be decrease in CBR, but general studies shows that for A-4 soil there will be maximum 3-6% CBR value, as rubber content was increased the MDD and OMC values was decreased.

Table 1: Sieve analysis result obtained for A-4 soil.

SEIVE ANALYSIS (T-27)						
Description: A-4 Soil						
Initial Wt. Of Dry Sample grams: 800.0 g				**Wt. of Dry Sample after washing: 156.0 g**		
ASTM Sieve No.	**Size (mm)**	**Wt. of Retained (g)**	**Cumulative wt of retained**	**Percent of Retained (%)**	**Percent of Passing (%)**	**SPECIFICATION**
4	4.75		0.0	0	100	
10	2.36		27.2	3.4	96.6	
40	0.42		43.2	5.4	94.6	
200	0.075		147.2	18.4	81.6	
Pan						

Table 2: Sieve analysis result obtained for A-4 soil with addition of 3% rubber.

SEIVE ANALYSIS (T-27)						
Description: A-4 Soil + 3% Rubber						
Initial Wt. Of Dry Sample grams: 800 g				**Wt. of Dry Sample after washing: 170g**		
ASTM Sieve No.	**Size (mm)**	**Wt. of Retained (g)**	**Cumulative wt of retained**	**Percent of Retained (%)**	**Percent of Passing (%)**	**SPECIFICATION**
4	4.75		0.0	0	100	
10	2.36		38	4.75	95.25	
40	0.42		62	7.75	92.25	
200	0.075		166	20.75	79.25	

Table 3: Sieve analysis result obtained for A-4 soil with addition of 5% rubber.

SEIVE ANALYSIS (T-27)						
Description: A-4 Soil + 5% Rubber						
Initial Wt. Of Dry Sample grams: 800.0 g				**Wt. of Dry Sample after washing: 189.0 g**		
ASTM Sieve No.	**Size (mm)**	**Wt. of Retained (g)**	**Cumulative wt of retained**	**Percent of Retained (%)**	**Percent of Passing (%)**	**SPECIFICATION**
4	4.75		0.0	0	100	
10	2.36		44.8	5.6	94.4	
40	0.42		72.8	9.1	90.9	
200	0.075		182.4	22.8	77.2	

Table 4: Sieve analysis result obtained for A-4 soil with addition of 7% rubber

SEIVE ANALYSIS (T-27)						
Description: A-4 Soil + 7% Rubber						
Initial Wt. Of Dry Sample grams: 800.0 g			**Wt. of Dry Sample after washing: 220g**			
ASTM Sieve No.	**Size (mm)**	**Wt. of Retained (g)**	**Cumulative wt of retained**	**Percent of Retained (%)**	**Percent of Passing (%)**	**SPECIFICATION**
4	4.75		0.0	0	100	
10	2.36		69	8.7	91.3	
40	0.42		105	13.125	87	
200	0.075		216	27	73	

Table 5: Sieve analysis result obtained for A-4 soil with addition of 10% rubber.

SEIVE ANALYSIS (T-27)						
Description: A-4 Soil + 10% Rubber						
Initial Wt. Of Dry Sample grams: 800.0 g			**Wt. of Dry Sample after washing: 246 g**			
ASTM Sieve No.	**Size (mm)**	**Wt. of Retained (g)**	**Cumulative wt of retained**	**Percent of Retained (%)**	**Percent of Passing (%)**	**SPECIFICATION**
4	4.75		0.0	0	100	
10	2.36		91.0	11.4	89	
40	0.42		132	16.5	83.5	
200	0.075		240	30	70	

Table 6: Sieve analysis result obtained for A-4 soil with addition of 15% rubber.

SEIVE ANALYSIS (T-27)						
Description: A-4 Soil + 10% Rubber						
Initial Wt. Of Dry Sample grams: 800.0 g			**Wt. of Dry Sample after washing: 246 g**			
ASTM Sieve No.	**Size (mm)**	**Wt. of Retained (g)**	**Cumulative wt of retained**	**Percent of Retained (%)**	**Percent of Passing (%)**	**SPECIFICATION**
4	4.75		0.0	0	100	
10	2.36		91.0	10.4	91	
40	0.47		128	16.4	85	
200	0.08		238	31	73	

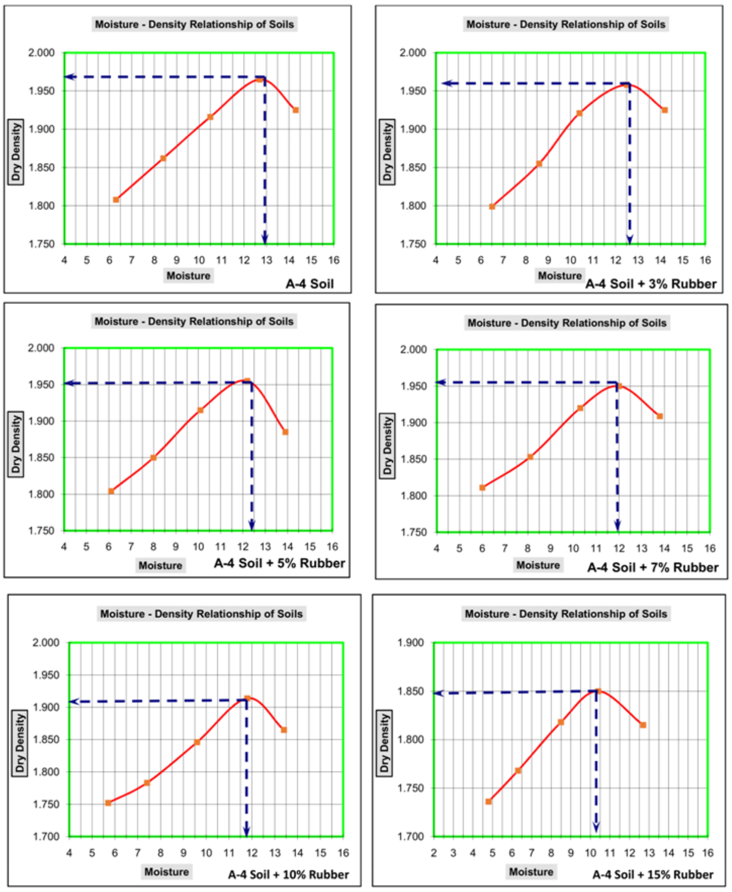

Figure 8: Values of MDD and OMC obtained from Modified proctor test, showing A-4 soil, A-4 soil+3% , 5%, 7%, 10%, and 15% rubber respectively.

4.3 Atterberg Limits Test

The study conducted by (Munnoli et al., 2013) involved conducting the test (T89/90) with varying percentages of rubber (3%, 5%, 7%, 10%, and 15%) added to the soil. For the plastic limit (PL), the results obtained were 5.3, 19.3, 5.3, 4.8, and 4.8, respectively. In contrast, the PL for simple A-4 soil was recorded at 8.3. Similarly, for the liquid limit (LL), the test was performed with different rubber percentages, yielding results of 24.0, 23.8, 23.8, 24.1, and 24.1. The LL for A-4 soil alone was determined to be 18.1. Regarding the Plastic Index (PI), the results were 6.9 for the uncompounded soil and 5.8, 4.5, 5.0, 4.8, and 4.5 for soil mixed with 3%, 5%, 7%, 10%, and 15% rubber, respectively.

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4.4 California Bearing Ratio Test

It was developed by Department of Transportation, California, used to evaluate the soil strength used in the road sub-grade and pavements (Otoko and Pedro, 2014). Many tests were used on the use of crumb rubber in soil, according to which the greatest crumb rubber efficiency was attained at 6 percent (Vaddi et al., 2015). In the study centered on A-4 soil samples, examinations were carried out using different proportions of rubber, replicating the ratios employed in the Modified Proctor Test at their respective Optimum Moisture Content (OMC). The results revealed that the California Bearing Ratio (CBR) values for A-4 soil mixed with rubber at 3%, 5%, 7%, 10%, and 15% concentrations were 5, 6, 7, 8, 4, and 3.4, respectively. These CBR values were obtained by applying unit weight load through dial penetration. Upon analysis, it was observed that the trend in CBR values exhibited an upward trajectory, peaking at 7% rubber content, followed by a gradual decline. This pattern suggests a threshold effect, wherein the CBR value initially increases with the rise in rubber content but subsequently decreases. Additionally, it's worth noting that the correction factor for the test machine's piston region was 19.35, enhancing the precision of the results.

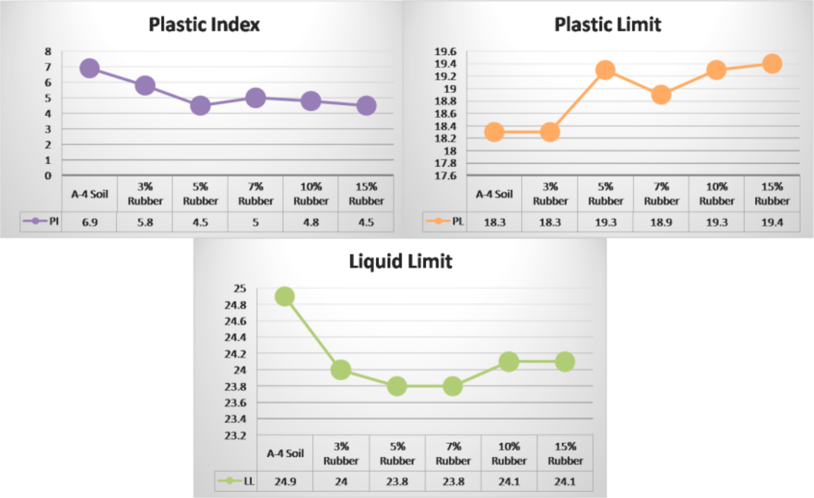

Figure 9: Results obtained after performing atterberg limit test showing variations in values of plastic limit, liquid limit and plastic index.

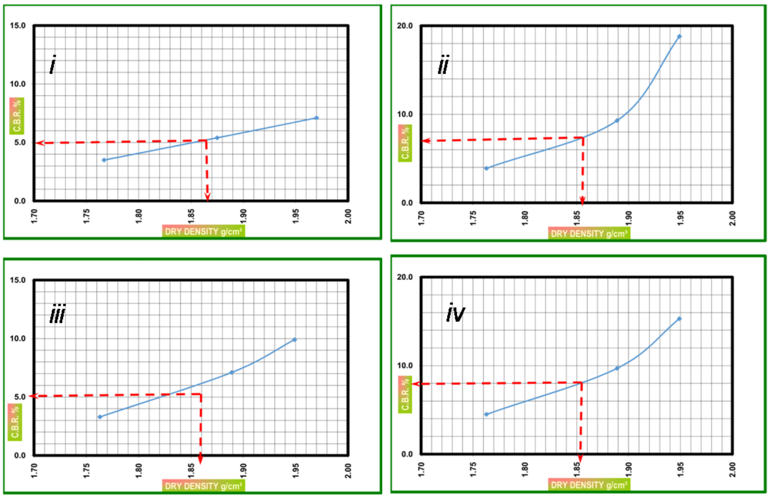

Figure 10: (a) CBR values obtained after the test performed respectively in order (i) A-4 soil (ii) 3% rubber (ii) 5% rubber (iv) 7% rubber.

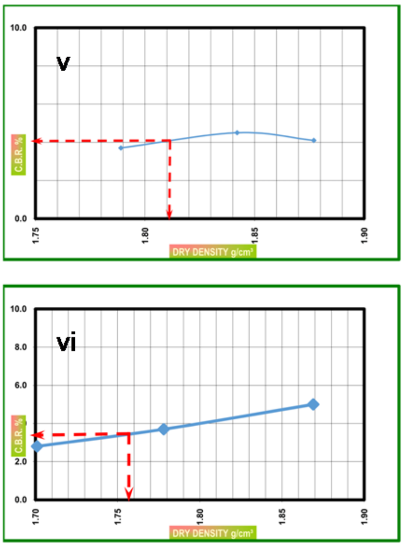

Figure 10: (b) CBR values obtained after the test performed respectively in order (v) 10% rubber (vi) 15% rubber.

5. DISCUSSION

This study focused on investigating the feasibility of utilizing crumb rubber derived from waste tyres as a soil stabilizing agent. Soil samples, predominantly exhibiting clayey characteristics, were sourced from Sector H-12, in Islamabad. The primary goal was to evaluate the efficacy of integrating crumb rubber in augmenting the geotechnical properties of the soil, focusing on Optimum Moisture Content (OMC), Maximum Dry Density (MDD), California Bearing Ratio (CBR), and Plastic Limit Index (PI).

Results from Modified Proctor Testing showed interesting patterns in MDD and OMC values with varying crumb rubber percentages. Adding crumb rubber consistently reduced MDD and OMC, indicating changes in soil compaction characteristics. This reduction could be attributed to the lightweight and deformable nature of crumb rubber particles, altering the overall soil structure. CBR values, critical for assessing soil strength in road sub-grades, exhibited a notable trend. Up to 7% crumb rubber content, CBR values increased, indicating improved load-bearing capacity. However, beyond this threshold, CBR values declined, highlighting the need to carefully determine the optimal rubber content for effective soil stabilization.

PI results indicated changes in soil plasticity characteristics, with reduced PI values suggesting decreased soil plasticity, which can reduce volume changes and enhance stability. These findings support the exploration of waste materials like crumb rubber for soil stabilization. The study underscores the potential benefits of integrating crumb rubber into clayey soil, providing insights into optimizing rubber content for maximum effectiveness. While crumb rubber shows promise as a soil stabilizer, it is essential to acknowledge that further research is necessary to comprehensively understand its long-term effects, environmental impacts, and economic feasibility. Field trials and real-world applications will be crucial for validating laboratory findings and assessing the practicality of using crumb rubber in large-scale soil stabilization projects.

Table 7: Summarized table for results obtained by performing tests.

Soil & Rubber (%)	MDD	OMC	PI	PL	LL	CBR
A-4 Soil	1.965	12.7	6.9	18.3	24.9	5
3% Rubber	1.958	12.5	5.8	18.3	24.0	6
5% Rubber	1.955	12.2	4.5	19.3	23.8	7
7% Rubber	1.950	12.0	5.0	18.9	23.8	8
10% Rubber	1.914	11.8	4.8	19.3	24.1	4
15% Rubber	1.850	10.4	4.5	19.4	24.1	3.4

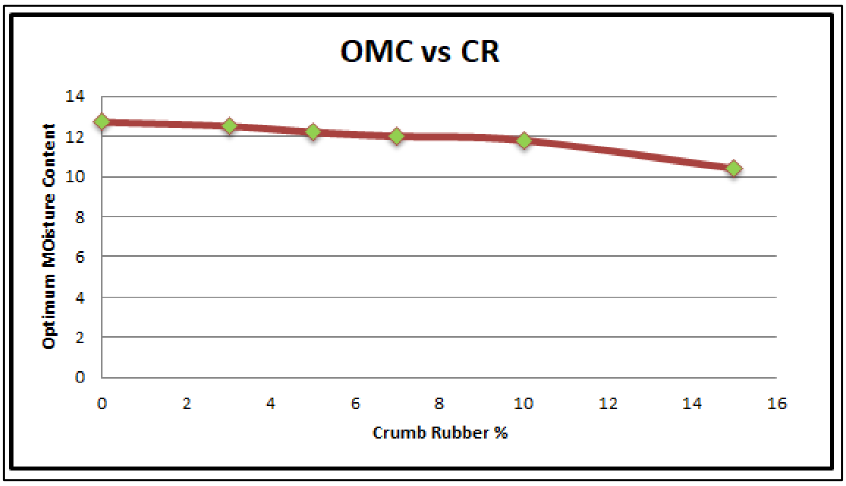

Figure 11: Optimum moisture content vs crumb rubber curve.

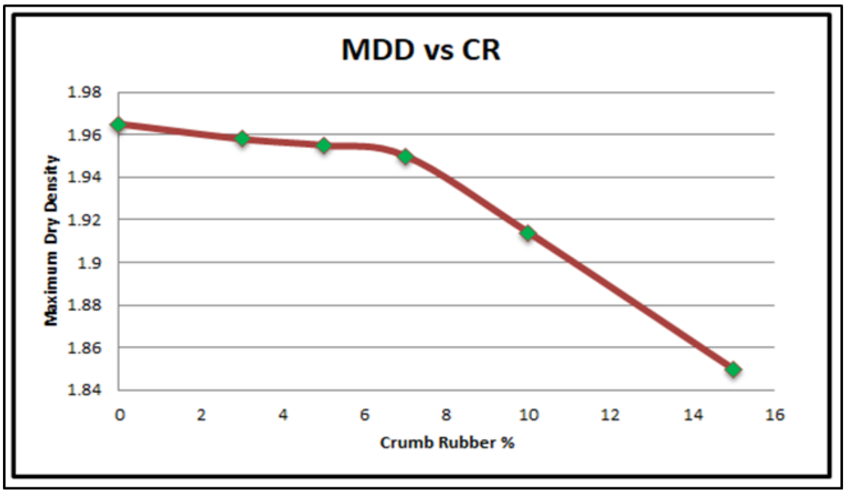

Figure 12: Maximum dry density vs crumb rubber curve.

6. CONCLUSION

In conclusion, the research demonstrates that incorporating crumb rubber into clayey soil can lead to a decline in optimum moisture content and peak dry soil density. The study indicates an enhancement in soil properties, particularly in the sample mixed with 7% tyre rubber content. However, beyond this percentage, there is a diminishing trend in strength. California Bearing Ratio (CBR) studies reveal an increasing trend up to 7% rubber content, followed by a decline at higher percentages. Overall, the findings suggest that adding tyre rubber waste to soil has the potential to improve soil strength and mitigate environmental concerns associated with rubber disposal.

IMPLICATIONS AND FUTURE WORK

Utilizing waste materials such as tyre rubber or plastic to enhance soil characteristics holds significant importance. Based on the aforementioned findings, we propose that waste tyre rubber can be effectively employed in geotechnical and civil engineering applications, providing a sustainable alternative to disposal practices that pose environmental and health risks. The potential of tyre rubber goes beyond our current research. We advocate for its exploration in various geotechnical engineering contexts, aligning with AASHTO soil classification standards. Future endeavors could involve large-scale field applications to validate laboratory findings, thorough environmental impact assessments to ensure sustainability and investigations into other waste materials for soil stabilization purposes. Through these efforts, we aim to advance eco-friendly engineering solutions while addressing pressing environmental challenges.

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