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Utilization Potential of Glass Fiber and Crumbled Rubber as Subgrade Reinforcement for Expansive Soil

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Abstract

Due to its high potential for volume change, expansive soil is a problematic building material that can cause harm to road infrastructure. The purpose of this study is to examine the effect of glass fiber and rubber on the properties of expansive soil and their suitability as subgrade reinforcement in road applications. For different percentages of glass fiber and rubber in the soil, the Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and CBR were measured. The results demonstrated that the incorporation of glass fiber and rubber improved the soil's properties. With increasing fiber and rubber content, the MDD and CBR increased, while the OMC decreased. In addition, the strength of the reinforced soil was significantly greater than that of the unreinforced soil. The research indicates that the addition of glass fiber and rubber can improve the efficacy of expansive soil as subgrade reinforcement in road applications.

Keywords: Glass Fiber; Rubber Fiber; Expansive Soil; Soil Reinforcement; California Bearing Ratio.

1. Introduction

Expansive soil refers to a specific soil type that demonstrates notable alterations in volume because of fluctuations in its moisture content [1–3]. This soil variant exhibits a wide distribution and may be observed in several regions around the globe. The presence of expansive soil poses challenges in building projects due to its significant propensity for volumetric alterations, resulting in possible harm to road infrastructure. Expansive soil has the potential to inflict significant damage, necessitating expensive repairs. One potential approach to alleviating the adverse effects of expansive soil on road infrastructure is the implementation of soil reinforcement techniques with a range of materials [4–9]. These studies aimed to evaluate the impact of glass fiber and rubber on the characteristics of expansive soil and their potential application as subgrade reinforcement in road construction [10].

The presence of expansive soils poses a considerable challenge to the design and construction of pavements. The occurrence of expansive soils inside the subgrade layers has the potential to cause substantial deterioration of pavements, ultimately resulting in their breakdown [11, 12]. Hence, it is imperative to undertake measures for stabilizing expansive soils in order to enhance the performance of pavements. One plausible approach to addressing this issue is the use of reinforcing materials, such as glass fibers and rubber filaments, to enhance the strength and

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stability of soil. Research has demonstrated that glass fibers are a highly efficient material for reinforcing expanding soils [13, 14]. In a study undertaken by Su et al. [15], an examination was carried out to assess the impact of glass fibers on the engineering characteristics of expansive soil. The research revealed that the incorporation of glass fibers into the soil led to an augmentation in the maximum dry density and a reduction in the optimal moisture content, hence suggesting enhanced compaction properties. Furthermore, the research revealed that the incorporation of glass fibers resulted in enhancements to both the CBR and the UCS of the soil. The use of rubber filaments as a reinforcing material for expanding soils has also been the subject of scholarly investigation. The impact of crumb rubber on the characteristics of expansive soil was examined in a study done by Akbarimehr et al. [16]. The research conducted revealed that the incorporation of crumb rubber into the soil led to a rise in the maximum dry density and a decline in the optimum moisture content. Furthermore, the research revealed that the incorporation of crumb rubber resulted in an enhancement of the CBR of the soil.

In addition to enhancing soil characteristics, the use of glass fibers and rubber in soil stabilization presents a potential alternative for addressing the issue of plastic waste disposal. The utilization of recycled low-density polyethylene (LDPE) and waste tire rubber as stabilizing agents for expansive soils was examined in a study done by Archibong et al. [17]. The research revealed that the utilization of these waste materials resulted in enhanced CBR and UCS of the soil, concurrently mitigating the volume of waste materials that would otherwise be disposed of in landfills. In general, the utilization of reinforcing materials, such as glass and rubber fibers, can offer a financially viable and ecologically sustainable approach to address the stabilization of expansive soils in pavement applications. The findings of the aforementioned research indicate that the incorporation of these materials has the potential to enhance soil characteristics and the performance of pavements. Additionally, this approach offers a viable alternative for the management of waste materials.

2. Research Methodology

The research employed an expanded soil sample obtained from a specific location in Amman, Jordan. The soil was categorized as an A-7-6 soil in accordance with the Unified Soil Classification System (USCS) [18]. The physical and geotechnical qualities of the soil were assessed, encompassing the determination of key parameters such as the maximum dry density (MDD), optimum moisture content (OMC), and California Bearing Ratio (CBR). An investigation was conducted to examine the impact of glass fiber and rubber on the attributes. The glass fiber utilized in this investigation was sourced from discarded glass material and possessed a length of 12 mm and a diameter of 0.2 mm. The rubber material utilized in the study was sourced from discarded tires and further processed to achieve a particle size of 4.75 mm.

The soil was augmented with different proportions of glass fiber (0%, 0.5%, 1%, and 1.5%) and rubber (0%, 1%, 5%, and 9%) for reinforcement purposes. The values of the MDD, OMC, and CBR were obtained for every sample of reinforced soil. The evaluation of the strength of the reinforced soil was conducted through the utilization of the UCS test. The UCS test was performed to evaluate the effect of different proportions of glass fiber on the mechanical properties of the reinforced soil.

The main equipment selected for the laboratory test is shown in Figure 1.

Figure 1. Test arrangement and procedure

The flowchart of the research methodology that was used to achieve the study's aims is shown in Figure 2.

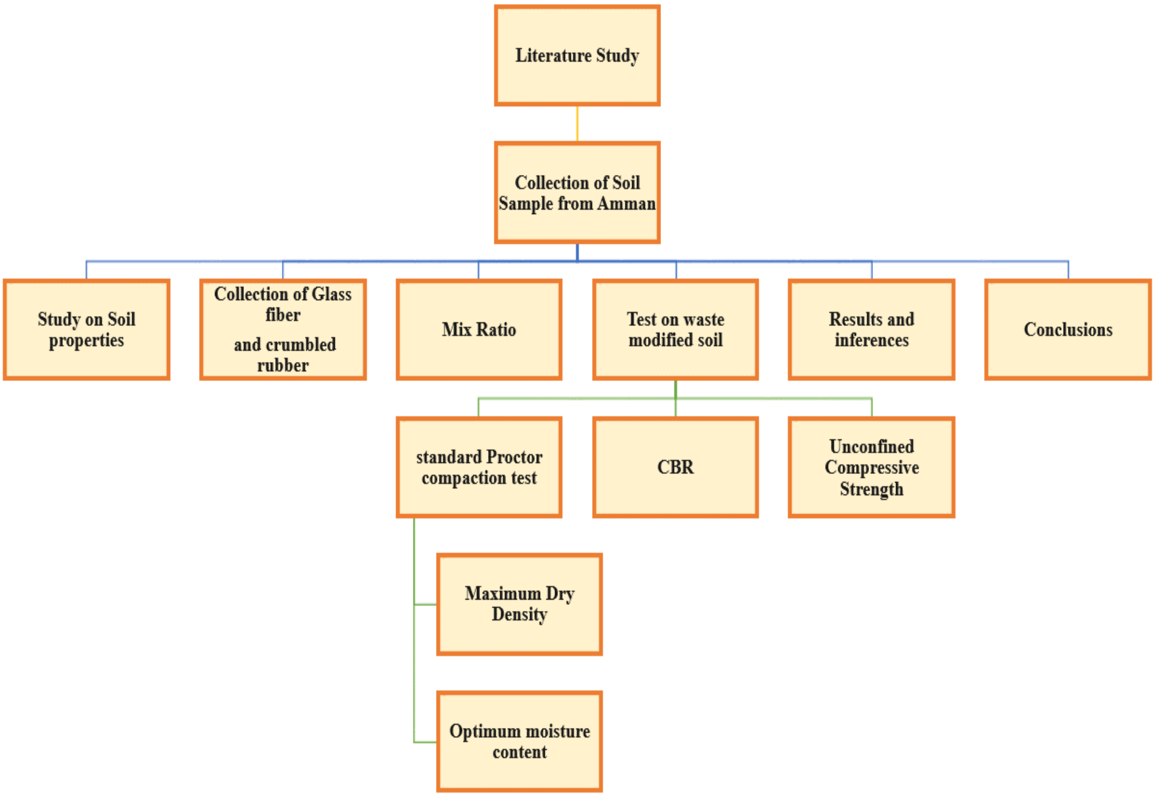

Figure 2. Flowchart of the research methodology

3. Results and Discussion

The study findings indicated that the incorporation of glass fiber and rubber materials yielded favorable outcomes in terms of soil parameters. The maximum dry density (MDD) exhibited a positive correlation with the rising proportions of fibber and rubber, as seen in Figures 3 and 7, respectively. The soil sample treated with a combination of 1.5% glass fiber and 0% rubber exhibited the highest MDD, and OMC exhibited a negative correlation with the proportion of fibber and rubber, as seen in Figures 4 and 6, respectively. The soil treated with 1.5% glass fiber and 9% rubber exhibited the lowest OMC. The CBR exhibited an upward trend as the proportion of fiber and rubber in the mixture increased, as seen in Figures 5 and 8, respectively. The soil sample treated with a combination of 1.5% glass fiber and 5% rubber exhibited the greatest CBR value.

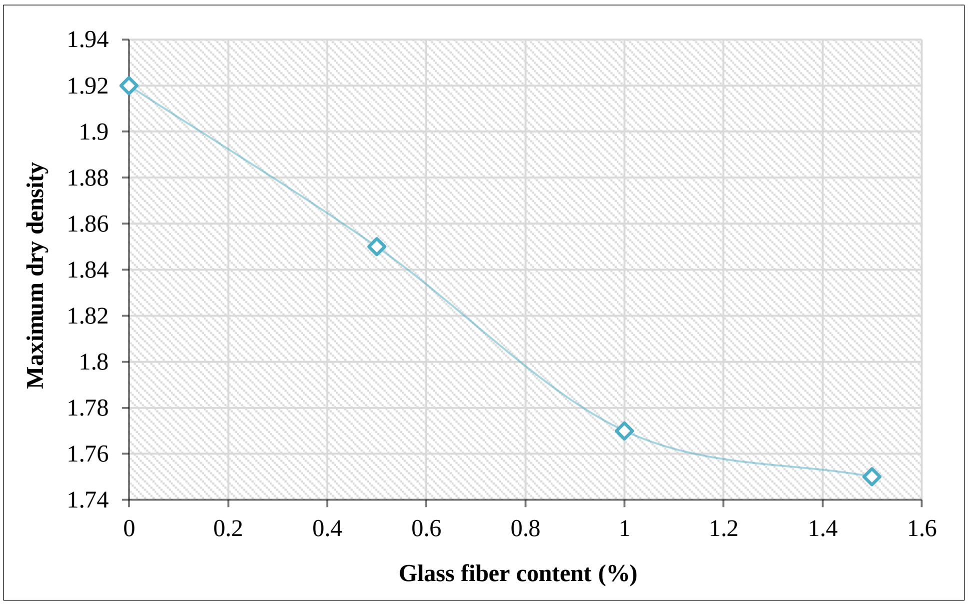

Figure 3. Test results of maximum dry density corresponding to glass fiber substitutions

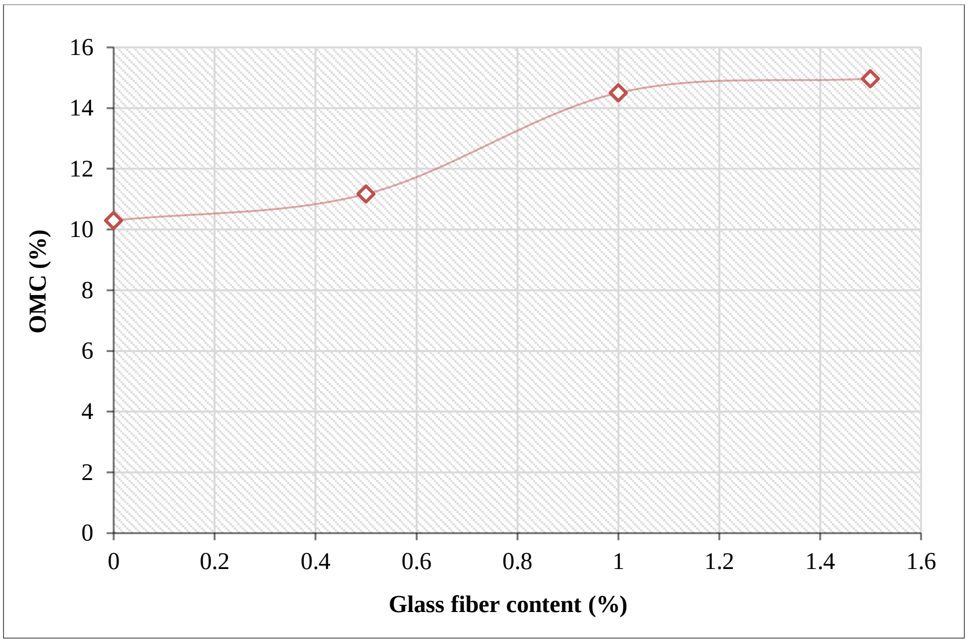

Figure 4. Test results of OMC corresponding to glass fiber substitutions

The CBR is a crucial factor in the construction of subgrade soil. The impact of glass fiber and rubber on the CBR of the soil is seen in Figures 5 and 8, correspondingly.

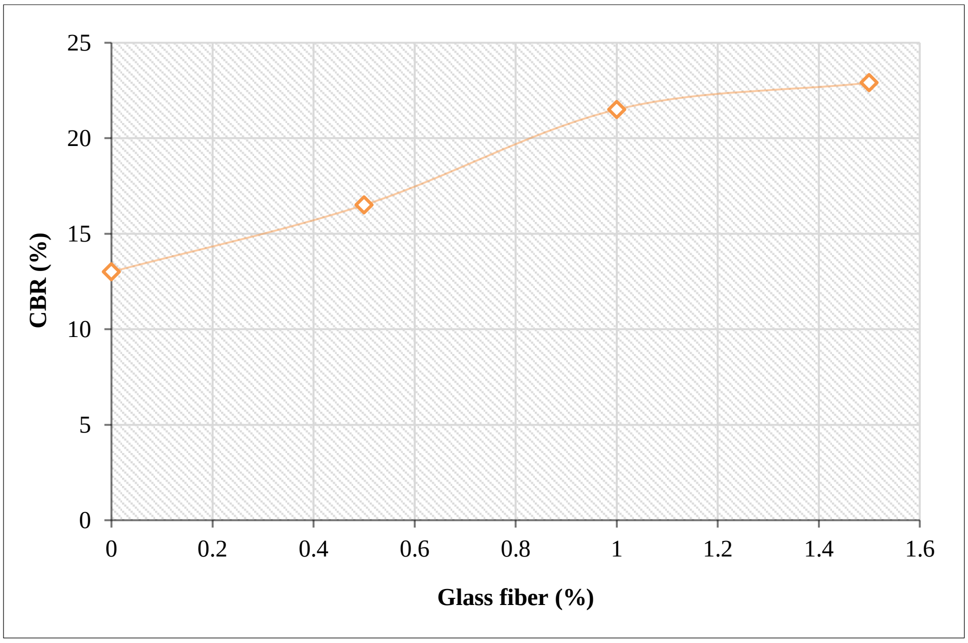

Figure 5. Test results of CBR corresponding to glass fiber substitutions

The correlation between the proportion of glass fiber and rubber in the soil and the corresponding rise in CBR may be discerned. The rise in CBR can be attributed to the enhancement in the maximum dry density and optimal moisture content resulting from the use of glass fiber and rubber materials. The incorporation of glass fiber and rubber materials contributes to the mitigation of soil plasticity, hence enhancing the CBR of the soil. The soil reinforced with 1.5% glass fiber achieved a maximum CBR value of 22.9%, whereas the soil reinforced with 5% rubber achieved a maximum CBR value of 20.96%. Figure 8 illustrates the comparative impact of glass fiber and rubber on the CBR. The data indicates that the CBR of the soil reinforced with 1% crumb rubber exhibits a little greater value compared to the CBR of the soil treated with 1% glass fiber. Nevertheless, the CBR of the soil that has been reinforced with 1.5% glass fiber exhibits a notably greater value when compared to the CBR of the soil that has been reinforced with 5% rubber. Hence, it may be deduced that glass fiber is a superior reinforcing material for enhancing the CBR of expanding soil.

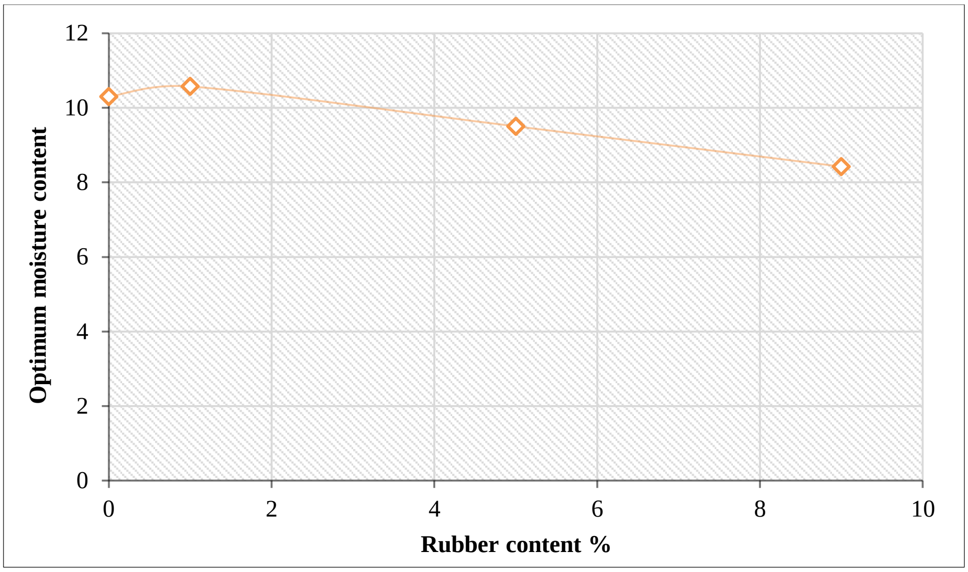

Figure 6. Test results of OMC corresponding to crumbled rubber substitutions

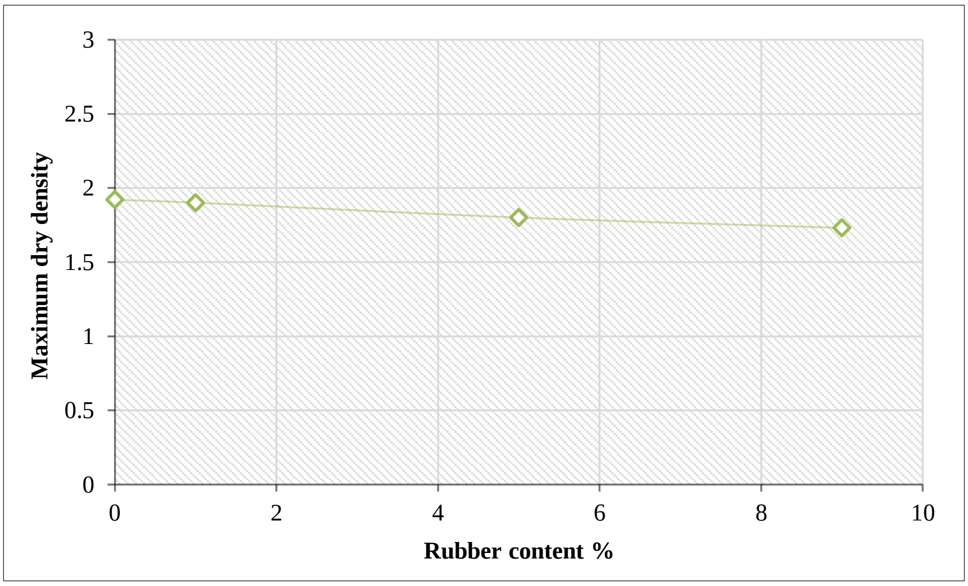

Figure 7. Crumbled rubber substitute vs maximum dry density test results

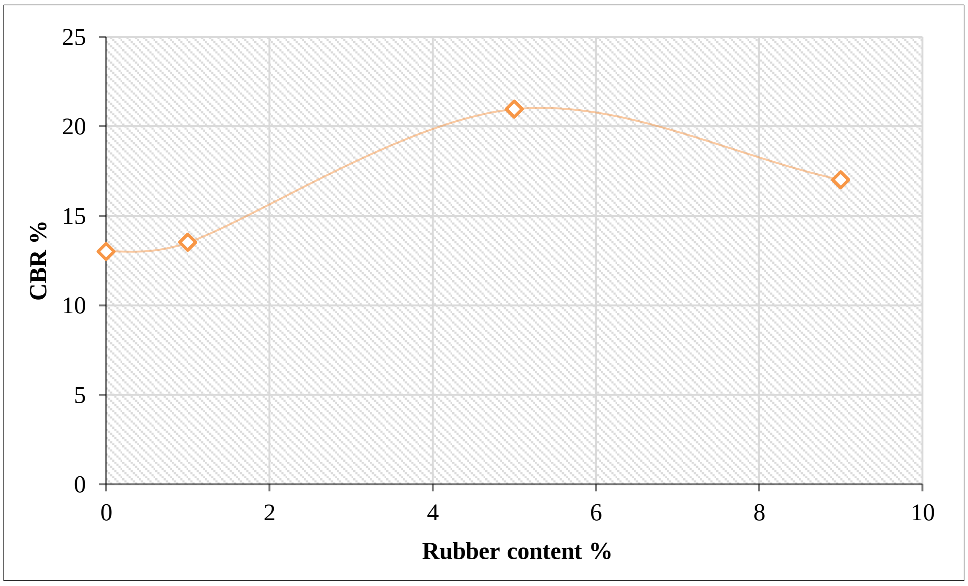

Figure 8. Crumbled rubber substitute vs CBR test results

3.1. Unconfined Compressive Strength (UCS)

Figure 9 illustrates the correlation between the proportion of glass fibers in reinforced soil and the UCS. It is evident that there is a positive correlation between the proportion of glass fiber in the soil and the UCS. The rise in UCS can be attributed to the enhancement in the maximum dry density and optimal moisture content resulting from the incorporation of glass fiber. The incorporation of glass fiber into the soil matrix contributes to a decrease in its plasticity, hence enhancing the UCS of the soil. The soil reinforced with 4% glass fiber achieved a maximum UCS value of 98.41 kPa.

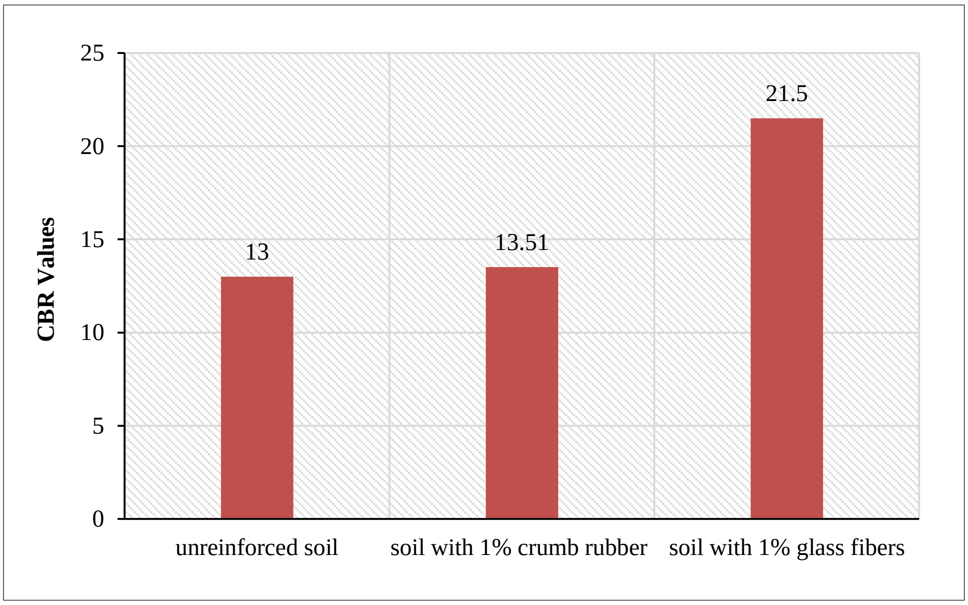

Figure 9. CBR values of different reinforced soil

The findings of the study indicate that the incorporation of glass fiber and crumb rubber into the expansive soil resulted in enhanced engineering characteristics, hence rendering it more suited for reinforcing the subgrade in road construction. The subsequent portions of this discourse delve into the impacts of glass fiber and rubber on the characteristics of expanding soil.

3.2. Effect of Glass Fibber on the Properties of Expansive Soil

The impact of glass fiber on the maximum dry density (MDD), optimum moisture content (OMC), and CBR of the expanding soil is illustrated in previous results. There is a positive correlation between the percentage of glass fiber and the maximum dry density (MDD) of the soil. The maximum dry density (MDD) exhibited an increase from 1.92 g/cm^3 in the case of the unreinforced soil to 1.75 g/cm^3 for the soil that was reinforced with 1.5% glass fiber. The observed rise in MDD can be attributed to the occupation of soil voids by glass fibers, resulting in a higher soil density and compaction.

The influence of glass fiber on the optimal moisture content (OMC) of the soil is depicted in Figure 5. The observed mean concentration (OMC) exhibited a positive correlation with the proportion of glass fiber. The organic matter content (OMC) exhibited an increase from 10.3% in the case of unreinforced soil to 14.97% when the soil was reinforced with 1.5% glass fiber. The observed rise in organic matter content (OMC) can be ascribed to the hydrophilic properties of glass fibers, which have a propensity to absorb moisture from the soil, thereby elevating the water content.

Figure 5 illustrates the impact of glass fiber on the CBR of the soil. The coefficient of bending resistance (CBR) shows a positive correlation with the proportion of glass fiber. The CBR exhibited an increase from 13% for the soil without reinforcement to 22.9% for the soil treated with 1.5% glass fiber. The observed rise in the CBR can be attributed to the enhanced reinforcement offered by the incorporation of glass fibers, resulting in an improvement in the soil's load-bearing capability.

Table 1 displays the dry density and moisture content of both the unreinforced soil and the soil reinforced with glass fiber. According to the data presented in the table, there is a positive correlation between the percentage of glass fiber and the dry density of the soil. The soil's moisture content had a positive correlation with the proportion of glass fiber, indicating that an increase in the latter led to an increase in the former.

Table 1. Dry density & moisture content for unreinforced and reinforced soil with glass fibber

(1.5% glass fibber)		(1.0% glass fibber)		(0.5% glass fibber)		Raw soil (0% glass fibber)	
Water content	**Dry density (g/cm^3)**	**Water content**	**Dry density (g/cm^3)**	**Water content**	**Dry density (g/cm^3)**	**Water content**	**Dry density (g/cm^3)**
13.5	0.87	12.8	1.55	9.5	1.62	4.2	1.71
14	0.9	13.5	1.6	10.1	1.7	6.4	1.75
14.5	0.95	13.9	1.69	10.81	1.77	8.5	1.88
14.97	1.02	14.5	1.73	11.17	1.78	10.3	1.92
15	0.88	15	1.64	12.5	1.72	11	1.85

The impact of rubber on the maximum dry density (MDD), optimum moisture content (OMC), and CBR of the expanding soil is illustrated. According to the data presented in Figures 6 and 7, there is a negative correlation between the percentage of rubber and the maximum dry density (MDD) of the soil. The maximum dry density (MDD) exhibited a drop from 1.92 g/cm^3 in the case of the unreinforced soil to 1.73 g/cm^3 for the soil that was reinforced with 9% rubber. The decline in MDD can be attributed to the reduced soil density.

The findings of the study indicated that the incorporation of glass fiber and rubber had a substantial positive impact on both the maximum dry density (MDD) and optimum moisture content (OMC) of the expansive soil. Figures 3 and 4 depict the impact of glass fiber on the maximum dry density (MDD) and optimum moisture content (OMC), respectively. The maximum dry density (MDD) exhibited an increase from 1.92 g/cm^3 in the case of the unreinforced soil to 1.75 g/cm^3 for the soil that was reinforced with 1.5% glass fiber. The organic matter content (OMC) exhibited an increase from 10.3% in the case of unreinforced soil to 14.97% when the soil was reinforced with 1.5% glass fiber. Figure 6 illustrates the impact of glass fiber on the CBR of the soil. The CBR exhibited an increase from 13% in the case of unreinforced soil to 22.9% when the soil was reinforced with 1.5% glass fiber. Table 1 presents the dry density and moisture content values for both unreinforced and reinforced soils with glass fiber. In a similar vein, the incorporation of rubber material yielded a notable enhancement in both the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the expansive soil. Figures 6 and 7 depict the impact of rubber on the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD), respectively. The maximum dry density (MDD) exhibited an increase from 1.92 g/cm^3 in the case of the unreinforced soil to 1.73 g/cm^3 for the soil that was reinforced with 9% rubber. The organic matter content (OMC) exhibited a drop from 10.3% in the case of unreinforced soil to 8.42%.

Moreover, it was noticed that the incorporation of glass fibers resulted in a notable augmentation of the CBR value, as depicted in Figure 5. The CBR value showed a notable increase, rising from 13% for soil without reinforcement to 22.9% for soil reinforced with 1.5% glass fiber. This suggests that the use of glass fiber as a means of reinforcing the subgrade has the potential to enhance the load-bearing capacity of expansive soils, rendering them more appropriate for the purpose of road construction.

Table 1 presents the impact of glass fiber on the dry density and moisture content of the soil. As the proportion of glass fiber was increased, there was a corresponding rise in the dry density of the soil, accompanied by a drop in moisture content. As an illustration, the dry density exhibited an increase from 1.71 g/cm^3 in the case of unreinforced soil to 1.55 g/cm^3 for soil that was reinforced with 1% glass fiber. In a similar manner, the moisture content exhibited a reduction from 11% in the case of unreinforced soil to 10.1% for soil that was reinforced with 0.5% glass fiber. This finding suggests that the incorporation of glass fiber has the potential to enhance the compaction properties of soil, a crucial aspect in reinforcing the subgrade during road infrastructure development.

The study also examined the impact of rubber on the characteristics of expansive soil and its potential use as a means of reinforcing subgrade in road construction [19, 20]. The impact of rubber content on the optimal moisture content (OMC) of the soil is seen in Figure 6. The observed mean concentration (OMC) exhibited a negative correlation with the proportion of rubber material, indicating that as the rubber content increased, the OMC decreased. As an illustration, the Optimum Moisture Content (OMC) exhibited a decline from 10.3% in the case of unreinforced soil to 8.42% when the soil was reinforced with a 9% concentration of rubber. This finding suggests that the incorporation of rubber has the potential to enhance the stability of soil and mitigate its vulnerability to fluctuations in moisture content.

The influence of rubber content on the maximum dry density (MDD) of the soil is depicted in Figure 7. The mean diameter of the droplets (MDD) exhibited a positive correlation with the rubber content, reaching a peak at a specific threshold. Subsequently, the MDD began to decline. As an illustration, the maximum dry density (MDD) exhibited an increment from 1.92 g/cm^3 in the case of unreinforced soil to 1.8 g/cm^3 for soil reinforced with 5% rubber. However, it subsequently experienced a decline to 1.73 g/cm^3 for soil reinforced with 9% rubber. This suggests that the incorporation of rubber has the potential to enhance the compaction properties of the soil up to a specific threshold, beyond which its efficacy diminishes.

The influence of rubber content on the CBR value of the soil is depicted in Figure 8. The CBR exhibited a positive correlation with the proportion of rubber content, reaching a peak value at a specific threshold. However, beyond this threshold, the CBR began to decline. As an illustration, the CBR shows an increment from 13% in the case of soil without reinforcement to 20.96% for soil reinforced with 5% rubber. However, it subsequently experienced a decline to 17.01% for soil reinforced with 9% rubber. This observation suggests that the incorporation of rubber has the potential to enhance the soil's ability to bear loads, but only up to a specific threshold. Beyond this threshold, the efficacy of rubber in improving load-bearing capacity diminishes.

Table 2 presents the impact of rubber on the dry density and moisture content of the soil. As the proportion of rubber content was increased, there was a corresponding increase in the dry density of the soil until a specific threshold was reached. Beyond this threshold, the dry density began to decline, concomitant with a drop in moisture content. As an illustration, the dry density exhibited an increment from 1.71 g/cm^3 in the case of unreinforced soil to 1.85 g/cm^3 in the scenario where the soil was reinforced with 1% rubber. However, it subsequently experienced a decline to 1.54 g/cm^3 when the soil was reinforced with 5% rubber. In a similar vein, the moisture content exhibited a reduction from 11% in the case of soil without reinforcement to 10.57% in the case of soil reinforced with 1% rubber. However, it was further reduced to 10%.

Table 2. Dry density & moisture content for unreinforced and reinforced soil with rubber

(9.0% rubber)		(5.0% rubber)		(1.0% rubber)		Raw soil (0% rubber)	
Water content	Dry density (g/cm^3)	Water content	Dry density (g/cm^3)	Water content	Dry density (g/cm^3)	Water content	Dry density (g/cm^3)
3.6	1.38	1.8	1.47	2.3	1.61	4.2	1.71
6.01	1.58	4.32	1.57	4.5	1.65	6.4	1.75
7.5	1.65	7.8	1.75	8.59	1.85	8.5	1.88
8.42	1.73	9.5	1.8	10.57	1.9	10.3	1.92
10.75	1.54	12.4	1.73	13.4	1.88	11	1.85

Table 3 displays a comparative analysis of the impact of crumb rubber and glass fiber reinforcement on the UCS measurements of a soil sample. The UCS is a parameter used to quantify the ability of a soil sample to withstand compressive force in the absence of any lateral confinement. The data presented in the table demonstrates that the incorporation of a 1% glass fiber content into the soil specimen results in a notable enhancement of the unconfined compressive strength (UCS), with values increasing from 27.8 to 75.3. This observed rise signifies a substantial improvement in the mechanical properties of the soil sample. In contrast, the incorporation of 1% crumb rubber into the soil specimen results in a corresponding rise in the UCS to 42.7 (Figure 10). While this enhancement is noteworthy, it is not as substantial as the improvement observed with the inclusion of glass fiber. Table 4 displays the fluctuations seen in the maximum dry density (MDD), optimum moisture content (OMC), California Bearing Ratio (CBR), and UCS of reinforced soil samples containing varying proportions of glass fiber. The values of maximum dry density (MDD) and UCS exhibit a positive correlation with the proportion of glass fiber, indicating an upward trajectory. Conversely, the observed marginal change (OMC) exhibits a slight rise as the proportion of glass fiber increases.

Table 3. Relationship between glass fibber percentage in reinforced soil verses UCS

0.00%		0.50%		1.00%		1.50%	
Stress (kPa)	Strain (%)	Stress (kPa)	Strain (%)	Stress (kPa)	Strain (%)	Stress (kPa)	Strain (%)
0	0	0	0	0	0	0	0
10.05	0.5	10.85	0.5	30.5	0.5	40.2	0.5
21	1	28.4	1	47.02	1	51.3	1
27.8*	1.5	43.34	1.5	50.4	1.5	68.7	1.5
27.68	2	**48.5***	2	66.3	2	78.9	2
27.65	2.5	48.2	2.5	72.7	2.5	85.6	2.5
27.4	3	47.6	3	**75.3***	3	87.4	3
27	3.5	45.9	3.5	73.4	3.5	90.3	3.5
26	4	44.3	4	68.2	4	98.41	4
20.1	4.5	35.64	4.5	60.7	4.5	**103.3***	4.5
-	-	27.2	5	55.8	5	100.3	5
-	-	21.3	5.5	49.8	5.5	96.5	5.5
-	-	-	-	52.4	6	90.4	6
-	-	-	-	-	-	88.7	6.5

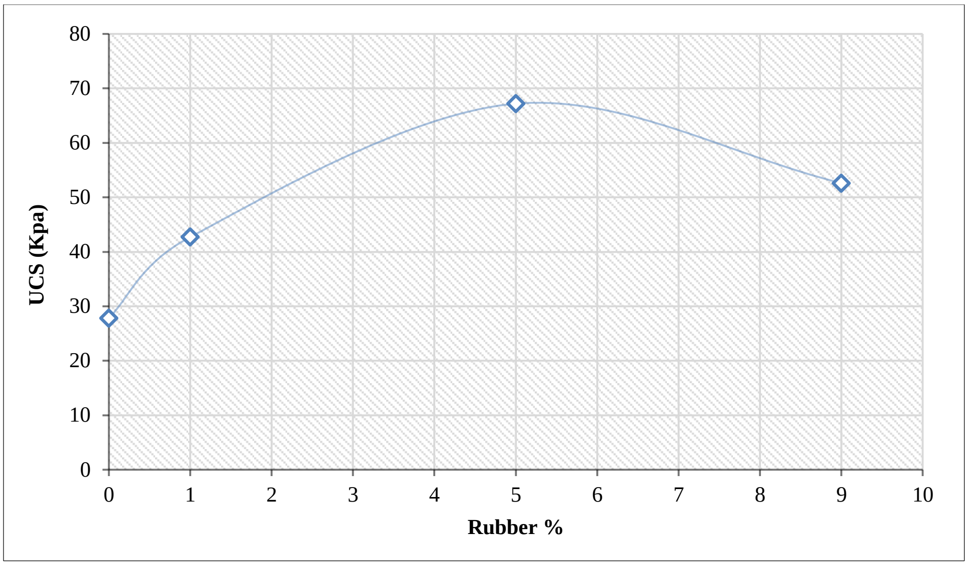

Figure 10. UCS values for different rubber substitutions

Table 4. MDD, OMC, CBR and UCS of reinforced soil with different percentage of glass fibber

Glass fibber %	CBR%	MDD	OMC	UCS
0	13	1.92	10.3	27.8
0.5	16.5	1.85	11.7	48.5
1	21.5	1.77	14.5	75.3
1.5	22.9	1.75	14.97	103.3

The table also shows the effect of glass fiber reinforcement on the CBR value of the soil. It is observed that the CBR value of the soil increases with an increase in the percentage of glass fiber. This finding suggests that the incorporation of glass fiber reinforcement enhances the soil's resistance to deformation and its capacity to withstand applied loads. It is noteworthy that the optimal values of ultimate compressive strength (UCS) and CBR are achieved when the glass fiber content is 1.5%. This suggests that 1.5% is the optimal percentage of glass fiber that can be added to the soil to enhance its mechanical properties.

In summary, the findings presented in Table 4 provide evidence that the incorporation of glass fiber into soil yields notable enhancements in its mechanical properties. Moreover, the optimal percentage of glass fiber to be added to the soil can be determined by analyzing the variations in UCS, OMC, MDD, and CBR values at different percentages of glass fiber.

Table 5 presents the relationship between the percentage of rubber content in reinforced soil and the corresponding UCS values. The table displays the stress-strain behavior of reinforced soil at different levels of rubber content. The strain values are expressed as a percentage of deformation, while the stress values are in kPa. The table shows that, as the percentage of rubber content in the reinforced soil increases, the UCS value decreases. For example, at 0% rubber content, the UCS value is 0 kPa. However, at 5% rubber content, the UCS value drops to 51.6 kPa. This trend is observed throughout the table, indicating that the addition of rubber to the soil has a detrimental effect on the UCS value.

It is noteworthy to mention that the stress-strain characteristics of reinforced soil exhibit variations in response to alterations in the proportion of rubber components. At lower levels of rubber content, the stress-strain curve exhibits a greater degree of linearity, whereas at higher levels of rubber content, the curve demonstrates a more pronounced nonlinearity, suggesting a heightened ductile response. The reason for this phenomenon is attributed to the role of rubber particles as energy dissipators, effectively absorbing the energy generated by external forces and thus promoting a greater degree of ductility in the material's behavior. In brief, the findings shown in Table 5 indicate that the incorporation of rubber into reinforced soil yields a detrimental impact on the UCS value. However, it is noteworthy that greater levels of rubber content can potentially result in enhanced ductile behavior. The table presents significant data for the purpose of determining the suitable rubber content in reinforced soil based on the intended performance criteria. The experimental findings pertaining to the influence of varying rubber percentages on the mechanical characteristics of reinforced soil are presented in Table 6. The presented table displays the recorded values of the maximum dry density (MDD), optimum moisture content (OMC), CBR, and UCS for the reinforced soil specimens that encompass different proportions of rubber.

Table 5. Relationship between rubber percentage in reinforced soil verses UCS

Rubber content							
0.00%		1.00%		5.00%		9.00%	
Stress (kPa)	Strain (%)	Stress (kPa)	Strain (%)	Stress (kPa)	Strain (%)	Stress (kPa)	Strain (%)
0	0	0	0	0	0	0	0
10.05	0.5	9.7	0.5	25.6	0.5	11.3	0.5
21	1	23.4	1	43.6	1	20.7	1
27.8	1.5	36.5	1.5	50.4	1.5	25.36	1.5
27.68	2	42.7	2	54.3	2	29.4	2
27.65	2.5	41.9	2.5	63.2	2.5	32.1	2.5
27.4	3	40.65	3	67.2	3	37.6	3
27	3.5	38.54	3.5	66.9	3.5	43.6	3.5
26	4	33.61	4	63.8	4	49.8	4
20.1	4.5	28.2	4.5	58.9	4.5	52.61	4.5
-	-	25.1	5	53.7	5	51.6	5
-	-	24.8	5.5	40.2	5.5	49.5	5.5
-	-	-	-	37.6	6	45.3	6
-	-	-	-	-	-	39.1	6.5

The findings suggest that the incorporation of rubber into the soil mixture has a substantial impact on the mechanical characteristics of the reinforced soil. As the proportion of rubber content increases, there is an observed increase in the UCS and CBR values; however, the maximum dry density (MDD) and optimum moisture content (OMC) exhibit a drop. The observed phenomenon can be attributed to the presence of rubber particles within the soil mixture, resulting in a decrease in soil density and an increase in porosity.

The sample containing 5% rubber exhibited the maximum UCS value of 67.2 kPa, but the sample with 9% rubber demonstrated the highest CBR value of 17.01%. Nevertheless, it can be observed that the values of MDD (Maximum Dry Density) and OMC (Optimum Moisture Content) exhibited a decline with the increase in the proportion of rubber. This suggests that the incorporation of rubber into the soil mixture leads to a reduction in compaction and an augmentation in water content.

To summarize, the findings shown in Table 6 indicate that incorporating rubber into the soil mixture has the potential to enhance the mechanical characteristics of the reinforced soil. However, this enhancement is accompanied by a reduction in soil density and an elevation in water content. Hence, it is important to meticulously ascertain the ideal proportion of rubber within the soil mixture, considering the distinct technical prerequisites and site circumstances.

Figure 11 presents a comparative analysis of the UCS values for soil reinforced with crumb rubber and glass fiber. The table provided in this document displays the UCS values for three different types of soil: raw soil, soil reinforced with 1% glass fiber, and soil reinforced with 1% rubber. The UCS value of the raw soil is 27.8 kilopascals (kPa), which is the smallest when compared to the other two soil types. The UCS of the soil reinforced with 1% glass fiber is measured at 75.3 kPa, indicating a notable increase compared to the unmodified soil. In contrast, the UCS of the 1% rubber-reinforced soil is measured at 42.7 kilopascals (kPa), positioning it between the UCS values of the unaltered soil and the 1% glass-fiber-reinforced soil.

Table 6. CBR, MDD, OMC, and UCS of reinforced soil with different percentage of rubber

Rubber%	CBR%	MDD	OMC	UCS
0	13	1.92	10.3	27.8
1	13.51	1.9	10.57	42.7
5	20.96	1.8	9.5	67.2
9	17.01	1.73	8.42	52.61

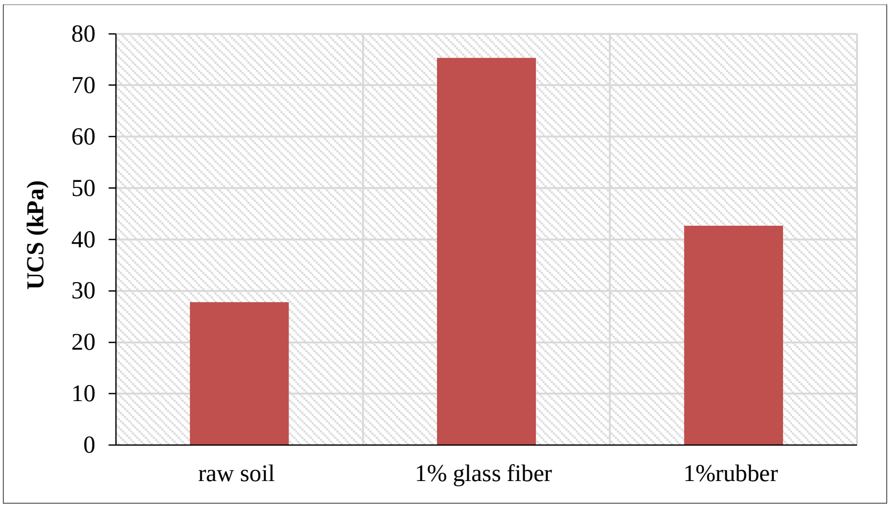

Figure 11. Comparison between crumb rubber and glass fibber depend on UCS values

This comparison implies that the utilization of glass fiber reinforcement is more efficacious in enhancing the UCS of soil as compared to the implementation of rubber reinforcement (Figure 11). Glass fibers are renowned for their exceptional tensile strength and stiffness, characteristics that can effectively enhance the overall strength of reinforced soil. In contrast, rubber particles tend to undergo deformation and absorb energy under stress, potentially leading to a reduced ultimate compressive strength (UCS) compared to glass fiber reinforcement.

Nevertheless, it is crucial to acknowledge that the selection of reinforcement material can be influenced by a multitude of elements, including but not limited to the specific application and prevailing climatic conditions. In certain applications that prioritize flexibility and deformation tolerance, the use of rubber reinforcement may be deemed more appropriate compared to the use of glass fiber reinforcement.

4. Conclusions

Based on the data presented in this study, it is possible to derive many conclusions pertaining to the impact of various types and proportions of reinforcement on the mechanical characteristics of soil.

The data presented in Table 3 provides a comparative analysis of the UCS values for soil reinforced with crumb rubber and glass fiber. It is evident from the table that the UCS of soil reinforced with 1% glass fiber is greater than that of soil reinforced with 1% rubber. This finding suggests that the use of glass fiber reinforcement yields superior results compared to rubber reinforcement when it comes to enhancing the soil's strength.

Table 4 displays the values of MDD (Maximum Dry Density), OMC (Optimum Moisture Content), CBR (California Bearing Ratio), and UCS (Unconfined Compressive Strength) for reinforced soil samples containing varying proportions of glass fiber. The data reveals a positive correlation between the proportion of glass fiber and the values of UCS and CBR, suggesting that greater levels of reinforcement lead to enhanced soil strength and durability.

The link between the rubber percentage in reinforced soil and the UCS is seen in Table 5. The findings suggest that the UCS of the reinforced soil exhibits an upward trend with an increasing proportion of rubber content, up to a specific threshold. Beyond this threshold, however, the UCS begins to decline. Hence, it can be inferred that the optimal rubber concentration for reinforced soil is approximately 3%.

Table 6 presents the values of MDD (Maximum Dry Density), OMC (Optimum Moisture Content), CBR (California Bearing Ratio), and UCS (Unconfined Compressive Strength) for reinforced soil samples containing varying proportions of rubber. The findings suggest that the UCS and CBR exhibit an upward trend when rubber is incorporated up to a concentration of 5%. However, beyond this threshold, the values begin to decline. Hence, it can be inferred that the optimal rubber concentration for reinforced soil is approximately 5%.

Figure 11 presents a comparison of the UCS values for three different soil conditions: raw soil, soil reinforced with 1% glass fiber, and soil reinforced with 1% rubber. The findings suggest that the UCS of the reinforced soil surpasses that of the raw soil, with the UCS of soil reinforced with glass fiber exhibiting a greater strength than that of soil reinforced with rubber.

In summary, the use of reinforcement materials, such as glass fiber and rubber, has been shown to yield substantial enhancements in the mechanical characteristics of soil. The determination of the ideal proportion of reinforcement material is contingent upon the application and prevailing soil conditions. The effectiveness of glass fiber reinforcement in enhancing soil strength is often superior to that of rubber reinforcement.

5. Declarations

5.1. Author Contributions

Conceptualization, M.A. and D.O.A.; methodology, M.A.; validation, M.A., M.H.S.A., and D.A.Y.H.; formal analysis, A.A.Y.H.; investigation, M.N.M.B.A.; resources, D.O.A.; data curation, M.H.S.A.; writing—original draft preparation, M.A.; writing—review and editing, M.A.; visualization, M.N.M.B.A.; supervision, D.O.A.; project administration, M.A. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Institutional Review Board Statement

Not applicable.

5.5. Informed Consent Statement

Not applicable.

5.6. Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

6. References

[1] Barman, D., & Dash, S. K. (2022). Stabilization of expansive soils using chemical additives: A review. Journal of Rock Mechanics and Geotechnical Engineering, 14(4), 1319–1342. doi:10.1016/j.jrmge.2022.02.011.

[2] Zamin, B., Nasir, H., Mehmood, K., Iqbal, Q., Bashir, M. T., & Farooq, A. (2021). Development of Some Novel Suction-Based Correlations for Swell Behavior of Expansive Soils. Advances in Civil Engineering, 2021, 1–13. doi:10.1155/2021/4825593.

[3] Mohamed, A. A. M. S., Yuan, J., Al-Ajamee, M., Dong, Y., Ren, Y., & Hakuzweyezu, T. (2023). Improvement of expansive soil characteristics stabilized with sawdust ash, high calcium fly ash and cement. Case Studies in Construction Materials, 18, 1894. doi:10.1016/j.cscm.2023.e01894.

[4] Soltani, A., Taheri, A., Deng, A., & Nikraz, H. (2022). Tyre rubber and expansive soils: Two hazards, one solution. Proceedings of Institution of Civil Engineers: Construction Materials, 175(1), 14–30. doi:10.1680/jcoma.18.00075.

[5] Zada, U., Jamal, A., Iqbal, M., Eldin, S. M., Almoshaogeh, M., Bekkouche, S. R., & Almuaythir, S. (2023). Recent advances in expansive soil stabilization using admixtures: current challenges and opportunities. Case Studies in Construction Materials, 18. doi:10.1016/j.cscm.2023.e01985.

[6] Yaghoubi, E., Yaghoubi, M., Guerrieri, M., & Sudarsanan, N. (2021). Improving expansive clay subgrades using recycled glass: Resilient modulus characteristics and pavement performance. Construction and Building Materials, 302, 124384. doi:10.1016/j.conbuildmat.2021.124384.

[7] Ikeagwuani, C. C., & Nwonu, D. C. (2019). Emerging trends in expansive soil stabilisation: A review. Journal of Rock Mechanics and Geotechnical Engineering, 11(2), 423–440. doi:10.1016/j.jrmge.2018.08.013.

[8] Miah, M. T., Oh, E., Chai, G., & Bell, P. (2022). Effect of Swelling Soil on Pavement Condition Index of Airport Runway Pavement. Transportation Research Record, 2676(10), 553–569. doi:10.1177/03611981221090517.

[9] Narani, S. S., Abbaspour, M., Mir Mohammad Hosseini, S. M., Aflaki, E., & Moghadas Nejad, F. (2020). Sustainable reuse of Waste Tire Textile Fibers (WTTFs) as reinforcement materials for expansive soils: With a special focus on landfill liners/covers. Journal of Cleaner Production, 247, 119151. doi:10.1016/j.jclepro.2019.119151.

[10] Rabab'ah, S., Al Hattamleh, O., Aldeeky, H., & Abu Alfoul, B. (2021). Effect of glass fiber on the properties of expansive soil and its utilization as subgrade reinforcement in pavement applications. In Case Studies in Construction Materials (Vol. 14). doi:10.1016/j.cscm.2020.e00485.

[11] Sujatha, E. R., Atchaya, P., Darshan, S., & Subhashini, S. (2021). Mechanical properties of glass fiber reinforced soil and its application as subgrade reinforcement. Road Materials and Pavement Design, 22(10), 2384–2395. doi:10.1080/14680629.2020.1746387.

[12] Valipour, M., Shourijeh, P. T., & Mohammadinia, A. (2021). Application of recycled tire polymer fibers and glass fibers for clay reinforcement. Transportation Geotechnics, 27, 100474. doi:10.1016/j.trgeo.2020.100474.

[13] Sosahab, J. S., Ardakani, A., & Hassanlourad, M. (2023). Resilient response and strength of highly expansive clay subgrade stabilized with recycled concrete aggregate and granulated blast furnace slag. Construction and Building Materials, 408, 133816. doi:10.1016/j.conbuildmat.2023.133816.

[14] Amakye, S. Y., & Abbey, S. J. (2021). Understanding the performance of expansive subgrade materials treated with non-traditional stabilisers: A review. Cleaner Engineering and Technology, 4, 100159. doi:10.1016/j.clet.2021.100159.

[15] Su, Y., Xiong, Z., Hu, Z., Zhu, W., Zhou, K., Wang, J., Liu, F., & Li, L. (2022). Dynamic bending study of glass fiber reinforced seawater and sea-sand concrete incorporated with expansive agents. Construction and Building Materials, 358, 129415. doi:10.1016/j.conbuildmat.2022.129415.

[16] Akbarimehr, D., Eslami, A., & Aflaki, E. (2020). Geotechnical behaviour of clay soil mixed with rubber waste. Journal of Cleaner Production, 271, 122632. doi:10.1016/j.jclepro.2020.122632.

[17] Archibong, F. N., Sanusi, O. M., Médéric, P., & Aït Hocine, N. (2021). An overview on the recycling of waste ground tyre rubbers in thermoplastic matrices: Effect of added fillers. Resources, Conservation and Recycling, 175, 105894. doi:10.1016/j.resconrec.2021.105894.

[18] Stevens, J. (1982). Unified soil classification system. Civil Engineering— American Society of Civil Engineers (ASCE), 52(12), 61-62.

[19] Fadmoro, O. F., Kar, S. S., Tiwari, D., & Singh, A. (2022). Environmental and Economic Impact of Mixed Cow Dung and Husk Ashes in Subgrade Soil Stabilization. International Journal of Pavement Research and Technology, 15(4), 835–846. doi:10.1007/s42947-021-00056-8.

[20] Saleh, S., Yunus, N. Z. M., Ahmad, K., & Ali, N. (2019). Improving the strength of weak soil using polyurethane grouts: A review. Construction and Building Materials, 202, 738–752. doi:10.1016/j.conbuildmat.2019.01.048.