Stress-strain and penetration characteristics of clay modified with crumb rubber

Tensión-deformación y penetración características de la arcilla modificada con caucho de miga

Titulo portugues

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Abstract

Waste disposal has become a serious issue worldwide due to the huge amount of by-products generated by refineries and smelting industries that threat the environment if they are disposed inefficiently. Development of roads leads to a large usage of vehicles and, hence, a large amount of rubber waste (*i.e.*, from tyres). Given that storing this material pollutes the environment, its recycled reused is currently trending. Various percentages of crumb rubber (0, 10, 15, 20, 30, 40 and 50) were mixed with highly and low compressible clay to understand the strength and penetration characteristics of the modified clay. Additionally, the thickness reduction of the pavement layer that reduces construction costs was visualize.

Keywords: bearing; clay; crumb rubber; strength.

Resumen

La eliminación de desechos se ha convertido en un problema serio en todo el mundo, dado que la cantidad de subproductos generados por las refinerías o las industrias de fundición es enorme y representa una amenaza para el medioambiente si no se elimina de manera eficiente. El desarrollo de carreteras propicia un gran uso de vehículos y la producción de grandes cantidades de desechos de caucho, es decir, de neumáticos. Como el almacenamiento de estos materiales conduce a la contaminación ambiental, la reutilización reciclada de este material es de tendencia. Se mezcló un porcentaje de goma de miga (0, 10, 15, 20, 30, 40 y 50%) con arcilla inorgánica y altamente compresible para comprender la resistencia y las características de penetración de la arcilla modificada. También se realizó un análisis para visualizar la reducción en el espesor de la capa de pavimento que reduce el costo de la construcción.

Palabras clave: arcilla; caucho de miga; fuerza; rodamiento.

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I. Introduction

Due to urbanization, the usage of vehicles has increased tremendously leading to a huge rise in the use of tyres. These tyres are made of a mixture of natural and synthetic rubbers with metals and chemical additives that produce a complex material for disposal. In 2011, around 7% of waste tyres was recycled in various civil engineering activities: 11% was burnt for fuel, 5% was exported, and the remaining 77% was dumped as landfill causing environmental issues [1]. In civil engineering, tyres are used as replacement material in concrete and sub-grade, as backfill for retaining sand and as stabilizing agent for weak soil. In India, by 2016, asphalt roads were laid with recycled rubber waste called *Crumb Rubber Modified Bitumen* (CRMB).

The weak soil (loose sand/soft clay) can be strengthened using additives composed of recycled material, which is environmental sustainable. Cao [2] studied the properties of recycled tyre rubber in different proportions (1%, 2% and 3% by weight) with asphalt mixture and found that the engineering properties of asphalt mixtures improved, including resistance to deformation, high temperature and cracking at low temperature. Calabar and Karabash [3] studied various combination of tyre chips and soil; they found that the maximum dry unit weight and optimum moisture content decreased when introducing tyre chips in the soil, and the California Bearing Ratio (CBR) value decreased when increasing the tyre chips in the sub-base gravel. A combination of 3% cement + 5% tyre chips and 5% cement + 15% tyre chips produced higher CBR value for sub-base. Tajdini *et al.* [4] observed that adding upto 5% of crumb rubber (CR) to clayey soil, decreases the strain and increases the CBR value; however, further addition of CR reduces the CBR value.

Anvari *et al.* [5], through various tests, calculated that an optimum percentage of rubber (5%) added to soil increases the internal angle of friction from 35.1° to 39.2° for a relative density of 50%. Nevertheless, the pattern changes when the soil is mixed for higher relative densities (70% and 90%). In addition, the shearing response of sand modified with granulated rubber was similar to loose sand. Reddy *et al.* [6] found that 30–40% of mixing tyre was optimal, and that it could be used as an environmental sustainable material as lightweight backfill in retaining wall. Bosscher *et al.* [7] addressed the porosity of the soil when mixed with rubber chips; they found that the porosity of the soil was affected by the tyre chip porosity due to its smaller size, pressure and alignment. By conducting triaxial tests, Lee *et al.* [8] indicated that the behaviour of the shredded tyre material was almost similar to sandy gravel backfill due to its physical properties. Crumb rubber mixed with expansive soil showed that reducing the volume changed the potential and increased the shear strength. Fine sand particle ranging from 2–0.075 mm can be replaced by shredded tyre of 4.75–2.00 mm and can be effectively used as backfill. Increasing the percentage of CR enlarged the horizontal displacement, and a mixture of CR and Sand (30:70) showed better performance [9].

Introducing scrap tyres into the soil increased both shear strength and tyre particle size and showed no significant change in specific gravity and water absorption [10]. Zornberg *et al.* [11] studied the influence of aspect ratio and content of shredded tyre by conducting triaxial tests; they inferred the optimum percentage as 35%, which shows the peak shear strength value, and observed that the strength of clay soil reinforced with scrap tyre rubber, polyethylene and polypropylene improved [12]. Centin *et al.* [13] mixed coarse and fine-grained tyre chips in clay soil, using maximum 20% of coarse grained tyre chip and 30% of fine-grained tyre chip; this modified soil can be used above the water table where road highway embankment is built on a low bearing soil. Crumb rubber, when mixed with highly compressible clay soil, works better than the compressible silt, and the optimum moisture content (OMC) increases at greater CR sizes [14]. Tabbaa *et al.* [15] used 20% of tyre waste in different types of clay and inferred that the compacted density, strength and permeability decrease when increasing the percentage of tyre chips and the amount and size of tyre particles. The maximum dry density and optimum moisture content decreases with the increase in rubber mixture. Adding rubber, the unconfined compressive strength decreases with increase in axial strain [16].

A case study by Humphrey *et al.* [17] allowed understanding that when soil is mixed with tyre chips, it suffers high compression, due to initial loading, that reduces upon further loading/unloading action. Due to the coarse nature of rubber chips, tyre chips have free drainage and low compacted density making them more suitable as fill material for retaining structure.

Humphrey and collaborators addressed water quality when the soil is mixed with rubber chips and found that the low compressible substance leached from the tyres low levels into the ground water [18]. O'Shaughnessy and Garga [19] suggested that the soil modified with rubber should always be placed above the permanent ground water table. They conducted tests with the leachate collected from the modified soil with rubber to evaluate its influence in the environment, and although they found limited consequences for the environment, in case of fire, the residue of rubber is considered hazardous [20, 21]. Gacke *et al.* [22] emphasised the need of monitoring combustion when using shredded tyre chip as embankment fill. The shear strength increases up to 4% addition of CR, further addition of CR reduces the soil strength [23].

Given that major literature shows the effect of CR in the environment, embankment and subgrade soil, this study assess the effect of different ratios of CR on strength, deformation and bearing of modified soil and compares with previous studies. The reduction in thickness is also discussed, related with various proportions of CR in high compressible and intermediate clay.

II. Materials and methods

A. Soil

Soils were taken from two places in Chennai (India): S1 and S2. The properties of the soil (Table 1) were found using relevant codes of the Bureau of Indian Standards (BIS).

Table 1
Properties of Soil

Parameter	IS Code	Soil (S1)	Soil(S2)
Specific Gravity	IS 2720 [24]	2.71	2.63
Gravel	IS 2720 [25]	-	2
Sand		7	22
Silt + Clay		93	76
Liquid limit	IS 2720 [26, 27]	63	39
Plastic Limit		31	16
Shrinkage Limit		12	8
Soil Classification	IS 1498–1970 [28]	High Compressible Clay (CH)	Medium Compressible Clay (CI)

B. Crumb rubber

The crumb rubber (CR) and tyre chips show similar properties when mixed with soil. Hence, CR of specific gravity of 0.4 and particle size of 425 microns was used for all the experiments in 10,15, 20, 30, 40 and 50% by weight.

C. Methods

1) Unconfined compressive strength. The consistency of the soil was assessed by a strength determined unconfined compressive test referring IS 2720 part 10 [29]. The density of the unmodified soil sample was 16 and 19.2 kN/m^3 and the water content was 18.6 and 15.5%, for S1 and S2, respectively. Samples were prepared for these densities in a thin walled sampler mould of 38 mm diameter and 76 mm long, satisfying the L/D ratio as 2 by compacting statically. Once the sample was prepared, it was placed in a chamber, placing porous stones at the bottom and top of the sample. The dial gauge of 0.01 mm least count was fixed at the bottom to understand the deformation behavior, and the proving ring of 20 kN capacity was fixed in the loading frame to apply the load. A test was conducted under a controlled strain rate of 0.75 mm/min and continued until the sample failed. Once the sample fail, it was removed and dried in an oven to determine water content.

The axial strain was obtained from the dial gage at constant time intervals, and the strain was calculated using equation (1). Subsequently, the corrected area under the strain was calculated using equation (2), and the corresponding compressive stress was determined using equation (3). The undrained shear strength (c_u) was calculated using equation (4).

$$\varepsilon = \frac{\Delta L}{L} \quad (1)$$

$$A = \frac{A_0}{1-\varepsilon} \quad (2)$$

$$\sigma = \frac{P}{A} \quad (3)$$

$$c_u = \frac{\sigma}{2} \quad (4)$$

Where, ε is the strain, ΔL is the change in length (mm), L is the original length (mm), A is the modified cross section area (mm^2), A_o is the original cross section area (mm^2), σ is the compressive stress (kN/m^2), P is the load (N), and c_u is the unconfined compressive strength (kPa).

2) California Bearing Ratio (CBR). The penetration behaviour of the sample was obtained by conducting CBR test as per IS 2720 –part 16 [30], and calculated using equation (5). The sample was prepared similar to that for the unconfined compressive strength test and loaded statically. The CBR was defined as the ratio in percentage of force per unit area to penetrate the soil with 50 mm diameter circular plunger at a rate of 1.25 mm/min to a corresponding penetration of 2.5 mm for standard material.

$$CBR = \frac{P_t}{P_s} x100 \quad (5)$$

Where, P_t is the corrected unit (or total) test load, corresponding to the chosen penetration from the load penetration curve and P_s is the unit (or total) standard load for the same depth of penetration in percentage. The load corresponding to 2.5 mm penetration is noted and divided by the standard load (1370 kg).

D. Parameters

The study involved various proportions of CR (0, 10, 15, 20, 30, 40 and 50%) mixed with soil to understand compressive strength and CBR properties for high and medium compressibility clay.

III. Results and Discussion

A. Compressive strength

The compressive strength of the soil was found using equation (4). Figure 1 shows the stress-strain graph of S1 and S2 soils mixed with various proportions of CR (0, 10, 15, 20, 30, 40 and 50% by weight). The compressive strength of S1 and S2 were 160 and 191 kPa, respectively. Upon increasing the percentage of CR in the soil, the compressive stress decreased beyond 15% of CR intrusion. The strength increased to 260 kPa (38.5%) in S1 and to 263 kPa (27.7%) in S2. Strength gain ratio (treated soil strength to untreated soil strength) showed a typical increase in strength up to 15% and decreased after further addition. Beyond 40% for S1 and 30% for S2, the strength was less than the untreated soil (Fig. 2); hence, for highly compressible soil, the usage limit of CR is 40% and for low compressible soil, is 30%.

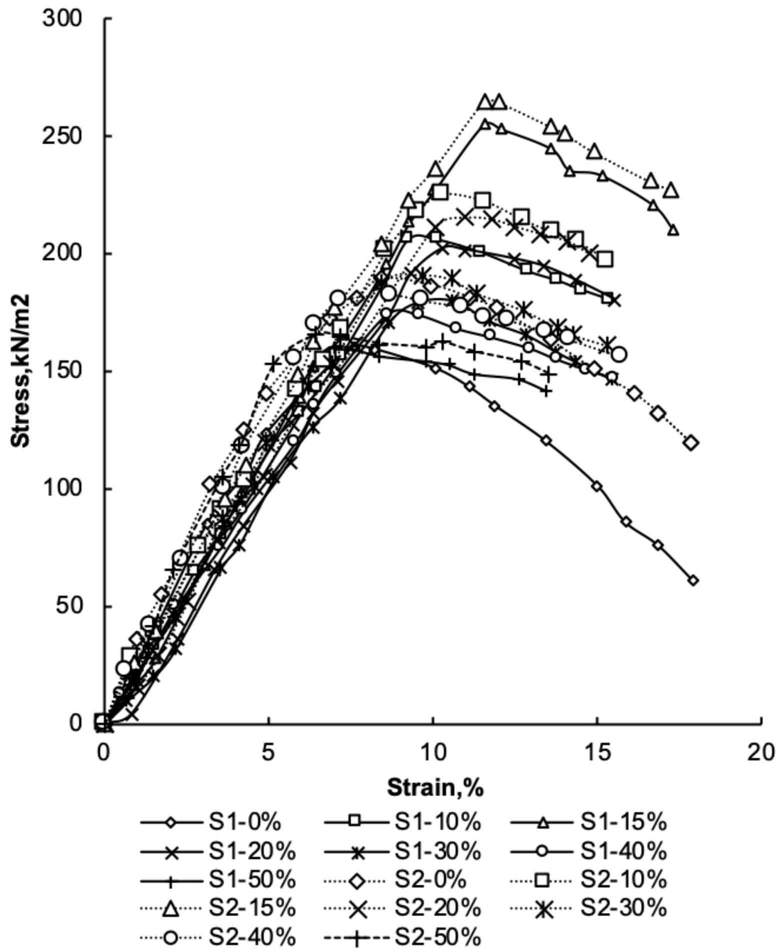


Fig. 1. Stress Strain of modified clay.

Modulus of soil can be the tangent or secant of the stress–strain graph of uniaxially loaded soil sample and in the current study tangent modulus is considered from the stress-strain graph of soil sheared until failure.

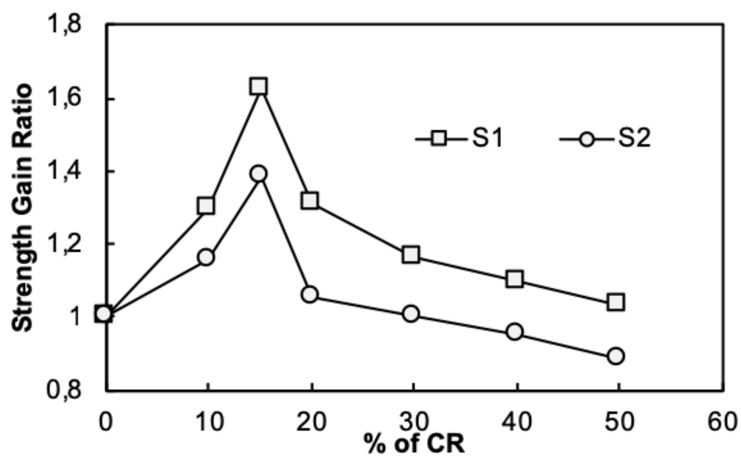


Fig. 2. Strength gain ratio for soil modified with CR.

For highly compressible clay (S1), an initial addition of 10% CR to the soil reduced the modulus of the soil, whereas an addition of 15% CR increased the modulus to 32 kPa. However, the modulus values decreased drastically beyond 15% addition up to 20%, and then, they gradually increased; although they did not reach the modulus value of the unmodified soil. For medium compressible clay (S2), the initial modulus was 35.07 kPa. A 10% addition of CR reduced the modulus to 32.81 kPa, whereas a 15% addition increased it to 34.56 kPa. Subsequently, the modulus value fall and any further CR addition increased the modulus. For a maximum addition of 50% CR, the modulus value was 36.36 kPa, which was higher than the unmodified soil modulus. The initial behaviour for both soils modified with CR was the same, but after 15%, the soils showed different behaviours. Upon addition of 40% CR, S2 showed a modulus similar to that of unmodified soil; however, adding 50% of CR to S1 showed a modulus almost similar to that of unmodified soil (Fig. 3). The axial strain, taken as the strain occurred at failure stress for both soils, followed a similar pattern, being maximum in S2. Further addition of CR beyond 15% showed reduction in strain (Fig. 4).

B. Penetration behaviour

Table 2 shows the CBR values for different proportions of CR in S1 and S2. From these values, the *Admixture Influencing Factor (AIF)* and a ratio of CBR value of treated soil to untreated soil were calculated (Fig. 5).

Table 2

CBR Values of various proportions of CR

CR (%)	0	10	15	20	30	40	50
S1	5.8	7.1	7.9	6.2	5.4	4.9	3.6
S2	6.9	7.4	8	6.5	5.8	5.2	4.8

Up to 15% increase of CR increased AIF to maximum values of 1.36 (S1) and 1.16 (S2). Further addition of CR decreased the AIF reaching a value lower than the untreated soil. Additionally, upon adding up to 20% CR to soil, the AIF was higher than that of unmodified soil, which emphasizes the fact that CR influences the soil up to 20%, showing a peak value at 15% of CR.

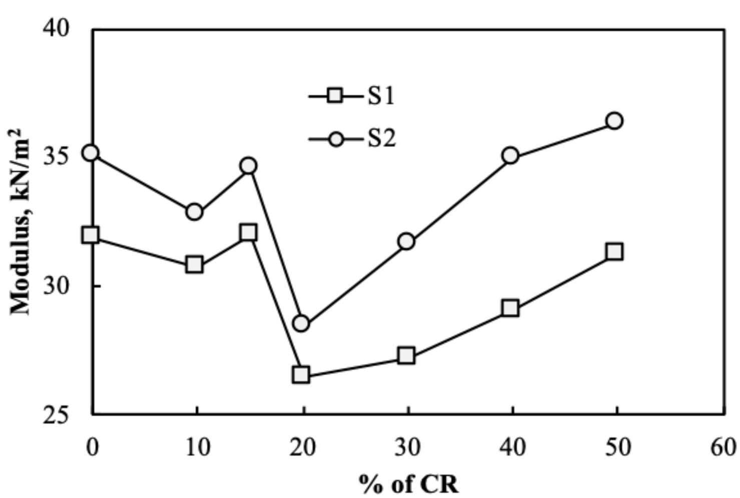


Fig. 3. Modulus of soil with varying proportions of CR.

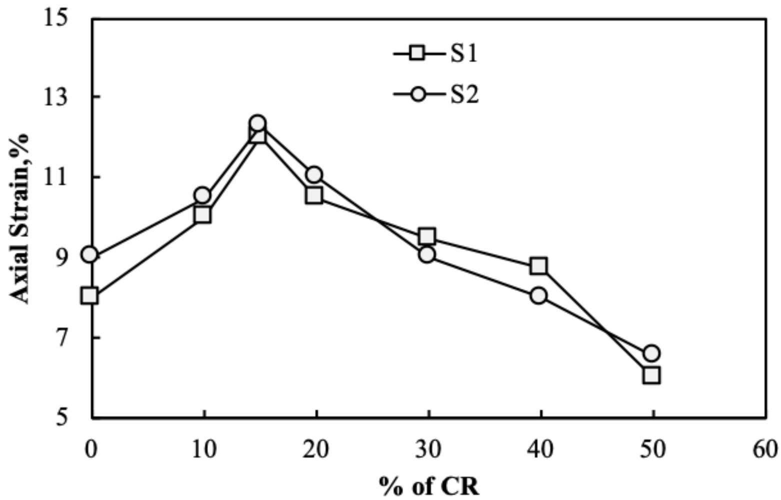


Fig. 4. Influence of CR on strain.

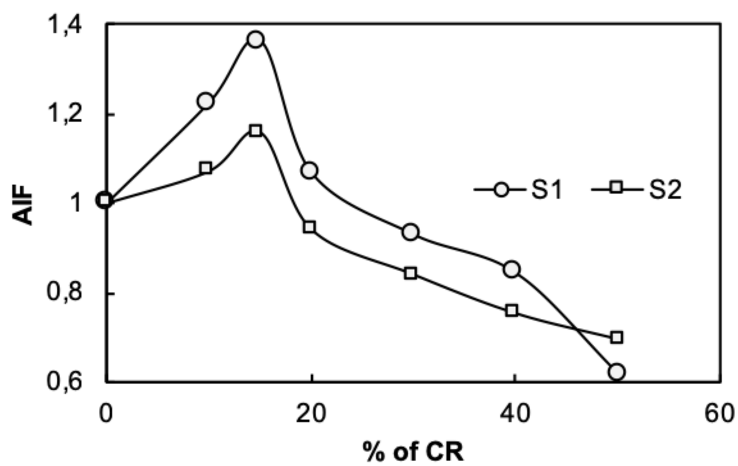
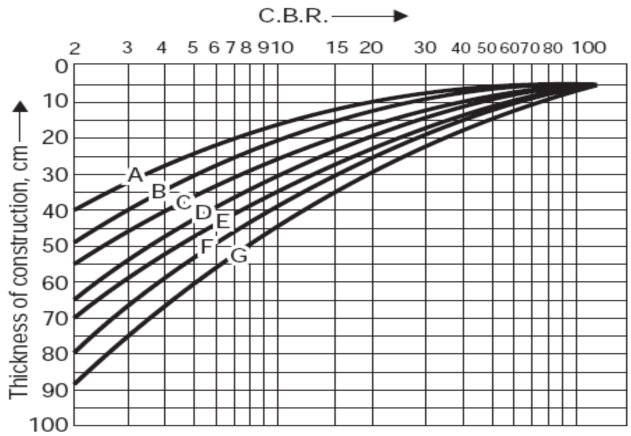


Fig. 5. AIF for different proportions of CR with soil.

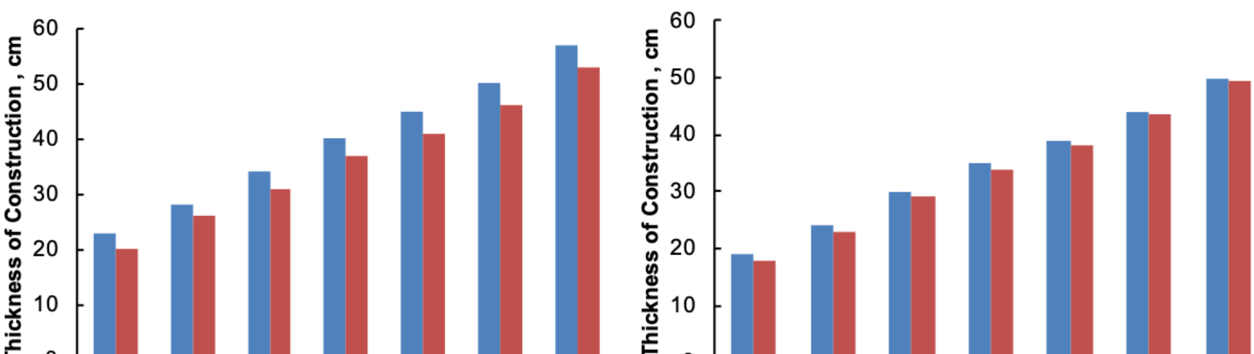
The vehicles per day for untreated soil and the optimum percentage of CR (15%) were found and compared using the CBR value; the thickness of the flexible pavement was calculated using the chart developed by Alam [31] (Fig. 6). The thickness of the layer was calculated based on the number of vehicles per day (Fig. 7).



Curve	No. of vehicles day (> 3t)
A	0 – 15
B	15 – 45
C	45 – 150
D	150 – 450
E	450 – 1500
F	1500 – 4500
G	Over 4500

Fig. 17.4 Design charts for flexible pavements—CBR method
(After R.R.L., London & Alam Singh, 1967)

FIG. 6. Design Charts for flexible pavement– CBR method.



	A	B	C	D	E	F	G
S1	23	28	34	40	45	50	57
S2	20	26	31	37	41	46	53

(a) For untreated Soil

	A	B	C	D	E	F	G
S1	19	24	30	35	39	44	50
S2	18	23	29	34	38	43,5	49,5

(b) For optimum mix of CR of 15%

FIG. 7. Thickness of treated and untreated soil pavement.

Highly compressible clay (S1) showed higher thickness for various numbers of vehicles compared to low compressible clay (S2), due to its highly compressible nature. When 15% CR was introduced into the soil by weight, the thickness of the layer reduced. For S1 soil, the reduction in thickness of the construction layer was higher than that of S2 soil (Fig. 8).

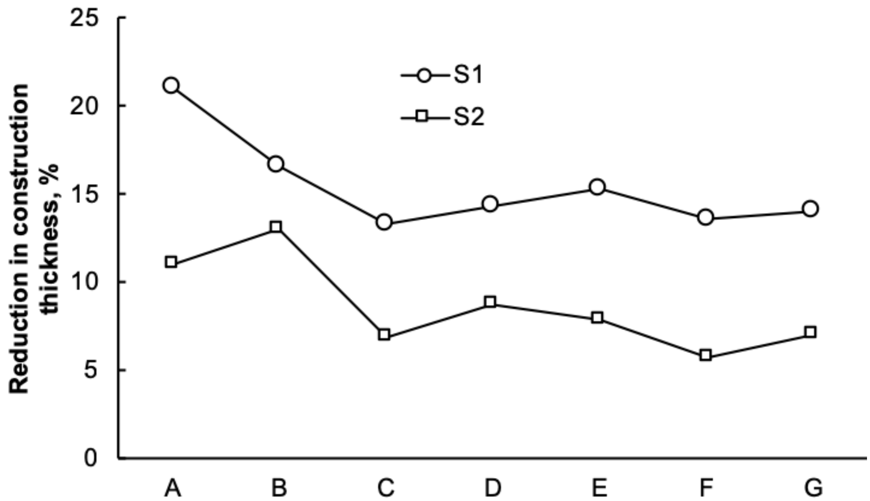


Fig. 8. Reduction in thickness of construction.

The thickness reduction for lower numbers of vehicles for S1 was around 21% compared to 11% for S2. With number of vehicles ranging between 15 and 45 per day, the reduction in thickness of layer decreased to 16% for S1 and increased to 13% for S2. By increasing the number of vehicles, the reduction in construction layer thickness of flexible road decreased. Moreover, the maximum reduction was observed for very low number of vehicles (0-15) for S1, whereas S2 showed higher reduction when vehicles ranged between 15 and 45 per day.

IV. Conclusion

Using recycled rubber as a partial replacement of soil helps improving ageing resistance and provides better aggregate and binder adhesion. The following conclusions are derived from the experimental results:

1. The maximum increase in shear strength of the soil happens at 15% of partial replacement. For highly compressible soil (CH), the strength increases from 160 kPa to 260 kPa, and for moderately compressible soil (CI) from 190 kPa to 263 kPa.

2. The shear modulus of the soil shows an increase in value up to 15% addition of CR.

3. The percentage of strain is maximum for both soils at 15%, and decreases upon further addition of CR.

4. With the optimum content of CR mixed in both soils, the thickness of the pavement considerably decreased about 14% for various intensities of traffic, which subsequently reduces the cost of construction.

References

[1] M. Lalatendu, “Turning waste tyre into ‘green steel,’” *The Hindu*, 2016. [Online]. Available: https://www.thehindu.com/business/Turning-waste-tyre-into-‘green-steel’/article14518524.ece.

[2] W. Cao, “Study on properties of recycled tire rubber modified asphalt mixtures using dry process,” *Constr. Build. Mater.*, vol. 21(5), pp. 1011–1015, 2007. DOI: https://doi.org/10.1016/j.conbuildmat.2006.02.004.

[3] A. F. Cabalar, Z. Karabash, R. Cabalar, and A. F. Karabash, “California Bearing Ratio of a Sub-Base Material Modified With Tire Buffings and Cement Addition California Bearing Ratio of a Sub-Base Material Modified With Tire,” *J. Test. Eval.*, vol. 43(6), pp. 1279–1287, 2015. DOI: https://doi.org/10.1520/JTE20130070.

[4] M. Tajdini, A. Nabizadeh, H. Taherkhani, and H. Zartaj, “Effect of Added Waste Rubber on the Properties and Failure Mode of Kaolinite Clay,” *Int. J. Civ. Eng.*, vol. 15(6), pp. 949–958, 2017. DOI: https://doi.org/10.1007/s40999-016-0057-7.

[5] S. M. Anvari, I. Shooshpasha, and S. S. Kutanaei, “Effect of granulated rubber on shear strength of fine-grained sand,” *J. Rock Mech. Geotech. Eng.*, vol. 9(5), pp. 936–944, 2017. DOI: https://doi.org/10.1016/j.jrmge.2017.03.008.

[6] S. Bali Reddy, D. Pradeep Kumar, and A. Murali Krishna, “Evaluation of the Optimum Mixing Ratio

of a Sand-Tire Chips Mixture for Geoengineering Applications," *J. Mater. Civ. Eng.*, vol. 28(2), p. 06015007, 2015. DOI: https://doi.org/10.1061/(ASCE)MT.1943-5533.0001335.

[7] P. J. Bosscher, T. B. Edil, and S. Kuraoka, "Design of Highway Embankments Using Tire Chips," *J. Geotech. Geoenvironmental Eng.*, vol. 123(4), pp. 295–304, 1997. DOI: https://doi.org/10.1061/(ASCE)1090-0241(1997)123:4(295).

[8] J. H. Lee, R. Salgado, A. Bernal, and C. W. Lovell, "Shredded tires and rubber-sand as lightweight backfill," *J. Geotech. Geoenvironmental Eng.*, vol. 125(2), pp. 132–141, Feb. 1999. DOI: https://doi.org/10.1061/(ASCE)1090-0241(1999)125:2(132).

[9] A. Srivastava, S. Pandey, and J. Rana, "Use of shredded tyre waste in improving the geotechnical properties of expansive black cotton soil," *J. Geomech. Geoengin.*, vol. 9(4), pp. 303–311, Apr. 2014. DOI: https://doi.org/10.1080/17486025.2014.902121.

[10] H. Moo-young, K. Sellasie, D. Zeroka, and G. Sabnis, "Physical and Chemical Properties of Recycled Tire Shreds for Use in Construction," vol. 129(4), pp. 921–929, 2003.

[11] J. G. Zornberg, A. R. Cabral, and C. Viratjandr, "Behaviour of tyre shred - sand mixtures," *Can. J. Civ. Eng.*, vol. 41(2), pp. 227–241, 2004. DOI: https://doi.org/10.1139/T03-086.

[12] S. Akbulut, S. Arasan, and E. Kalkan, "Modification of clayey soils using scrap tire rubber and synthetic fibers," *Appl. Clay Sci.*, vol. 38(1–2), pp. 23–32, 2007. DOI: https://doi.org/10.1016/j.clay.2007.02.001.

[13] H. Cetin, M. Fener, and O. Gunaydin, "Geotechnical properties of tyre- cohesive clayey soil mixtures as a fill material," *Eng. Geol.*, vol. 88(1–2), pp. 110–120, 2006. DOI: https://doi.org/10.1016/j.enggeo.2006.09.002.

[14] M. Tajabadipour, and M. Marandi, "Effect of rubber tire chips-sand mixtures on performance of geosynthetic reinforced earth walls," *Period. Polytech. Civ. Eng.*, vol. 61(2), pp. 322–334, 2017. DOI: https://doi.org/10.3311/PPci.9539.

[15] J. S. Yadav, and S. K. Tiwari, "Influence of crumb rubber on the geotechnical properties of clayey soil," *Environ. Dev. Sustain.*, vol. 20 (6), pp. 2565–2586, 2018.

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

[17] D. N. Humphrey, T. C. Sandford, M. M. Cribbs, and W. P. Manion, "Shear Strength and Compressibility of Tire chips for Use as Retaining Wall Backfill," *Transportation Research Record 1422, TRB, National Research Council, Washington. D.C.* pp. 29–35, 1993.

[18] T. B. Edil, P.J. Fox, and S. W. Ahl, "Hydraulic Conductivity and Compressibility of Waste Tire Chips," In *Procceeding of 15th Annual Madison Waste Conference*, 1992, pp. 49–61.

[19] V. O'Shaughnessy, and V. K. Garga, "Tire-reinforced earthfill. Part 3: Environmental assessment," *Can. J. Civ. Eng.*, vol. 37(1), pp. 117–131, 2000. DOI: https://doi.org/10.1139/t99-086.

[20] P. Hennebert, S. Lambert, F. Fouillen, and B. Charrasse, "Assessing the environmental impact of shredded tires as embankment fill material," *Can. J. Civ. Eng.*, vol. 51(5), pp. 469–478, 2014. DOI: https://doi.org/10.1139/cgj-2013-0194.

[21] A. Al-Tabbaa, O. Blackwell, and S. A. Porter, "An Investigation into the Geotechnical Properties of Soil-Tyre Mixtures," *Environ. Technol.*, vol. 18(8), pp. 855–860, 2010. DOI: https://doi.org/10.1080/09593331808616605.

[22] S. Gacke, M. Lee, and N. Boyd, "Field Performance and mitigation of shredded tire embankment," *Transp. Res. Rec.*, vol 1577, pp. 81–89, 1997. DOI: https://doi.org/10.3141/1577-10.

[23] B. Ajmera, B. Tiwari, and J. Koirala, "Geotechnical Properties of Clays Modified with Recycled Crumb Rubber," In *Geotechnical and Structural Engineering Congress*, 2016, pp. 14–17.

[24] Bureau of Indian Standards, *IS 2720(Part III/2) Determination of Specific Gravity for fine, medium and coarse grained soil*, 1997, pp. 1–10.

[25] Bureau of Indian Standard, *IS 2720 (Part IV) Grain size analysis*, 1995, pp. 1–40.

[26] Bureau of Indian Standard, *IS 2720 (Part V) Determination of Liquid and Plastic Limit*, 1995, pp. 1–17.

[27] Bureau of Indian Standard, *IS 2720 (Part VI) Determination of Shrinkage Factors*, 2001, pp. 1–20.

[28] Bureau of Indian Standard, *IS 1498 Classification and Identification of Soils for General Engineering Purpose*, 2002, pp. 1–28.

[29] Bureau of Indian Standards, *IS 2720 (Part X) Determination of Unconfined Compressive Strength*, 1995, pp. 1–8.

[30] Bureau of Indian Standard, *IS 2720 (Part 16) Laboratory Determination of CBR*, 1997, pp. 1–17.

[31] A. Singh, *Soil Engineering in Theory and Practice*. Bombay, India: Asia Publishing House, 1967.