Effectiveness of crumb rubber for subgrade soil stabilization

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Abstract. The properties of subgrade soil are important in the pavement design as its main function is to support the load transmitted from overlying pavement layers. Subgrade must have sufficient strength and stability even under bad traffic and climate conditions. Soil with good qualities should be used as subgrade but not all soil possesses the required abilities as there are some locations that have poor qualities of in-situ soil. The stabilization of soil can be used to improve the poor subgrade; hence it may reduce the thickness of pavement design and also increase life of the pavement. In this study, soil stabilization using crumb rubber is the alteration of subgrade soil as the properties of crumb rubber are lightweight and high shear strength. Moreover, it can also reduce the improper tyre’s disposal problem and pollutions. The soil used are collected from a landslide site located near to Mengkuang Dam in Seberang Perai Tengah, Penang in order to investigate the performance of subgrade soil stabilized with 2%, 4%, 6% and 8% of Crumb Rubber (CR). A series of laboratory testing of unsoaked and soaked (4 days) California Bearing Ratio (CBR) test have been performed to evaluate the best percentage of CR which fulfilled the JKR specification for subgrade. The results show that all mixtures; M2 (2% CR), M3 (4% CR), M4 (6% CR), and M5 (8% CR) are fulfilled the subgrade requirement according to the Public Works Department Malaysia (JKR) standard specification for road works where the CBR value must achieve more than 5%. The mixture with 4% CR (M3) shows the highest unsoaked and soaked CBR values, thus, the 4% CR is recommended to be implemented for subgrade soil stabilization.

1. Introduction
Subgrade can be in-situ natural or imported soil. The subgrade is not part of the pavement structure but act as the foundation, supporting the traffic loads which transmitted from the overlying layers [1]. When the number of vehicle increases, the road pavement performance also has an effect due to the insufficient pavement capacity to support heavy traffic loads. Hence, layers of highway pavement especially subgrade with stronger materials become essential to support and distribute the wheel load to the natural soil. The thickness and the material used for the upper layers are depends on the strength of the subgrade. According to [1], different traffic volume, traffic composition, climate condition and bearing capacity or strength of the subgrade might require different design thickness and quality of material use. Therefore, the strength of the soil in a road construction area is important in order to produce a quality subgrade.

Waste tyres become a growing problem in recent years due to continuous rise in the number of vehicles [2]. In Malaysia, it is estimated that 57 391 to 8.2 million tonnes production of waste tyres every year, where more than 50% amount of them were disposed wrongly [3]. Waste tyres are difficult to be recycled as they contain a complex mixture of synthetic rubber, fibre and wire materials [4].
Besides, tyres create major environmental problem as they do not decay down naturally because of their non-biodegradable properties and their open burning also causes air pollution [5]. In order to eliminate these negative impacts on the sustainable development, the recycling of waste tyres potentially can be usable in various forms including the whole tyres, shredded tyres, tyre chips and smaller size of crumb rubber.

The damage on road surface usually caused by the unstable subgrade soil. Poor condition of road surface like pothole, rutting, shoving and other road defects brought the uncomfortable and inconvenienced to the road users. In this study, a problematic soil of a landslide which occurred along a main road was assumed to have low soil strength and moreover have affected the subgrade layer of the road. Additionally, the road defects also increase the pavement maintenance cost. In order to overcome these problems, a strong subgrade should be provided throughout the road construction stage and a soil improvement method is necessary.

Soil improvement technique is a method to increase bearing capacity and strength of soil. Stabilization refers to a long-term subgrade treatment that is intended to increase the soil properties such as shear strength, permeability and compressibility. Soil stabilization is a frequently used technique for soil improvement as it offers the most economical method. The subgrade soil which is weak has to be treated or stabilized to suit the requirements [6]. The construction costs can be potentially saved by stabilizing the subgrade soil compared to cutting and replacing with unbalanced subgrade soil [7].

This study contributes benefit especially for the construction industries to discover alternative construction materials which simultaneously reduce the pollution and disposal problems. From the findings, waste tyres can be a new alternative material for soil stabilization which good in cost effective solutions and also for conservation of scarce natural resources.

According to Public Works Department of Malaysia’s (PWD) Specification for Road Works (JKR/SPJ/2014) [8], a minimum CBR of 5% is recommended for pavements that have to support traffic volumes corresponding to Traffic Classes T2 through T5. For road pavements designed for large volumes of traffic (Traffic Classes T4 and T5), a minimum subgrade strength corresponding to CBR of 12% is recommended.

2. Materials
The soil used in this study was collected at coordinate (5.394064, 100.505981) within a landslide site located near to Mengkuang Dam in Seberang Perai Tengah, Penang as shown in Figure 1. The landslide was occurred along the road and this situation give an indication of the soil strength at that particular area. The soil was obtained as disturbed sample from a depth of 2 m below ground level by using hand auger. This problematic soil was selected for this study in order to improve the soil strength by using local available material as additive.

![Figure 1](image-url)
Several soil properties laboratory testing were conducted. From the results, the composition of the soil is dominated by 42% of silt, 37.46% of sand and 20.54% of gravel and it was identified as sandy SILT of Intermediate Plasticity (MI). The summary of the soil physical properties is shown in Table 1.

| Physical Properties          | Results |
|------------------------------|---------|
| Specific Gravity             | 2.66    |
| Moisture Content, (%)        | 20.14   |
| Liquid Limit, (%)            | 46.42   |
| Plastic Limit, (%)           | 40.41   |
| Plasticity Index, (%)        | 6.01    |
| Particle Size Distribution   | Sandy SILT |
| Soaked CBR value (%)         | 3.40    |

Crumb rubber was produced from rubber tires which the iron and tyre (fluff) have been removed. The crumb rubber used in this study was obtained from Gcycle Factory located in Sungai Petani, Kedah with 30 mesh in size (0.595 mm) as shown in Figure 2. The crumb rubber from this factory is the recycled rubber specifically from truck scrap tires.

![Figure 2. Crumb rubber in 0.595 mm size.](image)

From research conducted by [9], the chemical composition of crumb rubber is listed in Table 2 below.

| Test                              | Results |
|-----------------------------------|---------|
| Ash content, %                    | 5.11    |
| Carbon black content, %           | 28.43   |
| Acetone extract, %                | 9.85    |
| Volatile matter, %                | 0.56    |
| Hydrocarbon content, %            | 56.05   |
| Polymer analysis, %               | SBR     |

3. Methodology
The previous study conducted by [10] proved that the Crumb Rubber (CR) which mixed with two (2) samples of weak soils indicate improvement in CBR value with addition of CR up to 10% only and
onwards the CBR value decreased with further increase in CR. As to further the research, in this study four (4) different percentages of CR were added to the soil in proportion of 2, 4, 6, and 8 in terms of percentage as in Table 3. The soil without CR (0%) is also prepared as control sample throughout this study.

| Mixture       | Percentage Mixture (%) | Soil | Crumb Rubber (CR) |
|---------------|-------------------------|------|-------------------|
| M1 (control sample) | 100                      | 0    |                   |
| M2            | 98                      | 2    |                   |
| M3            | 96                      | 4    |                   |
| M4            | 94                      | 6    |                   |
| M5            | 92                      | 8    |                   |

The California Bearing Ratio (CBR) test is commonly used to determine the strength of subgrade soil, subbase and base materials for road and airfield pavement design. In order to achieve the objective of this study, the CBR test is carried out to evaluate the strength of subgrade soil at ratio of the load sustained by the specimen at 2.5 or 5.0 mm penetration. CBR is performed in accordance to standard BS 1377: Part 4:1990 [11] for unsoaked and soaked (4 days) conditions.

The CBR mould has an internal diameter of 152 mm and the mould is fitted with a detachable normal or perforated baseplate and a removable extension collar. For compaction purpose, a mechanical hammer of 4.5 kg with 450 m drop height is used. The CBR test is carried out on materials that passing 20 mm sieve size and the value of moisture content added to the sample is adopted from compaction test that have been conducted before.

Then, the samples are compacted in 5 layers with 62 blows per layer. For soak condition, the CBR samples are soaked for 96 hours (4 days) in basin. The CBR tests were performed using load-measuring device, which is connected to the compression machine with the loading rate of 0.025 kN/div for penetration reading at every 0.25 mm interval of the penetration dial gauge. The mould with CBR sample and surcharge weights were placed in a CBR testing machine as illustrated in Figure 3 and measured at 2.5 mm and 5 mm displacement. The penetration readings are taken at top and bottom of the sample and then the CBR value can be calculated.

![Figure 3. A schematic representation of CBR testing.](image)
4. Results and Discussion

The CBR test was conducted in order to determine the bearing value, thus to evaluate the strength of road subgrade and subbase for pavement thickness design. In this study, two types of CBR tests have been conducted; unsoaked and soaked (4 days) conditions. The unsoaked CBR is represented the normal field condition, while soaked CBR is to simulate the worst condition of the road pavement encountered at field. The penetration test was carried out at the top and bottom part of the CBR samples. Table 4 shows the results of unsoaked and soaked CBR values at different percentage of crumb rubber.

Table 4. Results of unsoaked and soaked CBR values.

| Mixture    | Percentage Mixture (%) | Average CBR Value (%) | Soil | Crumb Rubber (CR) | Unsoaked | Soaked (4 days) |
|------------|------------------------|-----------------------|------|-------------------|----------|-----------------|
| M1 (control sample) | 100                    | 5.62                  | 0    |                   | 3.40     |                 |
| M2         | 98                     | 17.12                 | 2    |                   | 14.07    |                 |
| M3         | 96                     | 36.09                 | 4    |                   | 30.14    |                 |
| M4         | 94                     | 29.70                 | 6    |                   | 24.51    |                 |
| M5         | 92                     | 21.90                 | 8    |                   | 18.98    |                 |

The data obtained for control sample of M1 (0% CR) shows the soaked CBR value is only 3.4% which not fulfil the minimum JKR requirement of 5% CBR. Whereas, the unsoaked CBR value also indicates only 5.62%. According to Public Works Department of Malaysia’s (PWD) Specification for Road Works (JKR/SPJ/2014), if the subgrade does not meet the minimum CBR requirement, at least 300 mm of unsuitable subgrade soil shall be replaced or stabilised to ensure that the minimum CBR value is obtained under due consideration of applicable moisture conditions and probability of meeting the design input value. From the results, it proved that this problematic soil need to be stabilised to increase the soil strength.

Figure 4 shows the variation of CBR values with different percentage of crumb rubber in unsoaked and soaked conditions. The results indicate that there is significant loss in CBR due to soaking as all soaked CBR are lower than unsoaked and this had verified that the presence of water reduces the strength of soil.

Figure 4. Graph of unsoaked and soaked CBR values with 0%, 2%, 4%, 6% and 8% of crumb rubber.
From graph in Figure 4, the CBR values for M2 (2% CR), M3 (4% CR), M4 (6% CR) and M5 (8% CR) had fulfilled the minimum 5% of JKR requirement after crumb rubber has been added to the soil. The results indicate that the highest CBR values are from M3 (4% CR) which is 36.09% and 30.14% for unsoaked and soaked respectively. The unsoaked and soaked CBR values keep increases up to 4% of crumb rubber and start to drop at 6%. The lowest CBR values are proved at M5 (8% CR) which is 21.90% and 18.98% for unsoaked and soaked respectively. The decrease in the result is due to the presence of high crumb rubber which resulting in high compressibility [10] and the rubber elasticity is quite high compared to the soil [12]. Although the results decrease, the CBR value for M4 (6% CR) and M5 (8% CR) are still higher than M1 (0% CR) and moreover both mixtures also meet the JKR minimum requirement.

5. Conclusion and Recommendations

The effect of Crumb Rubber (CR) on the geotechnical properties of subgrade soil are investigated and analysed in this study. The results indicate that the presence of CR effected the increasing of subgrade soil CBR value. The CBR value for mixtures M2 (2% CR), M3 (4% CR), M4 (6% CR) and M5 (8% CR) had fulfilled the minimum 5% CBR of JKR requirement (JKR/SPJ/2014). The maximum improvement had occurred at 4% of CR which contribute the highest CBR value for both unsoaked and soaked conditions. Thus, 4% Crumb Rubber is recommended to be implemented for subgrade soil stabilization.

From the results obtained, it can be concluded that the industrial waste of crumb rubber had proved increase the subgrade soil strength. In addition, the introduction of crumb rubber as soil stabilizer also will reduce the road construction cost and significantly also will solve the waste tires disposal and pollution problems.

However, there are several recommendations that can be applied for further study. In order to measure the accurate percentage of CR for soil stabilization, the percentage of CR should be mixed to the soil in small range of gap, for example 0.5%, 1%, 1.5% and up to 6%. Different size of rubber like shredded (50 to 305 mm), chips (12 to 50 mm) and powdered (below 425 µm) should be used to get variations of data in order to compare the effectiveness on different size of rubber. CR also can be mixed with other additive material like Portland Cement to improve the strength of soil especially for soaked condition.

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References

[1] Tey, L. S., Yusof, M. A. R. and Juraidah, A. (2014). Basic Highway and Traffic Engineering. Selangor, Malaysia: UiTM Press.

[2] Munnoli, P.M., Sheikh, S., Mir, T., Kesavan, V. and Jha, R. (2013). Utilization of rubber tyre waste in subgrade soil. doi: 10.1109/GHTC-SAS.2013.6629940, 330-333.

[3] Thiruvangodan and Sandra K. (2006). Waste tyre management in Malaysia. PhD. Thesis, Universiti Putra Malaysia.

[4] Johns, D., Deepakraja, T. G. and Karthiga, D. M. (2017). Use of waste tyre as subgrade in flexible pavement. International Research Journal of Engineering and Technology, 4(3), 1130-1132.

[5] Hussain, F. and Khan, A. (2017). Sustainability of using crumb rubber and quarry dust for stabilization of expansive soils in road subgrade: a review. International Journal of Civil Engineering and Technology, 8(12), 837-842.

[6] Ranjitha, J., Kishan, K., Ankith, K. G. and Nithin, K. (2016). Laboratory study on CBR value of black cotton soil treated with crushed coconut shells. International Journal of Advances in Mechanical and Civil Engineering, 15-18.
[7] Olugbenga, O. A., Opeyemi, S. O. and Olakanmi, I. S. (2011). Potentials of coconut shell and husk ash on the geotechnical properties of lateritic soil for road works. International Journal of Engineering and Technology, 3(2), 87-94.

[8] Public Works Department of Malaysia’s (PWD) Specification for Road Works (JKR/SPJ/2014), Arahan Teknik (Jalan) 5/58: Manual Pavement Design, 2014.

[9] Yadav, J. S. and Tiwari, S. K. (2017). A study on the potential utilization of crumb rubber in cement treated soft clay. Journal of Building Engineering, 177-191.

[10] Ravichandran, P. T., Prasad, A. S., Krishnan, K. D. and Rajkumar, P. R. K. (2016). Effect of addition of waste tyre crumb rubber on weak soil stabilisation. Indian Journal of Science and Technology, 9(5), 1-5. doi: 10.17485/ijst/2016/v9i5/87259.

[11] British Standards Institution. (1995). BS 1377: Part 1 - Part 9: 1990: Soils for civil engineering purposes. London, England: BSI.

[12] Promputthangkoon, P. and Karnchanachetanee, B. (2013). Geomaterial prepared from waste tyres, soil and cement. PSU-USM International Conference on Humanities and Social Sciences, 91, 421-428.