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California Bearing Ratio (CBR) of Engineered Sand Backfill Admixed with Recycled Tyre Wastes

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Abstract

This study investigates the California Bearing Ratio (CBR) of engineered sand backfill admixed with recycled tire wastes, to determine whether using sustainable materials in geotechnical applications is feasible. In this study, CBR tests are systematically evaluated for three different mix ratios: 100% sand, 80% sand 20% rubber granule, and 60% sand and 40% rubber granule, both with and without stabilizer. Further research shows the effect of stabilizers and recycled tire wastes on the mechanical properties of the engineered backfill, whereas initial CBR testing on the 100% sand samples set a standard strength performance. The results show that adding rubber granules significantly reduced the CBR values, highlighting the need to take additional measures to improve strength. A major approach to mitigate the reduction is to add a stabilizer, which is shown by the significant increases in CBR values observed, especially with longer curing times. After 7 days of curing, an 80S20R mixture with a stabilizer is the optimal mix ratio for improved strength. This mixture showed promising performance. This study provides a viable backfill material substitute and important new insights into potential applications of recycled tire wastes in geotechnical engineering. The results not only address the engineering aspects of the mixture but also provide opportunities for additional research, such as a thorough evaluation of the long-term mechanical behavior and the optimization of stabilizer content.

1. Introduction

Backfilling is a method to control groundwater loss, reduce surface subsidence, and increase drainage or foundation insulation. Materials like gravel and soil are compacted for stability. Sand backfills, made from eroded sand, rocks, and granules, are commonly used in construction projects due to their high permeability and ability to maintain stability over time.

According to Beiser (2019), Sand is the most used natural resource globally, is a major environmental issue due to its rapid growth. Recycling aggregates can partially replace sand usage, reducing CO2 emissions by over 50% in large-scale projects. This approach has positive environmental effects, as explored in various publications on environmental, financial, and technological aspects. Recycled rubber waste from tires can also be used in engineering.

Pilkington (2021) reports that 1.8 billion used tires are discarded globally annually, accounting for 2% to 3% of total waste. Recycling used tires is a feasible solution to the global waste tyre issue. Rubber, steel belts, textile overlays, reinforcing fillers, and additives make up 45% of tyres. Recycled rubber granules can partially substitute sand, lowering CO2 emissions and promoting environmental benefits.

1.1 Objectives and Scope of Study

The main objectives of the research are as follows:

- To evaluate the California Bearing Ratio (CBR) parameters of sand admixed with recycled tyre wastes.
- To formulate the optimum mix ratios for the best strength performance of the sand–recycled tyre waste composite.

The scope of this study is focused on geotechnical research. The project include a past report and desk study of existing literature to gather information on the relevant theories, principles, and previous research studies related to the CBR test as per British Standards and the use of recycled tyre waste in backfills. The study establishes the formulation of sand with recycled tyre waste composite including rubber granules, steel fibre and stabilizer as engineered backfill materials with satisfactory strength performance.

The experimental work involves a CBR test apparatus according to British Standard (BS 1377:4), coarse sand size for British Standard (< 2 mm), and recycled tyre waste including rubber granule size (< 2mm), steel fibre and stabilizer. The test run on a CBR test to carry out and find the result of the formulation of sand and recycled tyre waste composite. In addition to the CBR test, other tests such as the sieve analysis test, compaction test and soaked test also be conducted.

2. Material and Methods

The main topics that will discuss in this chapter is the methodology, the materials and the procedures that will be used to test during the experiment. This will also include the theoretical ideas and concerns the study. Plus, this chapter also will discuss further on how to perform all the test. This includes specific methods, technique and tools related to this study to provide an understanding on how the data is collected to describe the expected outcome. Several procedures must be followed by sequences so that the result can be obtained precisely.

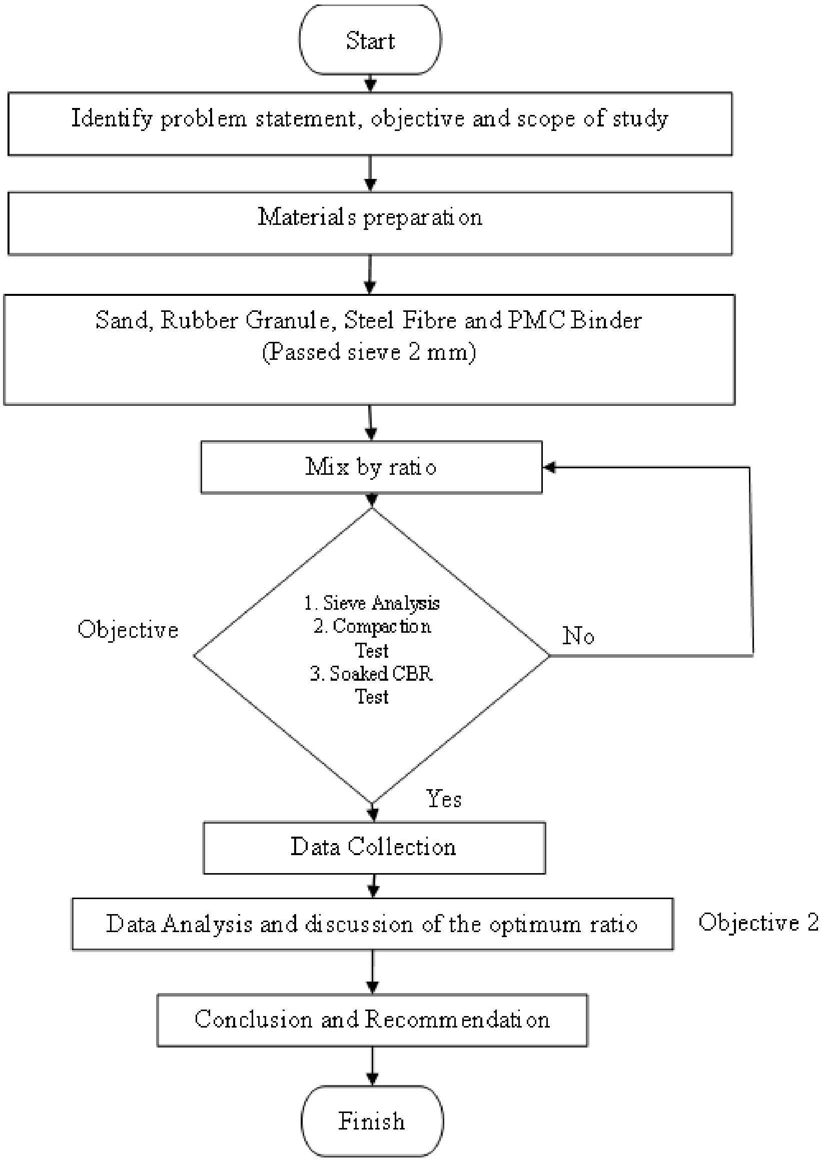

Figure 2.1: Flow Chart of Methodology

2.1.1 Materials

The materials used in this study are sand, recycled tyre wastes, steel fibre from tyre wastes, and Polymer Modified Cementitious (PMC) as stabilizers. The preparation of the sample is also explained in this chapter.

2.1.2 Sand

In this study, sand was taken from the Concrete Laboratory at Universiti Tun Hussein Onn Malaysia (UTHM) Pagoh. Next, the sand is put through a sieve. For the sample to be used in the mixture, the sand size should be less than 2 mm.

2.1.3 Recycled Tyre Waste Rubber

The recycled tyre waste used in this study is in size 2 mm and below after sieve. The size that has been provided by is in the granulated rubber (GR) category. The recycled tyre waste was obtained from industry. The type of tyre is truck tyre.

2.1.4 Steel Fibre

The steel fiber that was used in Figure 3.4 is also obtained from recycled tyre waste from industry. The percentage usage of steel fiber in the sample was (1.5 %) to reinforce the sample and diameter of Steel Fibre is 0.25-0.35mm.

2.1.5 Soil Stabilizer

Polymer Modified Cementitious (PMC) provided by was used as a soil stabilizer in this investigation. Soil stabilization is a common engineering technique that entails the treatment of unsuitable materials or the recycling of pre-existing materials to create materials with desirable properties. This sample was bound together with PMC

2.2 Sample Preparations

The materials for used as sand (S), rubber granule (R), steel fibre (SF) and Stabilizer (PMC) ratios are prepare based on Table 2.1 and Table 2.2. Each percent of the stabilizer was undergone curing process for 1, 3 and 7 days. For samples without stabilizer was soaked for 4 days. The total sample for this study is 20 samples.

Table 2.1: The number of samples for testing

Ratio	Without Steel Fibre	4% PMC and 1.5% Steel Fibre		
100S	3	-	-	-
80S20R	3	2	2	2
60S40R	2	2	2	2

Table 2.2: The sample list of curing process

4 days	1 day	3 days	7 days
100S	-	-	-
80S20R	80S20R+1.5SF+4PMC	80S20R+1.5SF+4PMC	80S20R+1.5SF+4PMC
60S40R	60S40R+1.5SF+4PMC	60S40R+1.5SF+4PMC	60S40R+1.5SF+4PMC

2.3 Laboratory Test

In this section, there was a discussion of many procedures for testing that have been carried out to accomplish the goals of this study.

2.3.1 Sieve Analysis

In the sieve analysis test, a mechanical sieve was used to determine the particulate size distribution of sand and recycled rubber. The measurement was conducted in accordance with BS1377: Part 2:1990:9.3, which specifies the method for classifying soils and determining their fundamental physical properties. The particles are then separated by vibrating the sample as it passes through a series of mesh-equipped containers. In the Geotechnical Laboratory at UTHM Pagoh, the sieve diameters used were 1.18 mm, 600 μm, 425 μm, 300 μm, 212 μm, 150 μm, and 63 μm, and the pan and sieve shaker were utilized.

2.3.2 Compaction Test

A standard proctor compaction test was used to ascertain the relationships between soil moisture content and dry density, as well as the optimal moisture content at which a given soil type becomes the densest and reaches its maximum dry density. The Proctor test measures soil compaction to determine the optimal moisture content and the maximum dry weight in which soils can be compacted most efficiently with construction equipment.

2.3.3 California Bearing Ratio

The CBR test can be performed on undisturbed specimens or remoulded specimens that were compacted either statically or dynamically. CBR is the ratio expressed in the percentage of force per unit area required to penetrate a soil mass with a standard circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration in a standard material. The ratio is usually determined for penetration of 2.5 mm and 5 mm. When the ratio at 5 mm is consistently higher than that at 2.5 mm, the ratio at 5 mm is used.

$$CBR = \frac{Measured\ force}{Standard\ force} x100\%$$

2.3.4 Procedures

a) Soaking test

Replace the baseplate with perforations and attach the collar to the end of the mold. Place the mould assembly in a soaking tank and place the perforated swell plate on filter paper. Place annular surcharge discs around the stem. Attach a dial gauge support and adjust the stem for zero readings. Pour water into the immersion tank and set a timer.

Record dial gauge readings at appropriate intervals. Allow the sample to soak for an additional day, allowing swelling time to fully develop. Remove the mould assembly, dial gauge, and support, and let the sample drain for 15 minutes. If necessary, weigh the sample with a baseplate and a mould to the nearest 5 g. Prepare the sample for testing after soaking.

b) Penetration test

Centre the mould on the lower plate of the testing apparatus, leaving the top face of the sample visible on the baseplate. Lay the proper annular surcharge discs over the sample. Depending on the anticipated value of the CBR, apply a seating force to the plunger, and fix the dial gauge for penetration in place. Record the reading at zero. Begin the test so the plunger enters the sample at a nominal rate of 1 millimeter per minute. Take force gauge readings at intervals of 0.25 mm penetration, with a maximum penetration of 7.5 mm. After the penetration test or tests are finished, determined the moisture is in the test sample.

3. Result Analysis and Discussion

This section discusses the analysis and results that have been obtained from the laboratory tests that have been done during this semester. In this chapter, the analysis results are based on the laboratory tests discussed in Chapter 3.
All the data obtained from the tests were presented by using graphs and tables to ensure that the results were easy to interpret and explained clearly. The entire tests were important to achieve the objective of this project which is to examine the objective of this project.

3.1 Sieve Analysis

In comparison with the size of rubber particles, the result shows that the size of sand particles is finer than rubber granules. As shown in Figure 3.1, it appears that the particle size of rubber is larger than sand through the sieve size between 1.18 mm and 600 µm. There was 7.28% passing at 600 µm for rubber granules which is much lower than sand with 76.44% passing. Both materials are (<2 mm) but sand is finer than rubber granules so it creates a uniform size of samples and is compatible with each other. Rubber granule is more elastic than sand. Due to size of rubber granule, the mixture of these material creates elastic samples.

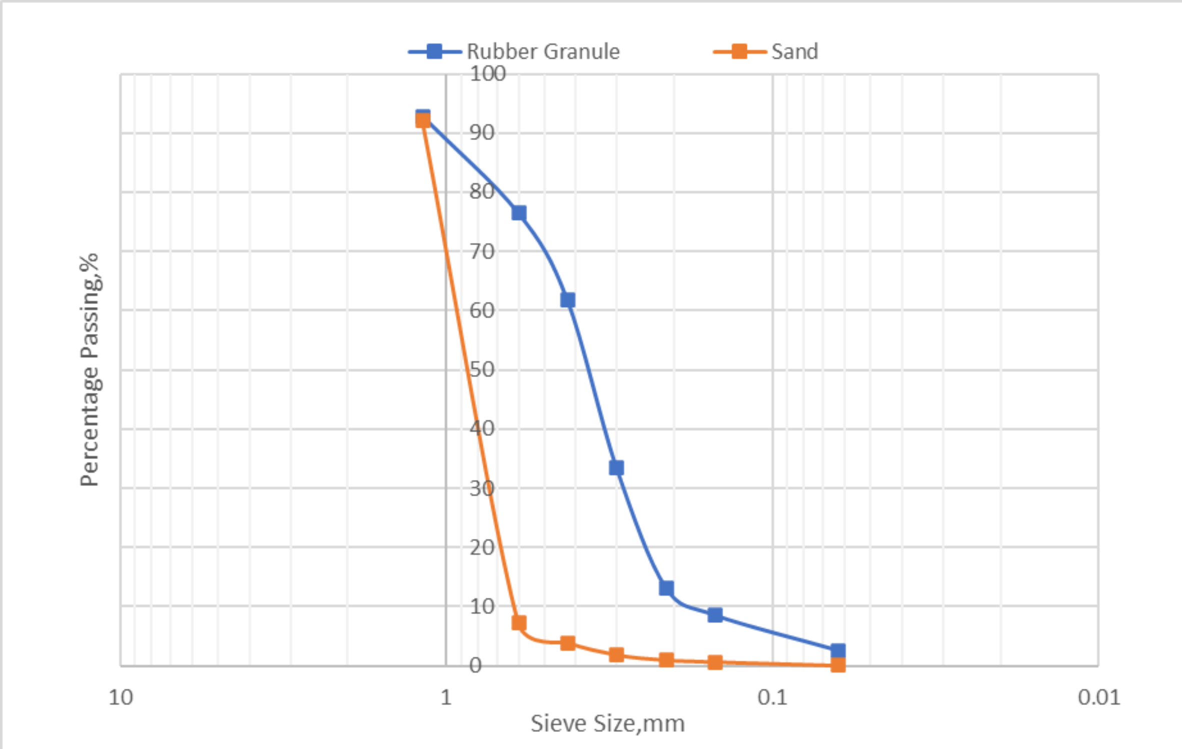

Figure 3.1: The distribution of particle size for sand and rubber

3.2 Compaction Test

Based on Figure 3.2, the graph shows the relationship between dry density and moisture content. This relationship helps in determining the OMC at which the maximum dry density can be obtained through a compaction test. 60S40R has the highest OMC which is 18.4% compared to 100S OMC which is 15%. The OMC for 70S30R, 80S20R, and 90S10R is 17.7%, 17.6% and 16.6% accordingly. The sample's optimum moisture content increases with the percentage of rubber in it. On the other hand, the maximum dry density decreases with increasing rubber percentage in the sample.

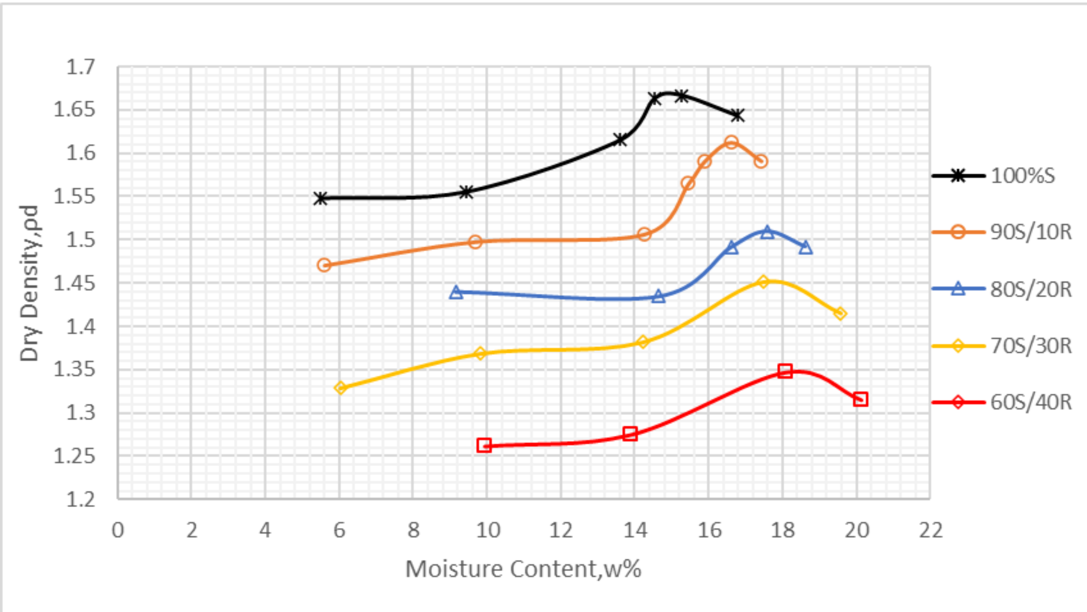

Figure 3.2: Graph of dry density against moisture content

Table 3.1: Results of optimum moisture content and maximum dry density of the sample

Sample	Optimum Moisture Content (%)	Maximum Dry Density (ρd)
100S	15	1.668
90S10R	16.6	1.612
80S20R	17.6	1.510
70S30R	17.7	1.452
60S40R	18.4	1.348

3.3 CBR Test of Sand and Rubber Granules Without PMC

Based on Figure 3.3, at both penetrations 2.5mm and 5.0mm, the CBR value for 100S is the highest with 5% at 2.5mm penetration and 6% at 5.0mm penetration. After that, the lowest CBR value is 60S40R with 0.76% and 0.75% at 2.5mm and 5.0mm respectively. In the meantime, the CBR values for 80S20R at 2.5mm and 5.0mm are 1.94% and 2.27% respectively. In short, the CBR value decreases with increasing percentage of rubber granules in the sample. Rubber granules are generally weaker and less stiff than the aggregate materials typically used in construction.

Table 3.2: Results CBR value of 4 days soaking CBR test

Ratio	CBR value at 2.5mm	CBR value at 5.0mm
100S	5	6
80S20R	1.94	2.27
60S40R	0.76	0.75

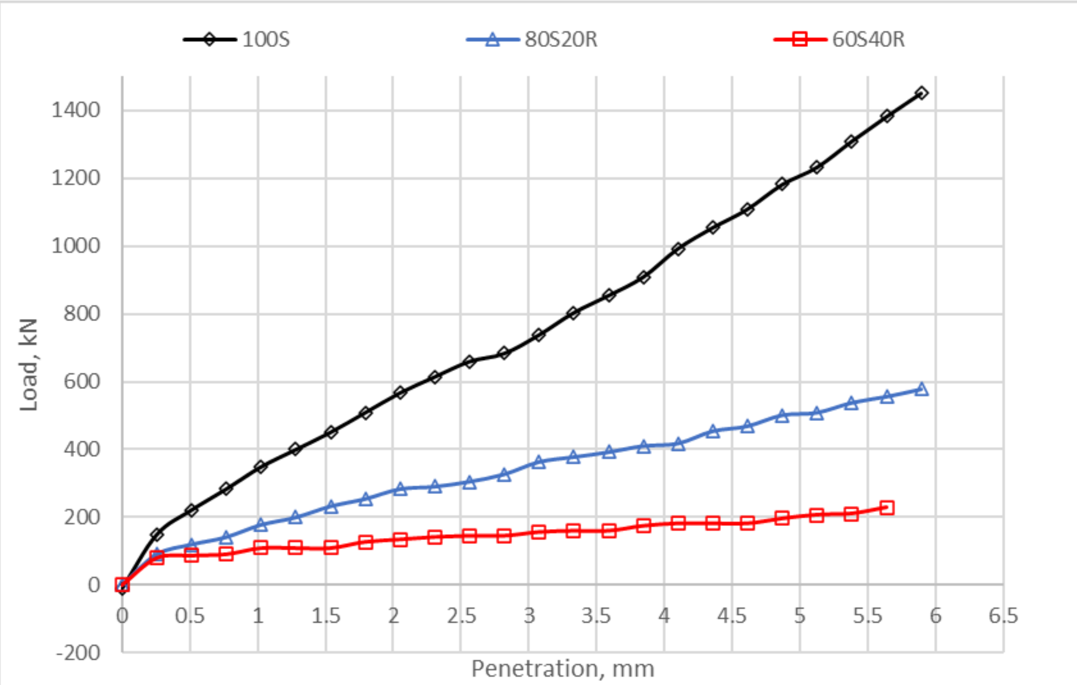

Figure 3.3: Graph load vs penetration of samples without PMC

3.4 CBR Test of PMC Effect in Engineered Sand Backfill

The dosage usage of Polymer Modified Cementitious (PMC) in this study is 4%, to determine the dosage effect of stabilized sand and rubber granules mixed with stabilizer to increase the usage of rubber granules in engineered sand backfill.

Table 3.3: Results CBR value for 1 day curing

Ratio	CBR value at 2.5mm	CBR value at 5.0mm
80S20R+1.5SF+4PMC	4.09	5.3
60S40R+1.5SF+4PMC	1.74	1.9

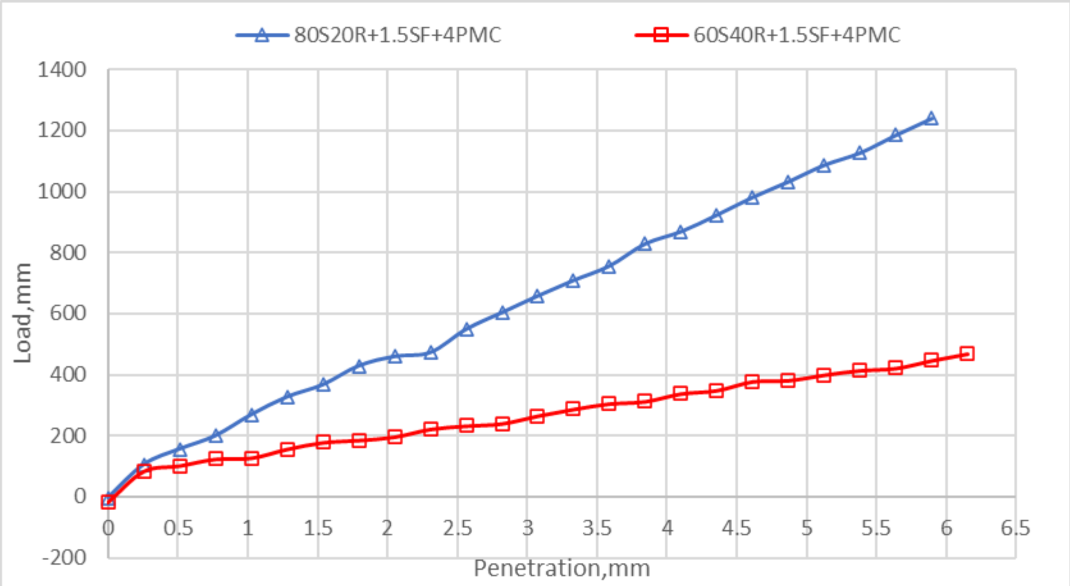

Figure 3.4: Graph load vs penetration for 1 day of curing

Figure 3.4 shows the result CBR value 1 day of curing for 4% of PMC and 1.5% Steel Fibres used in the ratio for both samples. At 2.5mm and 5.0mm penetration, as expected 80S20R+1.5SF+4PMC has the highest percentage of CBR value which is 4.09% and 5.3% respectively. While the CBR value for 60S40R+1.5SF+4PMC is 1.74% at 2.5mm penetration and 1.9% at 5.0mm penetration. This result shows that the presence of PMC and Steel Fibres will strengthen the sample.

Figure 3.5 shows the results of the CBR test on the 80S20R+1.5SF+4PMC and 60S40R+1.5SF+4PMC ratio sample but curing for 3 days. 80S20R+1.5SF+4PMC has the highest strength at 2.5 mm and 5.0mm penetration while 60S40R+1.5SF+4PMC has the lowest strength. The differences in strength between curing for 1 day and 3 days are improved. 80S20R+1.5SF+4PMC has 6.37% and 6.96% CBR values at 2.5mm and 5.0mm respectively while 60S40R+1.5SF+4PMC has 3.13% and 3.22% CBR values at 2.5mm and 5.0mm respectively.

Table 3.4: Results CBR value for 1 day curing

Ratio	CBR value at 2.5mm	CBR value at 5.0mm
80S20R+1.5SF+4PMC	4.09	5.3
60S40R+1.5SF+4PMC	1.74	1.9

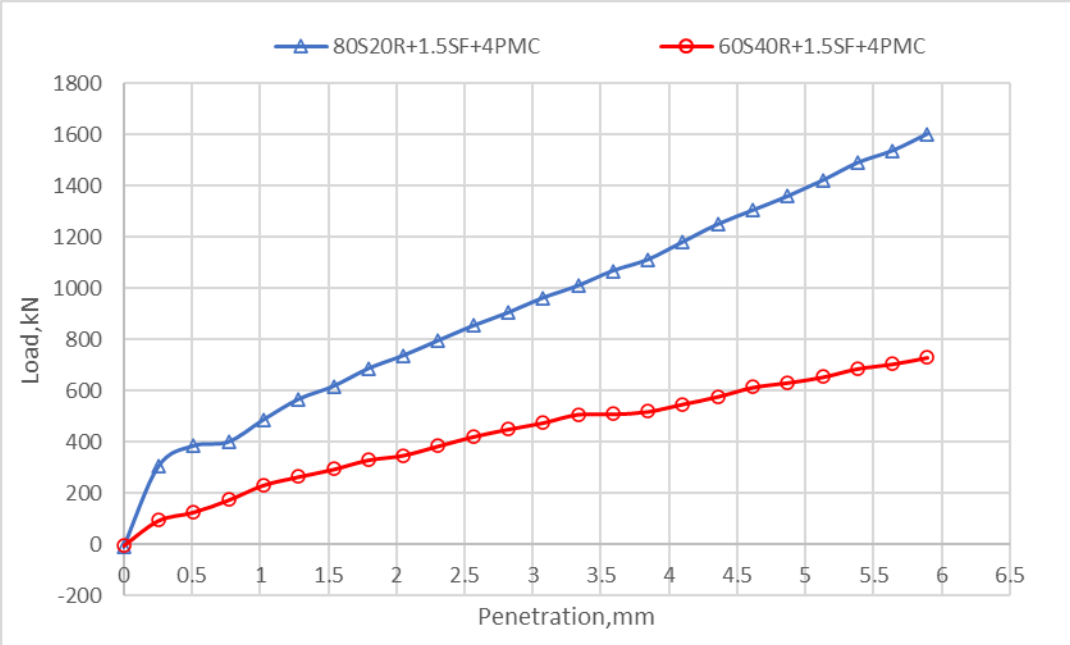

Figure 3.5: Graph load vs penetration for 3 days of curing

The result of 4% dosage of PMC and 1.5% Steel Fibres curing for 7 days is shown in Figure 3.6. 80S20R+1.5SF+4PMC has 13.01% and 15.08% CBR values at 2.5mm and 5.0mm separately which was expected to be the highest result. 60S40R+1.5SF+4PMC has 5.08% and 5.66% CBR values at 2.5mm and 5.0mm separately which was the lowest result. The difference between both samples is quite huge. For 7 days of curing, the results shown is the highest between 3 days and 1 day. PMC undergoes a process called hydration, where water reacts with the PMC to form hydration products that bind the aggregate particles together. This process continues over time, even after the initial setting time. Therefore, the 7-day cured sample would have had more time for hydration to occur, leading to a stronger and more rigid structure compared to the 1-day and 3-day samples. This increased strength translates to a higher CBR value.

Table 3.5: Results CBR value for 1 day curing

Ratio	CBR value at 2.5mm	CBR value at 5.0mm
80S20R+1.5SF+4PMC	4.09	5.3
60S40R+1.5SF+4PMC	1.74	1.9

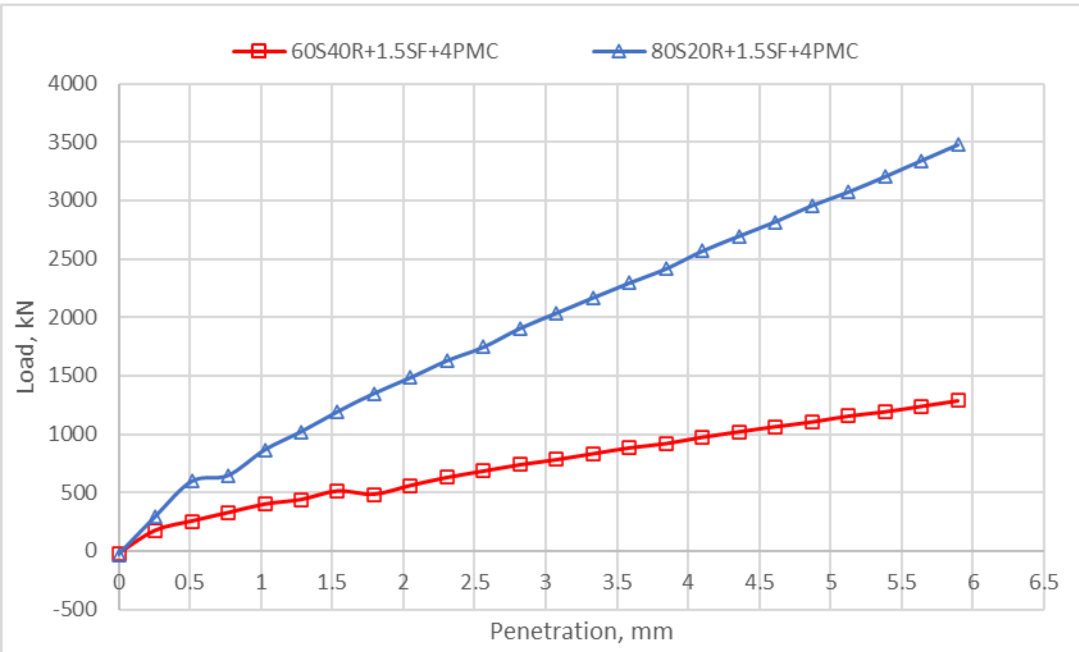

Figure 3.6: Graph load vs penetration for 7 days of curing

4. Conclusion

Based on the comprehensive evaluation of California Bearing Ratio (CBR) parameters for various sand and rubber granule mixtures with and without PMC and Steel Fibres, several key conclusions can be drawn. The CBR values of the 100% sand samples without PMC and Steel Fibres indicate moderate strength, with 5% at 2.5mm penetration and 6% at 5mm penetration. The introduction of 20% rubber granules reduces the CBR values significantly and shows the effects in strength, with the 80S20R displaying 1.94% at 2.5mm and 2.27% at 5mm penetration. Further increasing the rubber granule content to 40% worsens this reduction in strength, as evident in the 60S40R with CBR values of 0.76% at 2.5mm and 0.75% at 5mm penetration.

Introducing a stabilizer proves effective, especially in the 80S20R, with CBR values of 6.37% at 2.5mm and 6.96% at 5mm penetration after 3 days of curing, surpassing the 100S values. This trend is consistent and even more pronounced after 7 days of curing, highlighting the positive impact of the stabilizer on the strength performance of the sand and rubber granule admixed. Therefore, the optimum mix ratio for achieving the best strength performance involves an 80S20R with the presence of a PMC and Steel Fibres, particularly after a curing period of 7 days. PMC undergoes a process called hydration, where water reacts with the PMC to form hydration products that bind the aggregate particles together. This process continues over time, even after the initial setting time. Therefore, the 7-day cured sample would have had more time for hydration to occur, leading to a stronger and more rigid structure compared to the 1-day and 3-day samples. This increased strength translates to a higher CBR value.

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Author Contribution

The authors confirm contribution to the paper as follows: study conception and design, conduct testing, data collection, analysis and interpretation of results, and draft manuscript preparation: Ahmad Shahrul Ahmad Azam; provide source of material, and supervision: Chan Chee Ming. All authors reviewed the results and approved the final version of the manuscript.

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