The comparison of properties and cost of material use of natural rubber and sand in manufacturing cement mortar for construction sub-base layer

R Rahman1, M S Nemmang1, Nor Hazurina2, S Shahidan2, Raden Khairul Tajuddin Jemain1, Abdullah M E1, Hassan M F3

1 Department of Infrastructure & Geomatic (JKIG) Faculty of Civil and Environmental Engineering University Tun Hussein Onn Malaysia, Batu Pahat
2 Jamilus Research Center, Faculty of Civil and Environmental Engineering University Tun Hussein Onn Malaysia, Batu Pahat
3 Batu Pahat Municipal Council, Johor
Corresponding author: raha@uthm.edu.my

Abstract. The main issue related to this research was to examine the feasibility of natural rubber SMR 20 in the manufacturing of cement mortar for sub-base layer construction. Sub-base layers have certain functions that need to be fulfilled in order to assure strong and adequate permeability of pavement performance. In a pavement structure, sub-base is below the base and serves as the foundation for the overall pavement structure, transmitting traffic loads to the sub-grade and providing drainage. Based on this research, the natural rubber, SMR 20 was with the percentages of 0%, 5%, 10% and 15% to mix with sand in the manufacture of the cement mortar. This research describes some of the properties and cost of the materials for the natural rubber and sand in cement mortar manufacturing by laboratory testing. Effects of the natural rubber replacement on mechanical properties of mortar were investigated by laboratory testing such as compressive strength test and density. This study obtained the 5% of natural rubber replaced in sand can achieved the strength of normal mortar after 7 days and 28 days. The strength of cement mortar depends on the density of cement mortar. According to the cost of both materials, sand shows the lower cost in material for the cement mortar manufacturing than the uses of natural rubber. Thus, the convectional cement mortar which used sand need lower cost than the modified rubber cement mortar and the most economical to apply in industrial. As conclusion, the percentage of 5% natural rubber in the cement mortar would have the same with normal cement mortar in terms of the strength. However, in terms of the cost of the construction, it will increase higher than cost of normal cement mortar production. So that, this modified cement mortar is not economical for the road sub-base construction.

1. Introduction
In the highway engineering, the composition of road structure consists of several types of cross section layers which are sub-grade, sub-base, base and bituminous materials which is wearing course. Sub-base is the layer of aggregate material which is on the sub-grade located under the base course layer. Sub-base may be constructed of granular materials, cement mortar materials, lean concrete or open-graded, highly-permeable materials which may be stable or unstable [1]. Sub-base will be the main issue to be discussed in this research based on the cement mortar producing with different material in the sub-base construction. Cement mortar is widely used for construction of sub-base in the roadway, but financial and environmental concerns are causing concern, leading to the quest for alternative and
efficient stabilizers to provide a better modified sub-base layer. The road pavement that occur distress and failure that commonly happen in foundation of the road which involve the sub-grade and sub-base need the improvement to upgrade the condition of road pavement for better and long lasting use. The reason that may lead to these failure road condition due to inadequate maintenance, excessive loads, climatic and environmental conditions, poor drainage leading to poor subgrade conditions, non-uniform support of the surface layer, poor subgrade soil, and disintegration of the component materials [2]. According to this research, the alternative material which is natural rubber will be used as the replacement of sand in the manufacturing of the modified cement mortar to produce a better of the sub-base construction plus involved the factor of cost-efficiency to ensure the economical method in the construction.

2. Literature review
The assessment of the road pavement would be identified by the research on the material in the road construction in sub-base layer to fulfill the requirements for good performances of road pavement. According to this research, status of rubber properties to perform in the cement mortar to apply in the road sub-base construction would be identified based on the review the knowledge on past and current study. Based on the Table 1, there are many discussions about the uses rubber in the highway construction in Malaysia. The uses of the rubber in the highway construction also had been long time established for the rubberized road in Malaysia especially for the surface layer that involved the bituminous of the wearing course of the road structure. But the future study of the lower part of the road structure had not been established especially for the foundation of the road pavement. The utilization of rubber in cement mortar have widely applied in the industry based on the previous study in its capability to perform in the cement mortar. The previous study in Table 2 has shown the uses of the alternatives of rubber material in the with cement mortar.

| Year  | Location                               | Rubber used (Wet process) |
|-------|----------------------------------------|----------------------------|
| 1950  | Kota Bharu- Kuala Krai (90m)           | Crumb rubber and latex (5%) |
| 1968  | KL-Seremban, KL-Bentong                | 1.5 % & 3% latex           |
| 1988  | Klang                                  | 2% latex                   |
| 1993  | Rembau-Tampin (1km)                    | Crumb rubber and latex     |
| 1996  | Sungai Buluh (3 km)                    | Crumb rubber               |
| 1996  | KLIA (50 km)                           | Crumb rubber               |
| 2003  | Jalan kuantan-Gambang (4 km)           | Crumb rubber               |
| 2010  | Bukit Kuantan (0.6 km)                 | Crumb rubber               |
| 2015  | Kota Tinggi, Johor (1km)               | Cup lump (5%)              |
| 2016-2017 | Rubberized asphalt pilot projects in Negeri Sembilan, Pahang, Kedah, Kelantan and Johor | Cup lump (5%) |
Table 2. The previous study on utilization of rubber in cement mortar

| Title/Publisher/Year | Scope of research                                                                 | Result                                                                                                                                 |
|---------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| Investigation of    | Mechanical properties of rubber-based cement mortar were investigated and         | Compressive strength tests showed a sharp decline in strength when crumb rubber was used as a replacement of sand in all three batches.  |
| mechanical and      | compared to conventional cement mortar without crumb rubber                       |                                                                                                                                       |
| durability properties of cement mortar and concrete with varying replacement levels of crumb rubber as fine aggregate. Md Salamah Meherier, [3]. |
| The use of recycled | To find a rubber-concrete mixture using recycled rubber tire crumbs that can       | Recycle rubber tire crumbs be used as partial replacement of aggregated which can reduce the water absorption, permeability and sorptivity of concrete which can make it waterproof. |
| rubber tire crumbs  | enhance the waterproofing capacity of concrete.                                    |                                                                                                                                       |
| for waterproofing   |                                                                                  |                                                                                                                                       |
| of concrete Anjerick J. Topacio et al. [4].                                                          |
| A comprehensive      | Use of waste tire rubber as a partial substitute for aggregate in cement concrete. | It was clear from the density of rubberized concrete decreases with increasing amount of rubber.                                      |
| review on the       |                                                                                  |                                                                                                                                       |
| applications of      |                                                                                  |                                                                                                                                       |
| waste tire rubber in |                                                                                  |                                                                                                                                       |
| cement concrete.     |                                                                                  |                                                                                                                                       |
| Blessen Skariah      |                                                                                  |                                                                                                                                       |
| Thomas et al.[5].    |                                                                                  |                                                                                                                                       |

3. Materials and methods

Based on this study, it discussed about the materials that used in cement mortar producing where the replacement of sand with natural rubber SMR 20 by 0% (as a control), 5%, 10% and 15% volume of the sand. Before that, the testing on properties of the natural rubber would be conducted to identify its performances with cement mortar by the laboratory testing. The ratio used in this cement mortar producing is 1:3 (BS 5628-1:1992) [6] and Ordinary Portland Cement (OPC) which representing the ratio of cement and sand. Other material used to produce mortar is water where the use is fixed due to water cement ratio of 0.5 [7]. This modified cement mortar produced following the flowchart below:

![Figure 1. Flowchart of modified cement mortar production](image-url)
4. Materials and methods

4.1. The comparison properties of natural rubber and sand

4.1.1 The comparison properties of natural rubber and sand

Table 3. Sieve test for fine aggregate

| Sieve size BS (mm) | Retain weight (g) | Cumulative retain weight (g) | Cumulative percent retain weight (%) | Cumulative passing weight (%) |
|--------------------|-------------------|------------------------------|-------------------------------------|------------------------------|
| 10                 | 0                 | 0                            | 0                                   | 100                          |
| 5                  | 0                 | 0                            | 0                                   | 100                          |
| 2.36               | 50                | 50                           | 10                                  | 90                           |
| 1.18               | 50                | 150                          | 20                                  | 80                           |
| 0.600              | 53                | 153                          | 31                                  | 69                           |
| 0.300              | 98                | 251                          | 50                                  | 50                           |
| 0.150              | 129               | 380                          | 76                                  | 24                           |
| 0.075              | 85                | 465                          | 93                                  | 7                            |
| Pan                | 35                | 500                          | 100                                 | 0                            |
| Total              | 500               | 280                          |                                      |                              |

Fineness modulus = 2.80

Table 4. Sieve test for rubber

| Sieve size BS (mm) | Retain weight (g) | Cumulative retain weight (g) | Cumulative percent retain weight (%) | Cumulative passing weight (%) |
|--------------------|-------------------|------------------------------|-------------------------------------|------------------------------|
| 10                 | 0                 | 0                            | 0                                   | 100                          |
| 5                  | 0                 | 0                            | 0                                   | 100                          |
| 2.36               | 15                | 15                           | 3                                   | 97                           |
| 1.18               | 30                | 45                           | 9                                   | 91                           |
| 0.600              | 170               | 215                          | 43                                  | 57                           |
| 0.300              | 165               | 380                          | 76                                  | 24                           |
| 0.150              | 75                | 455                          | 91                                  | 9                            |
| 0.075              | 35                | 490                          | 98                                  | 2                            |
| Pan                | 10                | 500                          | 100                                 | 0                            |
| Total              | 500               | 320                          |                                      |                              |

Fineness modulus = 3.20

The fineness modulus of rubber is higher than sand, signifying the existence of more coarser particles in rubber aggregate than sand aggregates [3]. Based on this research, the fineness modulus of natural rubber SMR 20 rubber is higher than sand had been proven. Notice that most of the fine aggregate pass through a No.4 (4.75mm) sieve, but a very large percentage of the coarse aggregates retained on a No. 4 (4.75mm) sieve. From the table as shown above, we noticed that most of the fine aggregates and crushed rubber pass through a 4.75 sieve which with the 90% and 97% not less than 45% as specified in JKR/SPJ/2008-S4. So both the data verified for Specification Standards for Road Work JKR/SPJ/2008-S4 [6].
4.1.2 Specify gravity

Table 5. Specific gravity test (fine aggregate)

| Bottle no | 1    | 2    | 3    | 4    |
|-----------|------|------|------|------|
| Mass of density bottle and stopper (m1) | 29.18| 29.88| 29.54| 27.88|
| Mass of density bottle plus oven dried soil (m2) | 34.32| 34.9 | 34.67| 32.97|
| Mass of density bottle plus stopper plus soil plus distilled water (m3) | 81.43| 82.20| 82.25| 80.19|
| Mass of sample (m2-m1) | 5.14 | 5.02 | 5.13 | 5.09 |
| Mass of water contained by the density bottle (m4-m1) | 48.88| 49.38| 49.65| 49.20|
| Mass of water occupying the volume not occupied by the soil (m3-m2) | 47.11| 47.30| 47.58| 47.22|
| Gs = \frac{(m4-m1)-(m3-m2)}{m2-m1} | 2.90 | 2.41 | 2.48 | 2.57 |

According to this study, the specific gravity of fine aggregates and rubber were analysed according to ASTM C 127 for the rubber and ASTM C 128 for fine aggregates. The average specific gravity for both materials used in this research for fine aggregates and the natural rubber were 2.60 and 0.96 respectively. Both the specific gravity in the range as specified which 2.4 - 2.9 for fine aggregate and 0.9 – 1.2 for rubber.

Table 6. Specific gravity test (rubber)

| Container | A |
|-----------|---|
| Mass of the mesh containing natural rubber in the water after the soak 24 hours at room temperature (m1) | 76.66 |
| Mass of the mesh containing before the soak (m2) | 23.10 |
| Mass of natural rubber with burner container (after been wiped) (m3) | 131.95 |
| Mass of the burner container and natural rubber (after drying in the sun 3-6 hours) (m4) | 120.6 |
| Mass of the burner container (m5) | 100.74 |
| Specific Gravity (drying oven) \( Gs = \frac{(m4-m5)}{(m3-m5)-(m1-m2)} \) | \( \frac{120.6 - 100.74}{131.95 - 100.74} = \frac{76.66 - 23.10}{0.88} = 0.88 \) |
| Specific Gravity (humidity) \( Gs = \frac{(m3-m5)}{(m3-m5)-(m1-m2)} \) | \( \frac{131.95 - 100.74}{76.66 - 23.10} = 1.4 \) |
| Specific Gravity (significantly) \( Gs = \frac{(m4-m5)}{(m4-m5)-(m1-m2)} \) | \( \frac{120.6 - 100.74}{76.66 - 23.10} = 0.6 \) |
| Average Specific Gravity (Gs) | 0.88 + 0.6 + 1.4 = 0.96 |
4.1.3 Plasticity index
Plasticity Index (Ip) of a soil is the numerical difference between the liquid limit and the plastic limit. Related to this study, the plasticity index cannot be defined because natural rubber SMR 20 in solid state. So it can be defined as non-plastic. So the plastic limit would be considered as 0. Based on Manual Pavement Design JKR, either the liquid limit or plastic limit cannot be determine, the plasticity index will be as non-plastic. The value of plasticity index for the fine aggregates would be 0.218 which from difference between the liquid limit and the plastic limit and dividing by 100. According to the standard JKR JKR/SPJ/2008-S4 for road sub-base work specification, the plasticity index when tested in accordance with BS 1377 shall be not more than 12 %. The value of plasticity index for the fine aggregates for this research is verified as it not more than 12 % [6].

Table 7. Liquid limit test (fine aggregate)

| Can number | 1  | 2  | 3  | 4  |
|------------|----|----|----|----|
| Mass of can + moist soil (Mcw) | 46 | 39 | 42 | 40 |
| Mass of can + dry soil (Mcs)   | 43 | 37 | 39 | 37 |
| Mass of can (Mc)               | 34 | 29 | 29 | 29 |
| Mass of dry soil (Ms)          | 9  | 8  | 10 | 8  |
| Mass of water (Mw)            | 3  | 2  | 3  | 3  |
| Water content                 | 3.33| 25 | 30 | 37.5 |
| Average Water content         | 31.46 |      |    |    |

However, based on the plasticity properties for the rubber, the Wallace plasticity test reports have two measures:

a) Plasticity (Po), which is a measure of the compression of a sample after a load has been applied for a defined time. For the value of plasticity of rubber properties for SMR 20 that used for this research is 30 [10].

b) Plasticity retention index (PRI), which measures recovery after a sample has been compressed, heated and subsequently cooled. PRI % is defined as (\[\] / Po) x 100 and where Po is the plasticity and \[\] is the plasticity after aging for 30 minutes at typically 140°C [9]. During processing in, for example, a tire factory, natural rubber with low PRI values tends to break down more rapidly than those with high values. For the value of plasticity retention index (PRI) of rubber properties for SMR 20 that used for this research is 40 [10]. Based on the standard JKR/SPJ/2008-S4, the value of plasticity retention index (PRI) of SMR 20 failed to fulfil the standard by JKR which stated the plasticity index when tested in accordance with BS 1377 shall be not more than 12. So the uses of crushed rubber does not verified in the standard JKR/SPJ/2008-S4 [6].

4.1.4 Properties of the cement mortar

Table 8. Summary of data

| No. | Density (kg/m³) | Compressive Strength Test (N/mm²) |
|-----|----------------|----------------------------------|
|     | 7 days 28 days | 7 days 28 days                   |
| A (Control) | 2000 1947 | 17.87 31.29 |
| B (5%)      | 1920 1867 | 9.13 15.99 |
| C (10%)     | 1840 1787 | 6.88 12.04 |
| (15%)       | 1760 1760 | 3.16 5.52 |

Figure 2. Graph of Compressive Strength
Based on the Table 8, it shows the differential of mechanical properties of mortar by using the vary percentage of natural rubber SMR 20. The value of the compressive strength of cement mortar shows the increasing of curing days, which provide more strength of the cement mortar. From the result obtained, the vary percentage of natural rubber SMR 20 provides the different strength of mortar. But when compared between the normal cement with the cement mortar with the percentage of natural rubber, show the decreasing the compressive strength value between normal cement mortar and cement mortar with the percentage of natural rubber. The result shows that at 7 days, the normal mortar achieved the early strength where greater than 16 N/mm² as specified in BS 4551:2005 [11]. The highest value of compressive strength is indicated by 5% of natural rubber SMR 20 as a sand replacement. The strength is increased a little until 28 days curing. The control sample gave the higher strength at 7 days and 28 days curing higher than the replacement of sand with percentage of natural rubber SMR 20. Based on graphs in Figure 2, it shows the compressive strength of cement mortar in different percentage of rubber in the cement mortar after curing days. For the control sample, it shows the higher strength at 7 days and 28 days than other cement mortar. It differs with the cement mortar containing 5% of natural rubber where it increases and almost achieved to the near strength for normal mortar at 28 days. Meanwhile, cement mortar in C and D show the relation between compressive strength with the curing days from 7 days until 28 days with increasing strength with the increasing curing days even though cement mortar C and D show the decreasing strength than the mortar A and B. Based on the graph obtained, it was concluded the strength of each type of mortar increased with the increasing of curing days and achieve the maximum strength at 28 days. In Figure 3, the graph shows the density of mortar decreased by the increasing percentage replacement of natural rubber in cement. The density of rubberized concrete decreases with increasing amount of rubber [12]. While Figure 4 shows the compressive strength of mortar decreased during the increasing of percentage replacement of natural rubber. This may be attributed to the decrease in the adhesive strength between the surface of the rubber and cement paste [13].

![Figure 3. Graph of Density against Percentage of Natural Rubber](image1)

![Figure 4. Graph of Compressive Strength against Percentage of Natural Rubber](image2)

**Table 9.** Cost of production in cement mortar for sand and rubber smr 20.

| Rubber percentage (%) | Natural rubber content in cement mortar per mould (kg) | Cost of natural rubber (RM) | Sand content in cement Mortar per mould (kg) | Cost of sand (RM) | Cost of cement per mould (RM) | Total cost in cement mortar (RM) |
|-----------------------|------------------------------------------------------|-----------------------------|---------------------------------------------|------------------|-------------------------------|----------------------------------|
| 0 (Normal)            | 0                                                    | -                           | 0.203                                       | 0.0164           | 0.026                         | 0.04                             |
| 5                     | 0.011                                               | 0.08                        | 0.192                                       | 0.0156           | 0.026                         | 0.12                             |
| 10                    | 0.021                                               | 0.15                        | 0.182                                       | 0.0147           | 0.026                         | 0.19                             |
| 15                    | 0.030                                               | 0.21                        | 0.173                                       | 0.0140           | 0.026                         | 0.25                             |
Table 10. Cost production in conventional and modified cement mortar in the sub-base.

| Rubber percentage in cement mortar (%) | Total cost in cement mortar (RM) | Amount of cement mortar to occupy 7 meter width along 1 kilometer sub-base | Total cost of cement mortar for the road sub-base (RM) |
|----------------------------------------|---------------------------------|--------------------------------------------------------------------------|-----------------------------------------------------|
| 0 (Normal)                             | 0.04                            | 2,800,000                                                                | 112,000                                             |
| 5                                      | 0.12                            | 2,800,000                                                                | 336,000                                             |
| 10                                     | 0.19                            | 2,800,000                                                                | 532,000                                             |
| 15                                     | 0.25                            | 2,800,000                                                                | 700,000                                             |

The type of sub-base design should be selected while considering the purpose of the sub-base, locally available materials, and their cost-effectiveness. At the early stage, the study would compared the cost of both materials which are sand and rubber in the construction of road sub-base for 1 kilometers with the width of 7 meters with the normally thickness of 200 mm. Related to this research, the uses of 50 mm thickness of the cement mortar would be replaced from the 200 mm thickness layer of road sub-base structures as the modified road sub-base with the identification to its cost-effectiveness of the materials in the cement mortar manufacturing. From the Table 9, it shows that the normal cement mortar shows the lowest cost of material in the production of the cement mortar than the modified cement mortar. Besides that, it shows that the increasing the percentage of the natural rubber in the cement mortar provides the increasing the cost of the materials in the manufacturing of the cement mortar. Meanwhile, Table 10 shows that the normal cement mortar shows the lowest cost of the road sub-base construction than the modified cement mortar with different percentage of natural rubber. Based on the objectives that have been defined, we concluded that the most economical method for this research was convectional method mortar because it provides higher strength and have a reasonable market value in industrial than the modified cement mortar even though the modified cement mortar for the percentages 5% almost achieved to the strength for the normal cement mortar. Obviously, based on the comparison between both materials, the replacement of natural rubber with sand in the cement mortar production provide the higher cost than the conventional cement mortar due to the additional material in the mixture and cost in the market price.

5. Conclusions
The potential of mortars was identified through the laboratory testing where the mechanical properties are investigated such as density and compressive strength. By replacing some percentage of natural rubber SMR 20, it indicated the mechanical of properties of cement mortar achieved low strength and low density compared to the control sample. Based on this study, it found that 5% of natural rubber SMR 20 replaced in sand material got the initial strength higher than others percentage of natural rubber uses after it cured in 7 days. The mechanical strength becomes increased and almost achieved strength of control sample after 28 days. Besides that, the strength of cement mortar increased with the increasing of curing days. It also could be concluded that the higher of mortar density will be performed in higher compressive strength. This study shows that the percentage of 5% of natural rubber would be achieved strength of normal cement mortar and the most optimum compared to other percentage of rubber. The increasing of the percentage of cement mortar would be decreasing the density and compressive strength of the cement mortar because there is lack of the workability of the natural rubber to perform in the cement mortar. As conclusion, the percentage of 5% natural rubber in the cement mortar would have the same with normal cement mortar in terms of the strength. However, in terms of the cost of the construction, it will increase higher than cost of normal cement mortar production. So that, this modified cement mortar is not economical for the road sub-base construction. But, this study could be applied for the future research with the new improvement to upgrade the road sub-base in highway construction for better and long lasting use.
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