Geomaterial prepared from waste tyres, soil and cement

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Abstract

Discarded tyres are becoming globally problematic because recycling them may cause environment related problems. Thus, making use of them needs to be considered, and solutions must be sustainable. In addition, the solution should cover social, environmental, and economic sustainability. Nowadays, the waste tyres are increasingly being considered as construction material. This is because their basic properties are desirable for engineers. This work investigated the utilisation of used tyres as geomaterials by mixing them with low-strength soil and stabilised by cement for road and embankment construction. Two standard test methods were conducted: (1) California Bearing Ratio test and (2) Unconfined Compressive Strength test. The former and the latter were to determine the penetration resistance and shear strength, respectively, of which are some of the most important parameters in road design. The test results showed that low strength soil mixed with up to 15 % of recycled tyre chips and stabilised by cement could be used for road construction thereby reducing the overall construction cost as well as improving the environment.

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1. Introduction

In Thailand, it has become very difficult to obtain suitable geomaterial for civil engineering projects such as embankment and road construction. As a result, civil and geotechnical engineers have always attempted to improve the nature of the materials available for the task. Even though there may be good quality materials; quite often their location is so far from a construction site that the cost of transport is prohibitive. According to Hausmann (1990), soil improvement techniques may be categorised as mechanical modification, hydraulic modification, physical and chemical modification, and modification by means of inclusions and confinement. Each year, in the United States over 250 million waste tyres are stockpiled (RMA, 2004), and more than 28

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million passenger car tyres are discarded in Canada (Garga and O’Shaughnessy, 2000). In the case of Thailand, an accumulated number of registered cars as of the 31st of December 2009 is almost 27 million (Department of Land Transport). Accordingly, if each vehicle needs changing tyres every three years; each year the waste tyres would approximate 36 million. Considering these enormous numbers, it can be seen that Thailand and any other country having a similar situation needs to think sensibly about how to manage the waste tyres in the near future.

Discarded tyres have been regarded as solid waste and have become an increasingly problematic globally because disposing of them in open areas is a danger to the environment. For instance, they are vulnerable to fire; subsequently, the burnt tyres may contaminate ground water as a consequence of raining. The contaminated ground water requires hundreds of years to become clean again. In addition, it is very difficult to examine the extent of damage done below the ground surface.

Portland cement has been widely used to increase the shear strength and stiffness of soil because it can be mixed with almost every soil type. The other benefit of cement modification is that cement-treated soil has better stability in terms of volume change and higher durability which are desirable properties required for road construction. In addition, the construction of cement-stabilised soil does not require advanced techniques and technologies. The method simply requires spreading cement over the soil and mixing, followed by applying water and mixing, and finishing with conventional compaction. Even though a wide range of soil types can be improved by mixing with cement; nonetheless, the greatest effectiveness and economy can be achieved when it is mixed with sands, sandy soils, and clayey soils having low to medium plasticity (FHWA, 1979).

This study reviews and assesses the possibility of the utilisation of waste tyres as geomaterial for use in construction projects by mixing them with low-quality soil and stabilised by some cement. It concentrates on their mechanical properties such as the penetration resistance and the shear strength, qualities that are essential for employment in civil engineering projects.

2. Mechanical properties

Discarded tyres, a kind of solid waste from industrial development are becoming increasingly problematic. In 1996, the scrap tyres generated by the United States were 260 million while Great Britain generated 23.4 million (North Carolina Department of Environment and Natural Resources). In Western Europe, the EU estimated that more than 2.5 million tonnes of post-consumer tyre material were produced annually. As such, stockpiling and destroying vast amount of discarded tyres are very difficult and would cause associated pollutions. Disposing of the whole used tyre into landfill was prohibited by the new EU Landfill Directive in July 2003. In July 2006, the prohibition also included shredded tyres (Khalid and Artamendi, 2004).

Because recycling tyres may cause consequent effects. Making use of them needs to be considered, and the solution must be sustainable. The solution should cover social, environmental, and economic sustainability. The details of sustainable development were given by Parkin et al., (2003). They use five capital frameworks to achieve the sustainable development: (1) natural capital, including soil, sea, air, and ecological systems, (2) human capital, including health, knowledge, motivation, and spiritual ease, (3) social capital, including governance systems, families, communities, and organisations, (4) manufactured capital, including existing tools, infrastructure, and buildings, and (5) financial capital, including money, stock, and bonds.

Countries around the world have been using shredded recycled tyres because of the availability of vast quantities and stockpiling causes environmental problems (Foose et al., 1996). To make use of these waste tyres, shredders and cutters are needed to make them smaller, depending on the application. However, each country has different machines and different measurement systems. Therefore, it is essential to have a standard for the classification of recycled tyres.

For civil engineering purpose, the American Society of Testing and Materials (ASTM) published ASTM D6270-98, Standard Practice for Use of Scrap Tires in Civil Engineering Applications (ASTM, 1998). This
The document gives a guideline for civil engineering application of waste tyres. Table 1 shows names of different size in accordance with ASTM D 6270-98.

The bulk and apparent specific gravity values of tyre shreds are 0.98 - 1.06 and 1.02 - 1.27 respectively (ASTM, 1998), compared to 1.13 to 1.36 by Edil and Bosscher (1994). If a larger size of tyre shred is to be used, materials belted in the used tyres should be considered in the determination of the specific gravity. Note that the belt mostly used for reinforcing the tyre is steel, but glass fibre is also used.

Another important property of engineering materials is density. The dry density of tyre shreds depends on the compaction methods used. In a loose state with no compaction, its density ranges from 341 to 489 kg/m³. Compaction by vibration gives a density of 473 to 496 kg/m³. At standard compaction and modified compaction, the densities are from 560 to 640 kg/m³ and 660 to 685 kg/m³, respectively (ASTM, 1998).

The compressibility of material is important in civil engineering in that it is used for the analysis of settlement. For tyre shreds, the compressibility on initial loading ranges from 7 to 20 kPa and from 8 to 28 kPa at 10 % and 25 % vertical strains, respectively (ASTM, 1998). However, it should be determined material by material because shape and size of shredded tyres play an important role in this property. Moreover, the type of machine used for recycling the tyre is not negligible.

Another important property in geotechnical design is shear strength. The shear strength of tyre shreds, reported from several papers, indicates that the value varies widely. This is because each part of the world uses different base material for producing the tyre. However, almost every standard device in geotechnical laboratory can be used for shear strength determination; but, the engineer should be aware of size and boundary effects if large size of shredded tyres will be tested.

### Table 1. Size of recycled tyres (Summarised from ASTM D6270-98, 1998)

| Name            | Size                                      | Note                              |
|-----------------|-------------------------------------------|-----------------------------------|
| Granulated rubber | Below 425 μm to 12 mm                     | Also refer to particulate rubber  |
| Ground rubber   | Below 425 μm to 2 mm                      | Also refer to particulate rubber  |
| Powdered rubber | Below 425 μm                              |                                   |
| Rough shred     | Between 50 x 50 x 50 mm to 762 x 50 x 100 mm |                                   |
| Tyre chips      | 12 mm to 50 mm                            | Most wire removed                 |
| Tyre shreds     | 50 mm to 305 mm                           |                                   |

### 3. Materials and test programmes

#### 3.1. Materials

To evaluate the possibility of making use of waste tyres as geomaterial, recycled tyre chips were mixed with low-strength soil and modified by adding some ordinary Portland cement. The soil was a laterite having low strength classified as SC according to Unified Soil Classification system. It had a specific gravity of 2.64. The mean particle size of the soil was 1.6 mm; the coefficient of uniformity Cu = 5.4, and the coefficient of curvature Cg = 0.5. The tyre chips were obtained from KKI Recycle, Nakhonpathom, Thailand. The specific gravity of the tyre chips was 1.11, which is quite similar to those studied by Promputthangkoon and Hyde (2010). The true scale pictures for the soil and tyre chips are shown in Figure 1 (a) and (b), respectively.

#### 3.2. Preparing of geomaterials

The mixtures were prepared by mixing the soil with the rubber, by weight. This is because this method would be easier for preparing the mixtures in the field. The soil to rubber ratios were 100:0, 98:2, 93:7, 85:15, and
75:25. Each compound soil-tyre chips was mixed with cement having the percentages ranging from 0, 1, 5, 10, and 15 %. The cement contents were calculated based on the weight of the soil portion, resulting in a total of 25 soil-tyre chips-cement mixtures. Table 2 shows the details of sample number, soil and cement contents, and test number.

![Fig. 1. True scale pictures for the soil (a), and tyre chips (b)](image)

Table 2. Sample number, sample composition, and test number

| Sample No. | % Soil | % Tyre Chips | % Cement* | Penetration Resistance Test (CBR) | Undrained Shear Strength Test (UCS) |
|------------|--------|--------------|-----------|----------------------------------|-------------------------------------|
| 100S       | 100    | 0            | 0         | CBR100S0                         | UCS100S0                            |
|            | 1      | CBR100S1     |           |                                  |                                     |
|            | 5      | CBR100S5     |           |                                  |                                     |
|            | 10     | CBR100S10    |           |                                  |                                     |
|            | 15     | CBR100S15    |           |                                  |                                     |
| 98S        | 98     | 2            | 0         | CBR98S0                          | UCS98S0                             |
|            | 1      | CBR98S1      |           |                                  |                                     |
|            | 5      | CBR98S5      |           |                                  |                                     |
|            | 10     | CBR98S10     |           |                                  |                                     |
|            | 15     | CBR98S15     |           |                                  |                                     |
| 93S        | 93     | 7            | 0         | CBR93S0                          | UCS93S0                             |
|            | 1      | CBR93S1      |           |                                  |                                     |
|            | 5      | CBR93S5      |           |                                  |                                     |
|            | 10     | CBR93S10     |           |                                  |                                     |
|            | 15     | CBR93S15     |           |                                  |                                     |
| 85S        | 85     | 15           | 0         | CBR85S0                          | UCS85S0                             |
|            | 1      | CBR85S1      |           |                                  |                                     |
|            | 5      | CBR85S5      |           |                                  |                                     |
|            | 10     | CBR85S10     |           |                                  |                                     |
|            | 15     | CBR85S15     |           |                                  |                                     |
| 75S        | 75     | 25           | 0         | CBR75S0                          | UCS75S0                             |
|            | 1      | CBR75S1      |           |                                  |                                     |
|            | 5      | CBR75S5      |           |                                  |                                     |
|            | 10     | CBR75S10     |           |                                  |                                     |
|            | 15     | CBR75S15     |           |                                  |                                     |

* The cement content was based on the soil portion
3.3. Test programmes

To achieve the purpose of the study, two standard test methods were carried out: (1) California Bearing Ratio test (CBR) and (2) Unconfined Compressive Strength test (UCS). The standard test methods for the CBR and UCS can be found in ASTM D 1883-93 (1999) and ASTM D 2166-00 (2000), respectively. The purpose of the former was to determine the penetration resistance of which is one of the most important for the design, but to a lesser extent. Examples of sample preparation and testing for the two tests are illustrated by Figure 2. Figure 3(a) shows the samples prepared for the UCS test; the UCS test in progress is illustrated by Figure 3(b). The samples prepared for the CBR test are shown in Figure 4.
4. Test results and discussion

All test results conducted are summarised and shown in Table 3. It displays sample number, mixtures and corresponding cement content added, soaked and unsoaked CBRs and unconfined compressive strength. The CBR test results for unsoaked and soaked specimen were also plotted and shown in Figure 5(a) and (b), respectively. Figure 6 illustrates the unconfined compressive strength test results.

Generally, the CBRs for the unsoaked specimens were slightly greater than those of the soaked ones. When the cement was introduced the CBRs for the soaked specimens are quite greater. This indicates the effects of the cement on the CBR in terms of increasing the strength and stiffness. Predictably, it was observed that as the percentage of rubber was gradually increased from 2 to 25 %; the gradual decrease of the CBR was observed. This may lie on the fact that the elasticity of the rubber is quite high, compared to that of the soil. Hence, the penetration resistance was lower than those of pure soil, as evident in the CBR test results.

| Sample No. | % Soil | % Tyre chips | % Cement | CBR (%) | UCS, \(q_u\) (kPa) |
|------------|--------|--------------|----------|---------|-------------------|
| 100S       | 100    | 0            | 0        | 19      | 18                | 227 |
| 1          | 23     | 25           | 145      | 181     | 1063              |
| 5          | 488    | 566          | 624      | 691     | 1804              |
| 98S        | 98     | 2            | 10       | 6       | 195               |
| 1          | 26     | 14           | 98       | 111     | 715               |
| 5          | 98     | 111          | 297      | 330     | 978               |
| 10         | 297    | 330          | 468      | 570     | 1213              |
| 15         | 1      | 2            | 4        | 5       | 87                |
| 5          | 52     | 60           | 52       | 60      | 416               |
| 10         | 101    | 121          | 298      | 336     | 750               |
| 15         | 101    | 121          | 298      | 336     | 750               |
| 85S        | 85     | 15           | 3        | 1       | 15                |
| 1          | 5      | 4            | 5        | 4       | 53                |
| 5          | 24     | 44           | 24       | 44      | 287               |
| 10         | 59     | 66           | 59       | 66      | 511               |
| 15         | 121    | 132          | 121      | 132     | 532               |
| 75S        | 75     | 25           | 1.3      | 0.6     | 8.2               |
| 1          | 2      | 2            | 2        | 2       | 29                |
| 5          | 11     | 8            | 11       | 8       | 181               |
| 10         | 22     | 23           | 22       | 23      | 211               |
| 15         | 39     | 42           | 39       | 42      | 287               |

* Based on the soil portion
Presumably, the CBR required for a road base is 80. It was observed that the CBR for pure soil (100S) is just 19; but, it was substantially increased to over 600 when 15% of cement added. However, for the unsoaked specimen it required only 2.9% of cement to attain the CBR of 80. Hence, it was interesting to compare this analogy to all of the other mixtures. For example, the cement required for the soaked specimen 85S to attain the CBR of 80 is 10.9%. This suggests that low-CBR soil mixed with up to 15% of rubber and modified by cement could be employed for road base construction. Notice that for 75S, the CBRs were very low even when the cement was at a maximum of 15%. Thus, it may be concluded that this particular mixture is not suitable as a road base.

For UCS, it was found that the unconfined compressive strength (qu) is gradually increased with the increase of cement content. When no cement added the qu for 100S and 98S were very similar, indicating that the behaviour was still dominated by the soil; and, the rubber just floated in the soil-rubber matrix.

For group (2), the initial qu values (no cement added) for 93S, 85S, and 75S were 37, 15, and 8.2 kPa. When a small amount of cement content of 1% was added, the qu values were observed to be slightly greater: they were 87, 53, and 29 kPa, for 93S, 85S, and 75S, respectively. They continued to increase almost linearly when the cement was increased from 5 to 10%. However, at the maximum cement content of 15%, the qu values are very similar to those mixtures having 10% cement content. This indicates that the cement added as high as 15% is no better when a mixture containing high proportions of rubber. The maximum qu values for 93S, 85S, and 75S were 750, 532, and 287 kPa, respectively.

5. Conclusions

A low strength soil was chosen as a base geomaterial to be mixed with recycled tyre chips and stabilised by cement for the purpose of using them as construction material. The soil to tyre chips ratios by weight were 100:0, 98:2, 93:7, 85:15, and 75:25. Each mixture was mixed with the cement ranging from 0, 1, 5, 10, and 15%. The California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests were conducted to evaluate the possibility of using the mixtures for road construction. Based on the experiences, test results, and analyses, the following conclusions have been drawn.

- The specific gravity values for the soil and tyre chips are 2.64 and 1.11, respectively.
- The CBR values for both soaked and unsoaked are gradually increased with the increase of cement content.
- For the mixtures having no cement added the CBR for unsoaked specimens is slightly greater than those of soaked specimens. However, this is contrary for the mixtures that were mixed with cement, i.e., the CBR values for soaked specimens are greater.
- As predicted, both unconfined compressive strength and indirect tensile strength are gradually greater with the increase of cement content.

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