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Effect of Tire Derived Aggregate on Maximum Dry Density of Kaolin

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Graphical abstract

Abstract

The use of Tire-Derived Aggregates (TDA) as highly permeable light weight material has been highlighted in different aspects of geotechnical engineering such as retaining walls, embankments and roads. In addition, in terms of human health and environmental matters, TDA usage is gaining attention. This paper gives an insight into the effect of TDA on the Maximum Dry Density (MDD) of Kaolin. A number of 273 compaction tests, were conducted on both Kaolin and Kaolin-TDA mixtures. Granular (5-8 mm), Granular (1-4 mm), Shredded (6-19 mesh) and Powdery (80 mesh) as various types of TDA, in different percentages from 0% to 60% by weight were mixed with Kaolin. Samples were compacted, using standard proctor procedures in accordance with British Standard. Findings show, that the MDD of Kaolin decreases within the range of 9% to 45%. Apart from that, based on the general results, it is observed that there is a significant change in the MDD of Kaolin-TDA mixture while the changes occurred in Optimum Moisture Content (OMC) is not remarkable. Depending on geotechnical problem, the wide range of the results could be used as a proper source for selecting the optimum percentage of Kaolin-TDA mixture.

*Keywords:*Maximum dry density; compaction test; Kaolin; tire derived aggregate; optimum moisture content

Abstrak

Penggunaan Tire-Derived Aggregates (TDA) sebagai bahan yang tinggi penelusannya, ringan dan murah semakin mendapat perhatian dalam bidang geoteknik seperti struktur tembok penahan,benteng and jalanraya. Tambahan pula, jika mengambil kira keperluan kesihatan, keselamatan dan persekitaran, penggunaan TDA semakin menjadi pilihan. Kajian ini adalah berkenaan dengan kesan TDA kepada ketumpatan kering maksima (MDD) Kaolin. Sebanyak 273 ujian mampatan dijalankan ke atas Kaolin dan campuran TDA-Kaolin untuk mengkaji kesan TDA terhadap MDD campuran. Saiz batuan (5-8mm), batuan (1-4mm), penapis (6-19 mesh) dan serbuk (80 mesh) digunakan sebagai jenis-jenis TDA, dalam kepelbagaian dari 0% hingga 60% berat dicampurkan dengan Kaolin. Sampel dipadatkan menggunakan prosedur proktor standard berdasarkan standard British. Keputusan menunjukkan MDD Kaolin berkurang sebanyak 9% - 45% dengan penggunaan TDA. Selain itu, terdapat perubahan yang signifikan dalam MDD Kaolin dan pada masa yang sama perubahan pada Kandungan Lembapan Optimim (OMC) juga tidak ketara. Walaubagaimanapun, ianya pergantung kepada permasalahan dalam geoteknik, yang mana perlu dapatan data yang banyak dalam permilihan peratus campuran Kaolin-TDA yang optimum.

Kata kunci: Ketumpatan kering maksimum; ujian mampatan; Kaolin; tire derived aggregate; kandungan lembapan optimum

■1.0 INTRODUCTION

In general, soil comprises solid particles, water and air. The existence of air voids in the soil decreases the shear strength of the soil as well as making the soil more susceptible to settlement under loading more specifically repeated loading such as traffic. Hence, in soil mechanic, reducing the volume of the air is of prime importance. The mechanical process of increasing the density of the soil by packing the soil particles closing together and consequently removing the air voids is defined as compaction. In fact, strict control of the desirability of the soil compaction is one of the key parameters in constructing dams, embankments, retaining walls, and roads. If the state of soil compaction is not desirable, future loading of the soil will cause further unexpected settlement with associated deformation and likely damage. The degree of compaction is measured in terms of dry density, γ_d, which represents the mass of solid particles in a given volume of soil. Dry density depends on the type and water content of the soil. Nevertheless, achieving a higher dry density in the soil is always of interest due to the aforementioned reasons. In practice, the maximum dry density (MDD) of soil occurs when the soil water content (moisture content) is neither low nor high. It is because it is hard to compact the soil in low water content and in high water content, the dry density decreases due to the inverse relationship between dry density and water content. The water content at which MDD occurs is defined as optimum moisture content.

This study is aimed to investigate the effect of Tire Derived Aggregate (TDA) on the maximum dry density of pure clayey soil (Kaolin) as to the knowledge of the authors; there is no extensive work which investigates the MDD of a mixture of Kaolin and various types of TDA. The use of such recycled material *i.e.* TDA is recently highlighted in various applications of Geotechnical engineering[1]. It is mostly due to the availability of TDA as a relatively cheap material as well as disposal problem alleviation. In addition, tires as permeable and lightweight material could be utilized in constructing retaining walls, landfills and embankments. Many researchers have studied the influence of the TDA addition on different engineering properties of the soils such as MDD[2-7]. Some scholars reported that the engineering properties of compacted clay can be explained through the study of compacted soil structure[8-9].

Edil *et al*.[10] conducted field experiments on test embankments of different side slopes. The three modification scenarios tested included embankments constructed from pure tire chips, soil mixed with tire chips, and alternating soil layers with tire chips. According to their report, although no unusual problems were encountered in using rubber modified soil, controlling the compressibility and compaction characteristics were difficult and needed further investigation. Ahmed and Lovell[11] provided some more insight for the applicability of shredded rubber tires in highway construction by conducting compaction tests using Modified Proctor, Standard Proctor, 50% of the Standard Proctor and vibratory compaction on Crosby till and Ottawa sand modified with seven different sizes of tire chips. By adding tire chips between 0 to 100% of the dry weight of the soil mass, researchers have determined that the unit weight varies insignificantly when rubber chips are added in excess of 20% of the dry weight of the soil. Cetin, *et al*.[12] considered samples by mixing a cohesive clayey soil with 10, 20, 30, 40 and 50% coarse and fine grained tire-chips. The results of their compaction tests indicated that the dry density of the tire-chips mixtures was less than that of typical soils including the clayey soil. Binod, *et al.*[13] mixed five different types of soil samples with 10%, 20%, and 30% (by weight) shredded rubber tires and conducted compaction tests of mixtures. Their findings showed that 10% mixture of tire aggregate with soil evidenced a consistent increase in dry unit weight compared to the soil without any tire aggregates, irrespective of the type of soils used.

2.0 MATERIAL AND TEST PROCEDURE

This study is divided into three main stages. In the first stage the required materials (Kaolin and TDA) were collected, weighed and mixed together. In the second stage the compaction tests were conducted according to British Standard.[14] Third stage dealt with investigating the effect of TDA on the maximum dry density of Kaolin.

2.1 Material Collection: Kaolin and TDA

The Kaolin used in this study was purchased from Kaolin (Malaysia) Sdn. Bhd. Kaolin properties are presented in Table 1.

In order to investigate the effect of TDA on Kaolin MDD, various types of TDA were collected from Yong Fong Rubber Industries Sdn. Bhd. The types of TDA consist of granular (5-8 mm), granular (1-4 mm), shredded (6-19 mesh), powdery (80 mesh), where mesh is defined as the number of particles per inch. Table 2 shows the specific gravity of TDA used in this study[15]. Whole tires or parts of scrap tires are shredded by shredders equipped with knives or blades. A typical tire shredding operation is performed as follows:

(1) The tires are brought into the factory;
(2) The tires are carefully inspected for any foreign debris; tire tubes and liners are also removed and recycled;
(3) The tires are loaded onto the conveyor feeding system;
(4) The tires pass through numerous shredders and are reduced in size to 2 inches or less depending on the setup;
(5) After completing the shredding process, the shredded tires travel through a trommel; oversized rubber pieces are re-circulated through the shredder until those pieces can pass through the sizing trommel.

The Kaolin and different types of TDA are shown in Figure 1 and Figure 2.

Figure 1 Kaolin

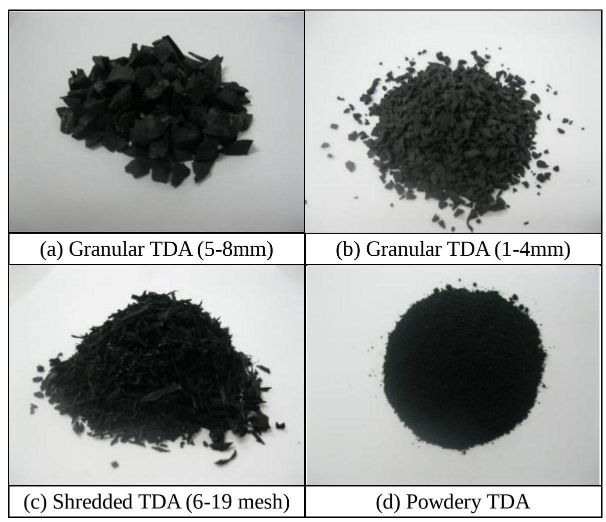

Figure 2 Tire derived aggregate used in this study

2.2 Sample Preparation

Kaolin-TDA mixtures were prepared using various percentages by weight (see Table 3). In order to prevent material flocculation, the mixing procedure was done sufficiently and properly in accordance with British Standard[11]. The mixtures were mellowed 24 hours prior to compaction test. Sample mellowing was conducted by adding water during mixture preparation. Water addition was continued until desired result was observed.

Color observation during mixing process can be a useful guide to prevent separate flocculation of either TDA or Kaolin before and after adding water .

2.3 Soil Compaction Test

Removing the air from the soil void spaces through a mechanically compression process is termed soil compaction. The test is standardized by British Standard.[13] According to the standard, for each compaction test, with the aid of a 2.5-kg rammer, a three-layered mixture was prepared in one-liter mold. Each layer was subjected to 27 blows. After that, water was added gradually to the prepared mixtures and mixed thoroughly and sufficiently. All 21 compaction tests in 3 series were performed for each Kaolin-TDA mixture. In other words, for 13 different Kaolin-TDA mixtures, a number of 273 compaction tests were conducted.

Table 1 Kaolin Properties (Kaolin Malaysia Sdn. Bhd.)

Physical Properties	
In-house Test Method	
Moisture Content	Below 5.0 %
60 Mesh per inch (24 Mesh per cm) Residue	Below 20.0 %
Chemical Composition	
XRF Test Method	
Aluminum (Al2O3)	15.0 – 25.0%
Silica (SiO2)	60.0 – 75.0 %
Iron (Fe2O3)	Below 5.0 %
Potassium (K2O)	Below 2.5 %
Magnesium (MgO)	Below 1.0 %
Loss on Ignition 1025 ºC	5.0 – 10.0 %

Table 2 TDA specific gravity

TDA Type	Size	Specific Gravity (gr/ml)
Powdery	80 mesh	1.155
Shredded	6-19 mesh	1.173
Granular (1-4)	1-4 mm	1.359
Granular (5-8)	5-8 mm	1.402

3.0 RESULTS AND DISCUSSION

The results of the 273 compaction test are presented in Figure 3 and Table 4 respectively. In Figure 3 the results are shown schematically for different points while in Table 4 the optimum compaction parameters (OMC & MDD) are tabulated. It was observed that pure Kaolin has the highest dry density. This is due to the fact that specific gravity (Gs) of Kaolin is much more than that of TDA.[15] However comparison among the influence of different type of TDA on MDD shows that Powdery TDA affects the MDD much more than other TDA types. For the 60% TDA, it was observed that MDD was 964 (kg/m^3) while for 60% granular, the MDD was 1310 (kg/m^3). The reason why MDD of granular TDA (5-8 mm) was higher than powdery TDA may be due to void ratio factor. The void ratio of granular TDA is higher than that of powdery TDA so while mixing and compacting with Kaolin; Kaolin filled these voids. As a result, the MDD of Kaolin-granular TDA (5-8 mm) mixture is higher than the MDD of Kaolin-powdery TDA.

The general trend of the optimum moisture content values shows that the values of OMC decrease when Granular TDA percentage increases. However, OMC increases with the increase in the percentage of other TDA types. This is due to higher moisture content required to lubricate Kaolin-powdery mixture. It might be due to larger effective surface area of the particles in Kaolin-powdery mixture.

Table 3 Kaolin-TDA mixture

Test No.	Percentage and Type of Material				
	Kaolin (%)	Granular TDA (5-8) (%)	Granular TDA (1-4) (%)	Shredded TDA (6-19 mesh) (%)	Powdery TDA (%)
Test No. 1	100	-	-	-	-
Test No. 2	80	-	-	-	20
Test No. 3	60	-	-	-	40
Test No. 4	40	-	-	-	60
Test No. 5	80	-	-	20	-
Test No. 6	60	-	-	40	-
Test No. 7	40	-	-	60	-
Test No. 8	80	-	20	-	-
Test No. 9	60	-	40	-	-
Test No. 10	40	-	60	-	-
Test No. 11	80	20	-	-	-
Test No. 12	60	40	-	-	-
Test No. 13	40	60	-	-	-

Table 4 Maximum dry density and optimum moisture content of Kaolin-TDA mixture

	Kaolin – Powdery TDA			
Mixture Percentage	Test No. 1	Test No. 2	Test No. 3	Test No. 4
Optimum Moisture Content (%)	16	18	20	24
Maximum Dry Density (kg/m^3)	1750	1432.5	1192	964
	Kaolin – Shredded TDA			
Mixture Percentage	Test No. 1	Test No. 5	Test No. 6	Test No. 7
Optimum Moisture Content (%)	16	16	17	18
Maximum Dry Density (kg/m^3)	1750	1488	1274	1010
	Kaolin – Granular TDA (1-4 mm)			
Mixture Percentage	Test No. 1	Test No. 8	Test No. 9	Test No. 10
Optimum Moisture Content (%)	16	20	18	16
Maximum Dry Density (kg/m^3)	1750	1493	1400	1260
	Kaolin – Granular TDA (5-8 mm)			
Mixture Percentage	Test No. 1	Test No. 11	Test No. 12	Test No. 13
Optimum Moisture Content (%)	16	14.5	14	13.5
Maximum Dry Density (kg/m^3)	1750	1590	1462	1310

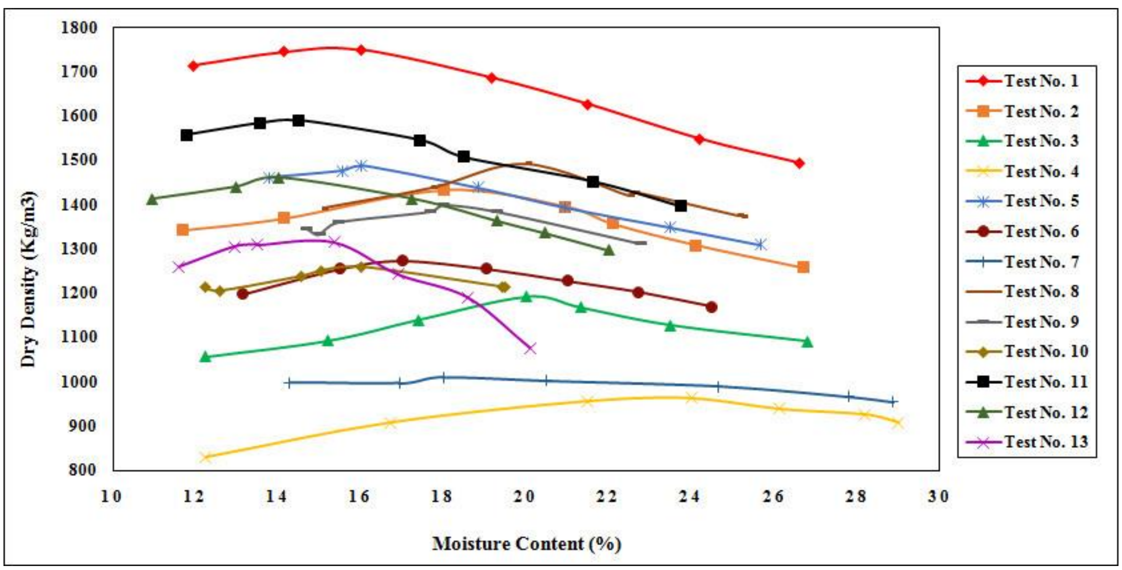

Figure 3 Compaction curves of Kaolin-TDA mixtures

Figure 4 depicts the effect of TDA percentage on MDD for each TDA type. It can be determined from this figure that any increase in TDA percentage results in a decrease of mixture MDD. For instance, in Kaolin-powdery TDA mixture, as the percentage of TDA increases from 0% to 60%, the MDD decreases from 1750 to 964 (kg/m^3). As mentioned earlier, this is mainly due to the effect of specific gravity (G_s). Hence, for any increase in the percentage of TDA, there is a decrease in the weight of the Kaolin-TDA mixture and consequently in the maximum dry density of the Kaolin-TDA mixture.

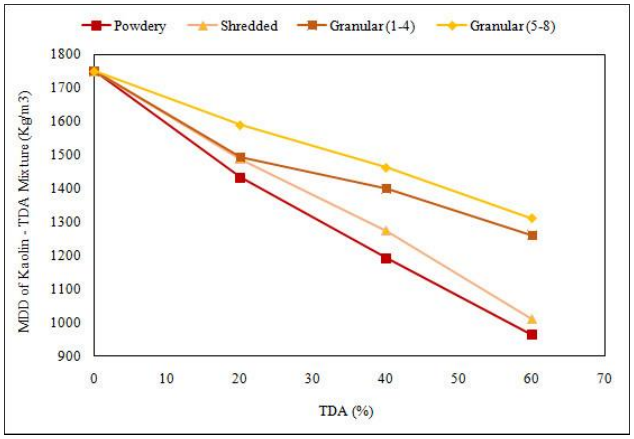

Figure 4 Effect of TDA percentage on maximum dry density of Kaolin-TDA mixture

The type of TDA can influence the maximum dry density of Kaolin-TDA mixture as shown in Figure 5. For example for 60% TDA category, the MDD of Kaolin-Powdery TDA is 55% of MDD of pure Kaolin while in the case of Kaolin-Granular (5-8 mm) TDA mixture, the MDD is 75% of MDD of pure Kaolin. Depending on the type of geotechnical problem, the TDA type can be selected. As an example, in a retaining wall problem for which lowering the weight of the soil behind it is of interest, the use of Powdery TDA type can be recommended.

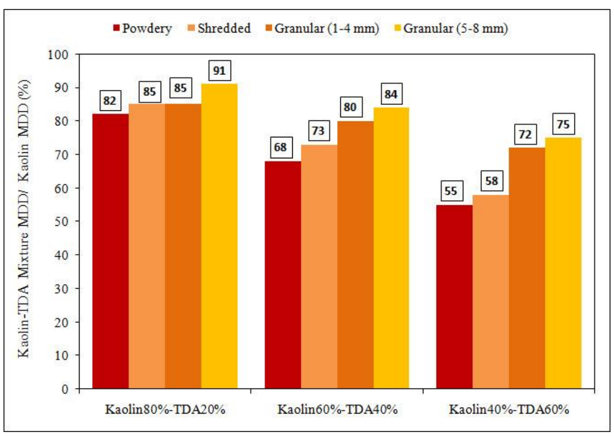

Figure 5 Effect of TDA type on the MDD of Kaolin

4.0 CONCLUSION

This study investigated the effect of adding TDA on the maximum dry density of Kaolin. For this purpose, a number of 273 compaction tests were conducted. For all TDA types, it was observed that as the amount of TDA increases in the soil, the MDD of the mixture decreases. The maximum reduction of 45% in Kaolin-MDD was achieved by mixing 60% powdery TDA while the minimum reduction of 9% Kaolin-MDD was determined when 20% Granular (5-8 mm) TDA was mixed with Kaolin. The general trend of optimum moisture content values show that there is no remarkable changes in OMC values. However, for lubrication purpose and consequently the need for more water in Kaolin-powdery TDA mixture, the variation of optimum moisture content was much more than other type of mixtures.

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