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Compactness of Scrap Tyre Rubber Aggregates in Standard Proctor Test

Magdalena Kowalska[a,*]

[a]*Department of Geotechnics and Roads, Faculty of Civil Engineering, Silesian University of Technology, ul. Akademicka 5, 44-100 Gliwice, Poland*

Abstract

Scrap tyre derived aggregates (TDA) have been used in civil engineering since 1990-ties, mainly in the USA. The material may be used in various forms and sizes – from powder, through granulates, tyre shreds, chips. The TDA applications include: lightweight fills in embankments over soft soils, lightweight backfills behind retaining walls, insulation and drainage layers etc. In most of the works the material needs to be compacted to decrease the void ratio of the aggregate and reduce future settlement. This paper presents a study on compactness of four different fractions of scrap tyre rubber (A: 0.1 – 1 mm, B: 0.5 – 2 mm, C: 2 – 5 mm and D: 10 – 40 mm) in the standard Proctor test. The results in the form of dependency of dry and bulk density on water content are compared also with adequate results obtained for a clean uniform medium sand. It turns out that the optimum moisture content can be clearly estimated only in the case of the finest fraction (sample A) and it is equal to about 40%. The variability of dry density is however small – it changes from 0.54 to 0.61 g/cm^3. Coarser TDAs behave more like self-draining materials – they retain much less water and the maximum moisture content equals to about 18%, 23% and 38% in case of tyre chips (D), 2 – 5 mm grains (C) and 0.5 – 2 mm grains (B) respectively. The dry densities for samples B, C and D possible to be obtained with standard Proctor energy have been estimated as: 0.61, 0.60 and 0.59 g/cm^3 respectively.

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Keywords: scrap tyre rubber; proctor test; compactness; self-draining materials;

* Corresponding author. Tel.: +48 32 237 15 43.
E-mail address: magdalena.kowalska@polsl.pl

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1. Introduction

The number of cars used in Europe is constantly growing and with more cars also mores scrap tyres follow. It is estimated that 3.4 million tons of scrap tyres are produced nowadays only in the European countries (ETRMA, 2013/2014). The 'Directive 1999/31/EC on the landfill of waste' has prohibited landfilling of used tyres: whole - since 2003 and shredded - since 2006. The reasons for this regulations were such that stockpiled tyres not only take up a significant amount of space, but they also create the danger of spontaneous combustion and the fumes emitted during such a fire contain chemicals dangerous to health (Jenish, 1990). Additionally, heaps of tyres are perfect breeding ground for disease carrying vermin like insects and rodents.

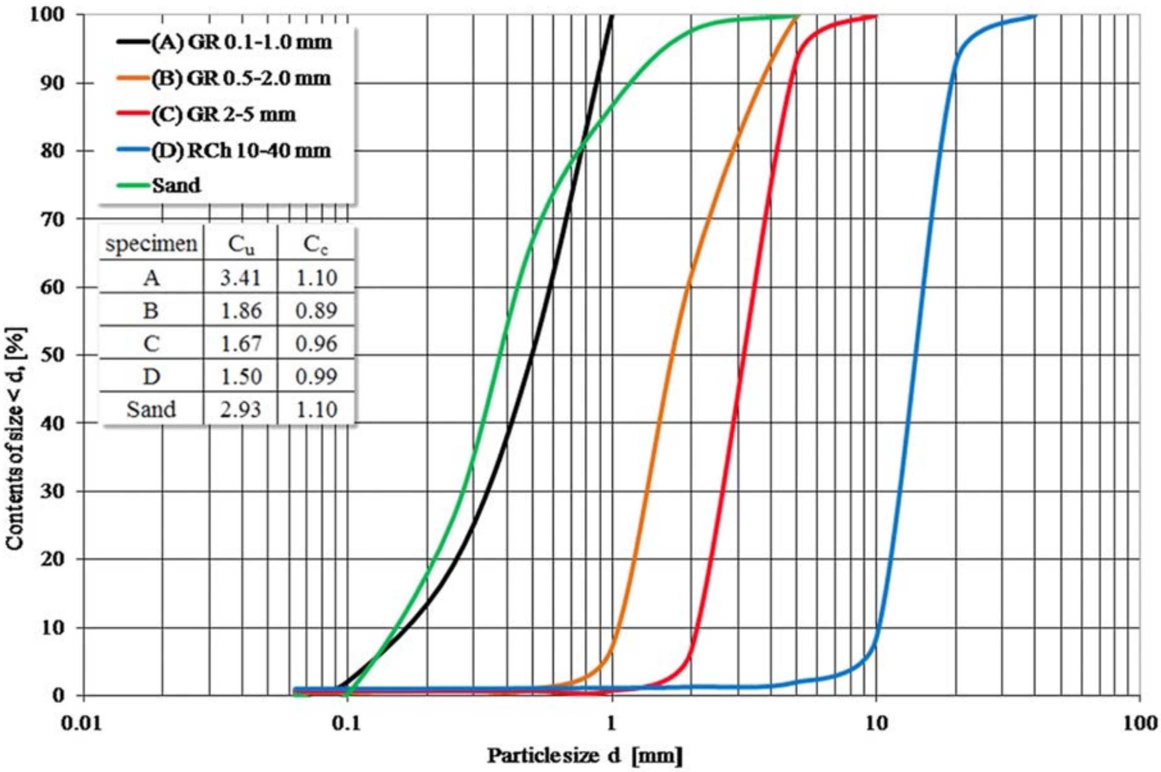
Thanks to the European regulations and activity of the tyre industry in 2012 almost 95% of end-of-life tyres have been recovered or recycled, out of which 39% was material recovery and 37% - energy recovery (the rest went for re-treading, reuse or export) (ETRMA, 2013/2014). Only 12% of this amount was used for civil engineering applications, even though Tire Derived Aggregates (TDA) have proven to be effective building and reinforcement material. It has been used since the 90s of the XX century in constructions of lightweight embankments on weak and expansive soils (Boscher and Edil, 1992; Yoon et al., 2005; Seda et al., 2007), as lightweight retaining wall backfills (Cecich et al., 1996 ; Tweedie et al., 1998; Lee et al., 1999), drainage layers, vibration and thermal insulation layers (Humphrey and Eaton, 1995; Lee and Roh, 2007), as additives to asphalt etc.

In civil engineering applications mostly the biggest sizes of TDA (referred to ASTM D 04, 2004) are used: tyre chips (12 – 50 mm, with most of the wire removed) and shreds (50 –305 mm, with wire cord) as their production cost is the lowest. Tyre recycling companies producing all sizes of shredded rubber are looking though for market also for the other sizes of crumb rubber – starting from the finest – powdered rubber. In most of the engineering works the material needs to be compacted to decrease the void ratio of the aggregate and reduce future settlement. According to Ahmed and Lovell (1993) mixtures of sand and rubber should be compacted by means of vibratory methods while for rubber chips alone and mixes of chips and fine grained soils non vibratory methods (Proctor type) are more appropriate. This paper presents results of compaction of four different fractions of scrap tyre rubber in the standard Proctor test. The objective of the research was to estimate the evolution of densities (bulk ρ and dry ρ_d) of TDA with the increase of moisture content and, where possible, to determine the maximum dry densities (ρ_{ds}) and optimum moisture contents (w_{opt}).

2. Methodology

In this research four sizes of TDA (offered by the local shredding companies) were used: ground rubber without any textile or steel cord in three sizes: fine 0.1 – 1 mm (specimen A), medium 0.5 – 2 mm (specimen B), coarse 2 – 5 mm (specimen C) and tyre chips containing textile and steel parts 10 – 40 mm in size (specimen D). Additionally, to compare the rubber behaviour with a natural soil a specimen of uniform medium river quartz sand was tested as well – its grading was very similar to the one of specimen A. Grain size distribution of all the materials with their grading characteristics (uniformity coefficient C_u and coefficient of curvature C_c) are presented in 0.

The specimens mixed with different amounts of distilled water were compacted following the recommendations of the Polish Standard PN-88/B-04481 (PN standard). The standard Proctor energy of 0.59 J/cm^3 was applied. Ground rubber and sand were compacted in three layers in the small mould (1 dm^3) and tyre chips in the large mould (2.2 dm^3). The PN standard, in contrast to the European Standard EN 13286-2 (EN standard), allows compacting one batch five times. In this research each batch (with water content different by 2 – 3%) was prepared separately but it was compacted at least three times in order to estimate the possible influence of the number of compactions. The test was ended if water bleeding through the gap between the mould and the base plate occurred.



specimen	C_u	C_c
A	3.41	1.10
B	1.86	0.89
C	1.67	0.96
D	1.50	0.99
Sand	2.93	1.10

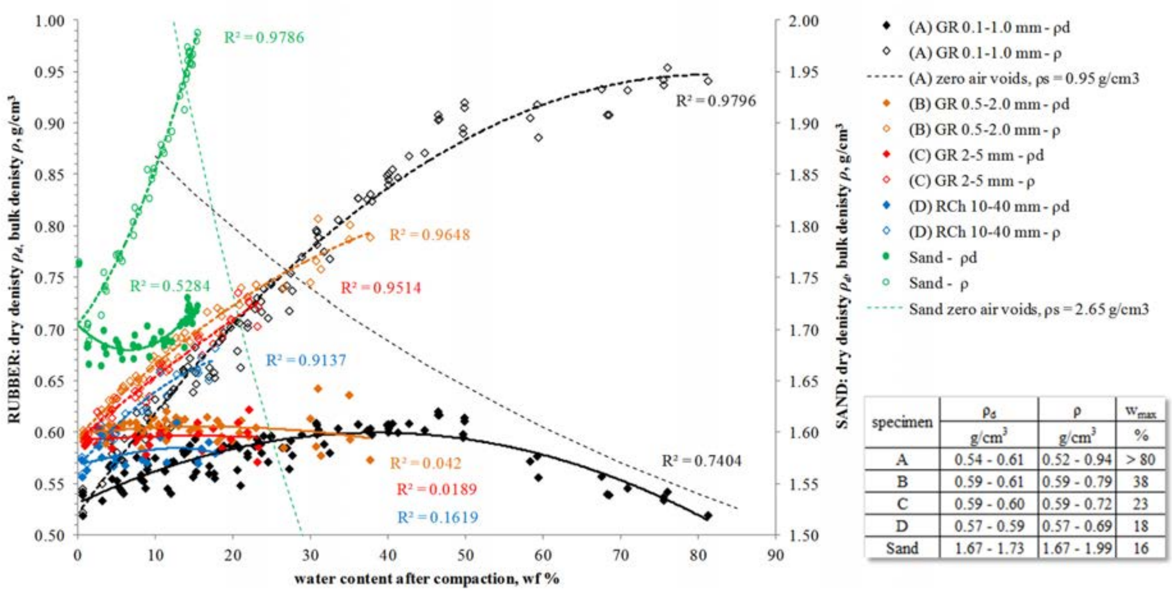
Fig. 1. Grain size distribution of aggregates used in the study.

According to EN standard some materials may be classified as 'self-draining mixtures', in which loss of water during compaction (greater than 0.3%) prevents determination of the maximum dry density. In such a case instead of ρ_{ds} a dry density at bleeding ρ_{db} shall be estimated. Tyre chips and shreds have proved to be well draining materials with coefficient of permeability close to the one of gravel (ASTM D 6270-98, Hazarika et al., 2010). Edil and Bosscher (1994) claimed that densification of shreds and chips cannot be improved by controlling the moisture content and/or increasing the compactive effort. Thus it was expected that the rubber aggregates considered in this study will behave like self-draining mixtures. This is why in each test the water content was measured before and after compaction (w_0 and w_f respectively) based on representative amount of material (taken from at least 10 points in the mould).

3. Results and discussions

The test results revealed that compaction repeated several times does not change the dry density of TDA or sand - this is why all the obtained values of water contents and densities were analysed independently on the number of compactions. In 0 presented are results of variation of dry density and bulk density of all the specimens versus their water content after compaction. The figure contains also parabolic trend lines with the values of their coefficient of determination R^2; below the legend a table showing the average range of densities and the maximum achieved water contents has been added.

It can be noted that bulk density of all the specimens was constantly increasing as the water was added, which was well described by the parabolic curves ($R^2 > 0.9$). In case of sand the maximum dry density, equal to about 1.77 g/cm^3, was achieved for oven dry specimen and the ρ_d - w_f function resembles a reversed parabola with the second maximum at the highest possible water content of about 16%.



specimen	ρ_d	ρ	w_{max}
	g/cm³	g/cm³	%
A	0.54 - 0.61	0.52 - 0.94	> 80
B	0.59 - 0.61	0.59 - 0.79	38
C	0.59 - 0.60	0.59 - 0.72	23
D	0.57 - 0.59	0.57 - 0.69	18
Sand	1.67 - 1.73	1.67 - 1.99	16

Fig. 2. Dry density and bulk density variation with water content for sand and rubber grains.

Rubber aggregate is about threefold lighter than sand. Its maximum dry density increases only slightly as the size of the grains decreases. In case of the coarser TDA (specimens B, C, D) the increase of water content shows insignificant influence on dry density.

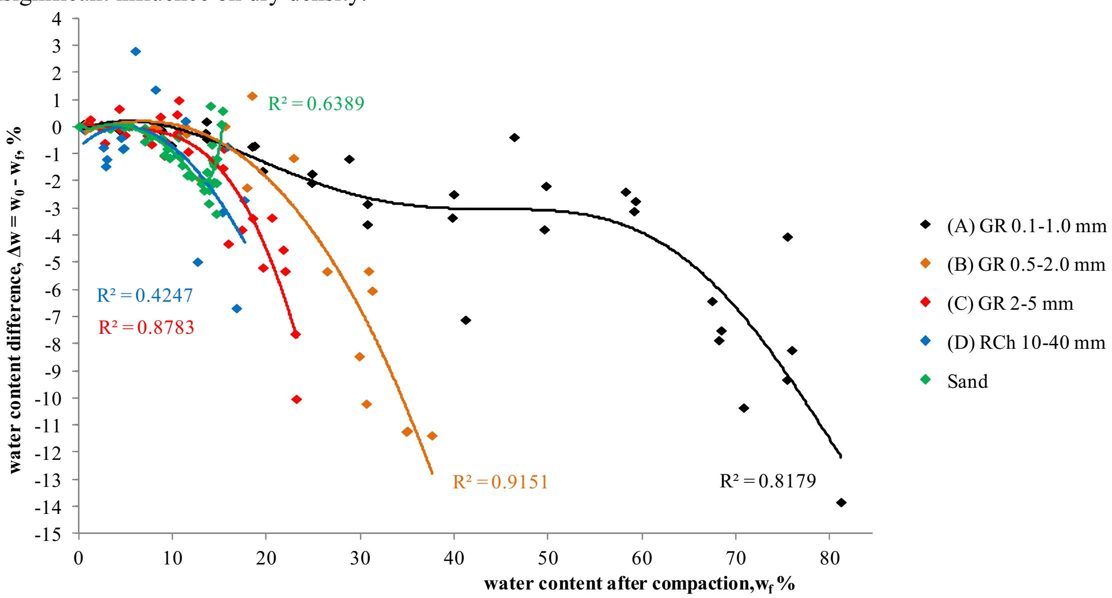


Fig. 3. Water content difference during compaction.

These materials, just like sand, behave like self-draining mixtures. Their maximum amount of water retained in these specimens was however greater than that of sand and it was the higher the finer was the rubber fraction.

Completely different characteristic can be observed in case of the finest rubber sample (A) – here the optimum water content can be easily determined as being equal to $w_{opt} \approx 40\%$. This specimen could retain more than 80% of water compared to its dry mass, even though the grain size of this specimen was not much different than the one of sand. The difference between the water content before and after compaction is presented in 0.

In all the rubber specimens the average water content measured after compaction was greater than before the test and the absolute difference $|\Delta w|$ (= $|w_0 - w_f|$) was increasing at higher water contents. This may be probably explained by migration of water from the moist excess material (sitting in the collar of the Proctor mould) into the specimen. Only in case of the finest TDA a 'peak value' of Δw was observed at the water content close to the optimal, however the difference Δw did not change into positive values. Estimation of the water content at bleeding w_b was possible only in case of the sandy specimen and it was equal to 15.5%.

4. Conclusions

Results of this study on compactness of TDA showed that in case of tyre chips and ground rubber with grains greater than 1 mm the water content had practically no influence on the dry density in Proctor test. Finer specimen however exhibited behaviour similar to cohesive soils (with distinct optimum water content), even though its grading curve was very similar to the one of quartz sand, which in turn occurred to be a true self-draining material.

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