Waste Recycling

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WASTE RECYCLING

EDITED BY

ZBIGNIEW WZOREK, JOANNA KULCZYCKA,

PETER FEČKO, MÁRIA KUŠNIEROVÁ

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CORRESPONDENCE ADDRESS
Minerals and Energy Economy Research Institute
Polish Academy of Sciences
Division of Strategic Research
31-261 Kraków, ul. Józefa Wybickiego 7
tel. (0-12) 632-33-00, fax. (0-12) 632-35-24

TECHNICAL EDITOR
Anna K. Nowak
Zbigniew Wzorek

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Contents

Introduction

Natural environment protection within the range of waste management has been carried out in systematic and organised way only for several years. Waste storage was recently the most acceptable and most often applied method of waste utilization. Practically from the industrial revolution outbreak to the turn of seventies of XX century every production processes were conducted without taking heed of natural environment, generating enormous quantities of waste. This policy, sacrificing natural environment for economy, leads to its appalling destruction and reduction of natural resources.

Accrescent pressure on removal of negative environmental results brings legislative changes and redesign social mentality. Nowadays the fundamental goal of natural environmental protection is not only the control of pollution level and waste utilization but also prevention of its formation.

Polish and European Union regulations establish an order of waste treatment:

- prevention of waste formation and minimalization of its quantities as well as negative impact on environment
- assurance of recovery (mostly recycling) for that waste, which can not be avoided under specific techno-economic conditions
- waste neutralization (except storage), safe for human health and environment waste storage

Modification of the way of waste processing necessitates developing improved low- and non-waste technologies with lower energy consumption as well as new methods of waste recycling and secondary raw material management.

This book contains discussion on current and important problems of waste management including obligatory regulations and accommodation of Polish low to European Union standards. Moreover raises problems connected with more commonly demanded and used environmental management mechanisms (LCA- Life Cycle Assessment) and its economical evaluation (LCC- Life Cycle Cost). Those techniques are realized by introduction of ideas of sustainable development and required by EU legislation best available techniques (BAT).

Authors represents international group of specialists in the range of waste management. Problems discussed in the following chapters concern methods of waste limitation and prevention of its formation, possibilities of recycling as well as waste utilization and energy production, etc.

This book contains:

- problems with using biotechnology in waste management
- selected solutions in the range of sewage treatment and utilization
- problems connected with waste combustion and toxic gaseous products emission (dioxins)
- exemplary utilization methods of post-flotation tailings, ashes from solid waste combustion
- proposals of rubber waste recycling

Wide range of treated subjects allows for almost profound look at waste management and prevention. Besides measurable economical and ecological benefits connected with mentioned solutions educational values are also particularly valuable.

15. Lightweight concrete for pavement leveling using rubber particles from used tyres*

15.1. INTRODUCTION

The growth of the world population causes an increase of solid waste. The used tyres are part of this solid waste and, as such, its deposition has become a serious environmental problem. The used tyres are considered to be a non biodegradable material that will remain in deposits for a long time without suffering any degradation. Nowadays, there are recycling companies that proceed in shredding of used tyres, obtaining separated materials such as crumbed rubber particles, steel fibres and textile fibres. The rubber particles have already been used in certain applications like asphalt concrete, pavements for playgrounds and athletics tracks. The steel fibres can be recycled in iron and steel foundry. However, these applications count for a small portion of the recycled material available and new applications are needed in order to achieve a higher rate of their utilization.

It is suggested in literature that rubber particles from scrap tyres can be mixed into Portland cement concrete. However, the results have shown that the compressive and flexural strength decreased on addition of granular rubber. Nevertheless, other properties are reported to have been improved, for example, freeze-thaw and impact resistance [1-3].

Based on the results available it appears to be unrealistic to expect that high volumes of rubber particles from recycled tyres can be used in structural concrete. However, in non-structural applications, where the required mechanical strength is reduced this material can be used in large quantities.

As the rubber contains a low specific weight, the application of this product in the development of a non-structural lightweight concrete could become a good solution. The non-structural lightweight concrete could be used for pavement levelling and filling requiring a low compressive strength.

On the other hand, it is well known that nowadays the world's ecosystem has been facing an increasing problem related to the high level of carbon dioxide (CO_2) released into the atmosphere. The production of each tone of Portland cement is responsible for the discharge of about one tone of CO_2. On worldwide scale the cement industry contributes with about 7% of the total amount of CO_2 production. With the objective of reducing the CO_2 production, it is fundamental that the use of Portland cement can be reduced.

The objective of this study was to create a low cement content lightweight non-structural concrete incorporating only rubber particles from used tyres as aggregate. With these purposes, this material must achieve a compressive strength of about 1.0 MPa and should have an adequate workability so as to be easy to place in practical applications.

Three different rubber tyre aggregates grading sizes were used in this research work: smaller than 0.7 mm, 0.8 to 2.5 mm and 2.5 to 4.0 mm.

Different rubber tyre concrete mixtures were produced and the following laboratory tests were performed: compressive strength, flexural strength and specific weight. The testing results obtained are presented and analysed.

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* Aires Camões, Said Jalali, Alexandre Peyroteo, Department of Civil Engineering, University of Minho, Campus de Azurém, Guimarães, Portugal

15.2. MATERIALS, MIXTURES AND CURING

The rubber tyre aggregates used in this research work were obtained from a Portuguese tyre recycling company (BioSafe [4]) dedicated to producing fine mesh crumb rubber. BioSafe uses its patented technology that uses no liquid nitrogen and produces crumb rubber product with significant surface area.

BioSafes' facilities process up to 20.000 tons of tyres – the equivalent to 2.5 million passenger vehicle tyres – annually. The crumb rubber produced has a wide range of sizes, according to customer's requirements. As a result of its efficient technology and strategic location, the Company is well positioned to become Europe's number one producer of fine mesh crumb rubber.

Currently, BioSafe produces five different standard size distributions, i.e. 0.5 to 1.5 mm; 1.0 to 2.5 mm; 2.5 to 4.0 mm; 4.0 to 7.0 mm and 7.0 to 9.5 mm. it also produces specific nominal dimensions of granulated rubber on customers request. In this research study three different rubber particle sizes were used: smaller than 0.7 mm, 0.8 to 2.5 mm and 2.5 to 4.0 mm. These selected grading sizes correspond to the major quantity of the rubber particles obtained by the recycling process. All the rubber particles were used as received, without any pre-treatment.

The specific mass of the different grading sizes of rubber particles were determined and are presented in Table 15.1. Figure 15.1 represents the grading curves obtained for the different sizes of rubber aggregates. Table 15.2 shows the results from chemical analysis of rubber tyres.

Table 15.1
Specific mass of the rubber particles

Rubber particles	**Specific mass (kg/m3)**
$\phi < 0.7$ mm	714
0.8 mm $<\phi < 2.5$ mm	1053
2.5 mm $<\phi < 4.0$ mm	1333

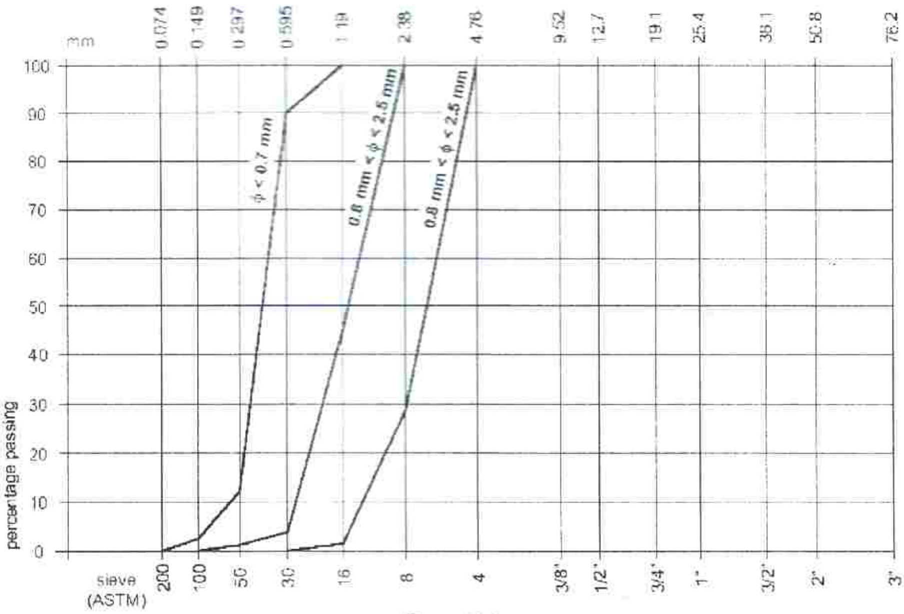

Figure 15.1
Sieve analysis of rubber particles

Table 15.2
Chemical analysis of rubber tyres

Components	**Variation [%]**
Polymer (natural rubber, SBR, BR)	45-49
Black of smoke	33-37
Aromatic oil	10-16
Zinc oxide	1-2
Estearic acid	1-2
Parafenilenodiamina	0.3-0.6
Parafinic wax	0.5-1
Trimetilquinoline	0.1-0.3
Sulfur	0.7-1.5
Derived sulfenamides	0.2-0.6

The cement used was a Portland cement type CEM I 42.5R. Calcium chloride was also used in almost all compositions. The dosage of calcium chloride used was determined according to 15.2.1 and is indicated as a percentage of the cement used.

In order to obtain a lightweight concrete with a minimum compressive strength of about 1.0 MPa several types of compositions were tested.

The first stage of this research work was to evaluate the compressive strength and the weight of the compositions in order to estimate the adequate proportions of cement, rubber particles and other constituents. The compositions tested are presented in Table 15.3. It was intended to create a lightweight concrete with a good workability. So the ratio of water to cement was kept quite high.

Table 15.3
Mixtures tested

Mix	**Cement [kg/m^3]**	**Rubber particles [kg/m^3]**			**Water [(l/m^3]**	**W/C**	**Calcium chloride [%]**
		$\phi < 0.7$ mm	**$0.8 < \phi < 2.5$ mm**	**$2.5 < \phi < 4.0$ mm**			
A	250	-	353	353	250	1.00	-
B	300	223	223	223	270	0.90	4
C	320	214	214	214	288	0.90	4
D	350	201	201	201	315	0.90	4
E	425	200	200	200	298	0.70	4
F	500	181	181	181	325	0.65	4
G	600	158	158	158	360	0.60	4

Prismatic specimens of 40x40x160 mm were moulded in order to evaluate the flexural strength. The compressive strength was assessed using 100x100x100 mm cubic specimens. The specimens were removed from the forms 24 hours after casting and were stored immersed in water at 21°C until their testing.

Figure 15.2 shows one Mix A after slump test. Figure 15.3 shows the overall appearance of one cubic specimen ready for compressive strength test.

15.2.1 CALCIUM CHLORIDE CONTENT

Observation of rubber concrete Mix A indicated a high setting time and low rate of strength gain. Analysing the chemical composition of the rubber it seems that the presence of zinc oxide is responsible for delay in setting time and the process of cement hydration. Thus, the addition of calcium chloride could accelerate the hydration process. In order to evaluate this setting time of cement pastes incorporating rubber tyre particles were estimate. Table 15.4 shows the percentages of chloride additions tested. The specimens contained fixed quantities of cement, rubber and water and different

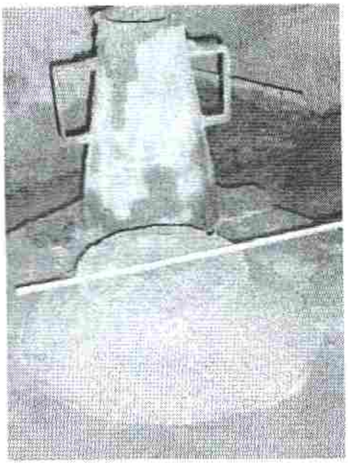

Figure 15.2
Behaviour of fresh rubber concrete Mix A

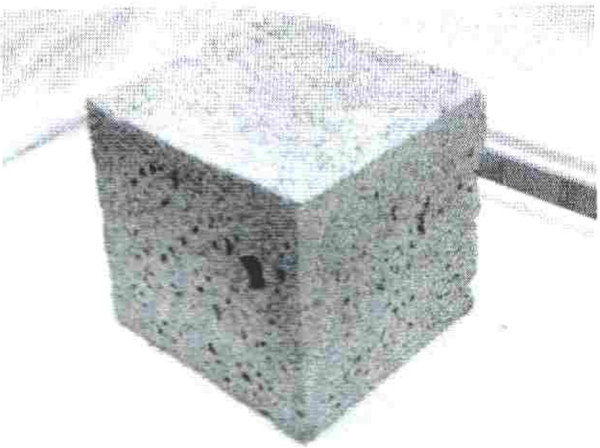

Figure 15.3
Rubber Concrete Specimen

calcium chloride dosages. The Vicat apparatus was used to evaluate the influence of the presence of calcium chloride in the mix. According to the results obtained the addition of calcium chloride was effective. It was considered that the adequate addition would be 4% because it provided sufficient acceleration of the hydration process.

Table 15.4
Percentages of calcium chloride addition tested

Calcium chloride content	Initial setting time [min.]	Final setting time [min.]
0%	194	240
4%	105	210
7%	69	118

15.3. EXPERIMENTAL RESULTS

Table 15.5 presents the main results obtained from the experimental tests. Figures 15.4 and 15.5 show the mechanical test results obtained.

Each value presented in Table 15.5 is the average of results from three specimens. In this table f_{cm} is the average compressive strength, $f_{ctm,fl}$ is the average flexure tensile strength and γ_m is the average specific mass.

The compressive strength was measured at 3, 7 and 28 days of age. The flexural strength was measured only in Mixes B, C and D and at 28 days. Flexural strength was evaluated by three-point bending tests according to EN 196-1 [5]. The specific mass was obtained by measuring all the specimens mass before the mechanical testing.

Table 15.5
Experimental results

Mix	γ_m **[kg/m³]**	f_{cm} **[MPa]**			$f_{ctm,fl}$ **[MPa]**
		3 days	**7 days**	**28 days**	**28 days**
A	877	0.213	0.230	0.203	-
B	1177	0.250	0.445	0.445	0.481
C	1057	0.174	0.286	0.498	0.452
D	1045	0.176	0.271	0.563	0.413
E	1108	0.303	0.442	0.562	-
F	1244	0.456	0.660	0.877	-
G	1330	0.565	0.871	1.084	-

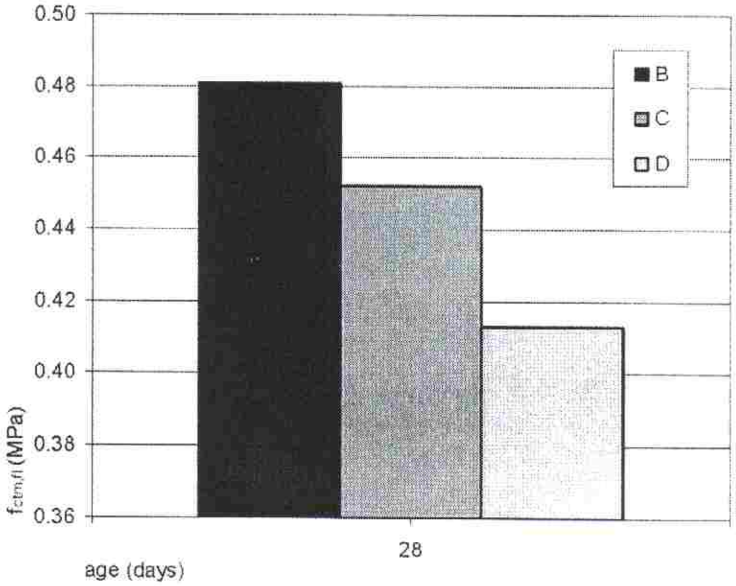

Figure 15.4
Flexural strength of Mix B, C and D

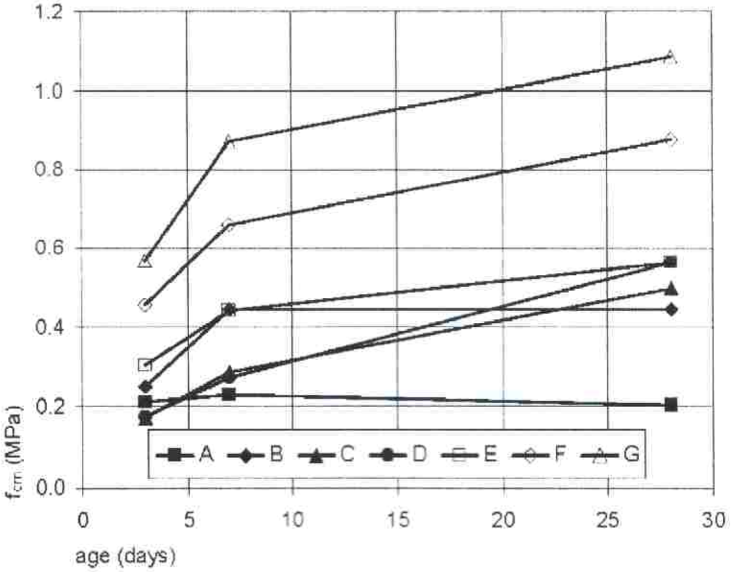

Figure 15.5
Compressive strength gain of different mixes with curing time

15.4. DISCUSSION

The results obtained from the mixes tested indicate that lightweight concrete can be produced using rubber particles as aggregate. The unit mass of the specimens varies between 876 kg/m^3 and 1330 kg/m^3. According to the mixes tested, as expected, the specific mass of the specimens increased as the cement content increased. Furthermore, the workability was quite good, clearly allowing this concrete to be placed using a pumping device.

However, the mechanical test results were not as high as expected. The specimens demonstrated a low flexural strength and a low compressive strength.

It is noted that all the studied mixes show low compressive strength. From all the compositions tested, only one reached the minimum compressive strength required. But, this composition (Mixture G) was made with a high cement content of 600 kg/m^3, which is economically not viable. With 500 kg/m^3 cement content (Mixture F) the compressive strength riches 0.9 MPa. The other concrete compositions show significantly lower compressive strengths, varying from 0.2 to 0.6 MPa.

By observing fractured specimens it was possible to verify that the rubber particles were pulled out from the cement matrix. This was taken as evidence of weak interfacial bonding between the rubber and matrix indicating the need for means of enhancing the interface bond.

15.5. CONCLUSIONS

Results from this research work indicate the following main conclusions:

- The workability of the lightweight rubber concrete is good, suggesting the possibility of a quick and easy application in the construction site.

- The behaviour of the specimens in compression is not encouraging. Results varied between 0.2 to 1.0 MPa.
- Results of the flexural test are somehow lower than expected. The highest value achieved was about 0.5 MPa.

The use of as received rubber particles obtained from recycled used tyres as aggregate for concrete in order to create a lightweight concrete is possible if low compressive strengths are expected. Increasing the cement quantity improved the compressive strength, however, the optimum amount remains to be established for an economically and environmentally viable solution for a given application.

Results obtained indicate that the adhesion developed in the rubber aggregate-cement paste interface is weak and needs further research to determine the best way of enhancing the interfacial bond. Observation of the fracture surface of the specimens tested indicated that the rubber particles could be pulled out from the cement paste matrix. The research work is on course for amelioration of the interface bonding of rubber particles and cement paste.

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