Research of the Use of Waste Rigid Polyurethane Foam in the Segment of Lightweight Concretes

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Abstract

The question of the reduction of waste production and the method of safe, environmentally acceptable and economically profitable use or disposal of waste has currently been a very widely discussed global issue from the point of view of the environment. According to data from the statistics of the largest companies in the world and the only global non-governmental organization dealing with the management of secondary raw materials, the Bureau of International Recycling based in Brussels, it is clear that the industry of secondary raw materials uses 700-800 million tons of secondary raw materials a year, which is more than 40% of all the materials used in industry. This article addresses the issue of the use of waste rigid polyurethane foam after the end of its life cycle with a density of 30 to 40 kg.m-3 as a new filler in the segment of lightweight concretes.

The introduction part of this article informs about the current state of the use of secondary raw materials, and it is focused on the incorporation of waste products in the building industry. It presents the results of research and development concerning the use of plastic, rubber and metallurgical waste materials in building industry and a general treatment of these waste materials for their further use. The article describes the individual materials used to prepare the experimental concrete mixtures and the methods used during the research. The experimental part evaluates the particle-size analysis of the input crushed polyurethane foam and selects a suitable type for subsequent incorporation into the concrete mixture. It is a new type of filler, which replaces the natural filler in the amount of 100%. It also presents the individual designed experimental formulas of concrete mixtures based on polyurethane and the test results of their physical and mechanical properties. The tests performed on the experimental mixtures included slump, density of fresh concrete mixture and compressive strength tests. The test results have shown that crushed rigid polyurethane foam can be used as the filler in lightweight concretes, and this new type of lightweight concretes can be produced with different densities, depending on the different ratios of the added components. The conclusion of this article confirms the possibility of using rigid polyurethane foam in building industry as a secondary raw material, representing a possible solution of the disposal of these waste materials.

Keywords: polyurethane foam, waste, use, lightweight concrete, research

Introduction

A wide range of utilizations of polymeric and other wastes can be found directly in building production; particularly the countries of Western Europe and the USA preferentially monitor the processing of wastes in the constructions of roads, dams, high buildings, as well as ground work and foundation engineering. Thanks to these facts, the use of waste as a secondary raw material is a popular subject of research teams from different research institutions. The frequent application of plastic wastes in building industry in the world includes various types of concretes, whether it is conventional concrete, concrete with increased thermal insulation effect, or lightweight concretes. For example, crushed PET bottles are used as filler in concrete mixtures for the production of structures resistant to earthquakes (Akcaozoglu et al. 2010). There are also researches focused on the use of thermoplastic waste materials that are very difficult to decompose using thermo-chemical methods and are therefore recycled mechanically and subsequently used as filler in lightweight concrete (Panyakapo at al. 2008). Other directions of the researches dealing with the applications of plastics and elastomers in building industry include the use of a mixture of crushed PET bottles with crushed tires as filler in concretes with increased thermal insulation effect (Yesilata et al. 2009), or even crushed PET plastics as an additive to asphalt (Ahmadinia et al. 2011).

The use of metallurgical waste is another strong topic dealing with the use of waste as a secondary raw material in building production. There are researches dealing with the use of fly ash in the production of geopolymers (Svarla et al. 2011), or as a partial substitute of cement in the production of concretes (Ondová et al. 2011; Junák et al. 2009). Other studies focus on the use of waste based textile materials obtained from recycled used tires in the production of composite materials (Knapcikova et al. 2012). There are researches focused on the possibilities of the processing of these metallurgical waste materials for further use (Jursova 2010),(Pustejovska, Jursova 2013)

Materials and methods

Concrete mixture components

Polyurethane Foam

It is rigid or semi-rigid macromolecular foam with a high share of closed cells. In its raw state, it is a system of two liquid components, whose mixing under certain conditions creates non-absorbing, water and thermal insulating material having shape and dimensional stability, resistant to aggressive environment. The basic raw materials of modern polyurethanes are polyhydric alcohols (polyols), isocyanates.

Cement

The main binding component used in experimental mixtures on the basis of PUR waste materials was CEM I 42,5R and CEM II/S-V 32,5 R (Cement Hranice, a. s., properties according to ČSN EN 197-1).

Finely Ground Lime Stone

Finely Ground Lime Stone served as an additive to reduce the water-cement ratio w and to reduce the costs (according to ČSN EN 206-1). Specification VMV 15/V (kotouč Štramberk, parameters according to ČSN 72 1217 and ČSN 72 1220).

Mixture Water

Drinking water was used as the mixture water in all experimental mixtures.

Particle-size analysis

Samples of crushed, rigid polyurethane foam with the density of 30 – 35 kg.m^{-3} from the following companies were acquired for the experimental research, Unikasset, spol. s. r. o.,ING. ČASTULÍK, s. r. o., Profing Piešťany spol. s. r. o., materials and firm, D&Daxner Technology s. r. o.. The screen analyses were performed using laboratory sieving machine with standardized screens according to ČSN EN 933-1.

The particle-size analysis used the following screens: 0,063, 0,125, 0,25, 0,5, 1, 2, 4, 5,6, 8, 10, 11,2 and 16 mm. At the same time, the average grain size with 10, 30 and 60% of siftings using square sieves, the uneven grain size number Cu according to formula (1) and the curvature number Cc according to formula (2) have been determined for all samples of crushed polyurethane foam.

$$C_u = \frac{d_{60}}{d_{10}} \quad (1)$$

C_u – uneven grain size number; d_{60} – grain diameter corresponding to 60% of siftings [mm]; d_{10} – grain diameter corresponding to 10% of siftings [mm].

$$C_c = \frac{(d_{30})^2}{(d_{60} \cdot d_{10})} \quad (2)$$

C_c – curvature number; d_{10} – grain diameter corresponding to 10% of siftings [mm]; d_{30} – grain diameter corresponding to 30% of siftings [mm]; d_{60} – grain diameter corresponding to 60% of siftings [mm].

Tab. 1. The results of the determination of sifting values

Tab. 1. Skład ziarnowy pianki

Sample marking	Siftings 10%	Siftings 30%	Siftings 60%	Uneven grain size number C_u	Curvature number C_c
	Grain diameter [mm]				
Unikasset	10,7	10,9	11,1	1,04	1
Častulík comb.	4,3	6,7	8,0	1,86	1,3
Častulík	5,8	10,2	10,4	1,79	1,72
Profing	0,7	2,4	5,0	7,14	1,65
968 - B6	3,4	4,5	5,0	1,47	1,19
968 - B40/5	1,1	1,9	2,8	2,55	1,17
968 - B81	3,3	4,7	5,7	1,73	1,17

Tab. 2. Composition of experimental mixtures

Tab. 2. Skład badanej mieszaniny

Marking	Measuring unit	PUR	Cement		Lime stone VMV 15/V	Water
			CEM I 42,5R	CEM II/S-V 32,5 R		
M1	kg per 1 m^3	40	-	544	-	350
M2	kg per 1 m^3	40	-	392	-	259
M3	kg per 1 m^3	40	-	260	68	221
M4	kg per 1 m^3	40	-	260	132	259
M5	kg per 1 m^3	40	260	-	132	259

Preparation of experimental mixtures

Crushed polyurethane foam with the grain size of 4/8 mm was used as filler during the preparation of the experimental mixtures in order to produce lightweight concrete. 5 experimental mixtures of lightweight concrete based on polyurethane foam were prepared. We were looking for the optimal ratio between the amount of the individual components and the physical-mechanical properties of the test specimens.

Testing of experimental formulas

The experimental mixtures were subjected to tests of physical and mechanical properties. Testing fresh concrete – Part 2: Slump-test (according to ČSN EN 12350-2.), testing fresh concrete – Part 6: Density (according to ČSN EN 12350-6), testing hardened concrete – Part 3: Compressive strength of test specimens (according to ČSN EN 12390-3).

Results and discussion

Particle-size analysis

The condition of the grain size of 4/8 mm of polyurethane foam, which had been specified before the experimental research, was met by samples Častulík comb. (4/8 mm), DDT 968 – B6 a, DDT 968 – B81. (see figure 1).The following samples were selected for experimental research DDT 968 – B6 a, DDT 968 – B81, in order to ensure a sufficient quantity for the entire experimental research (total of app. 3300 l of crushed polyurethane foam). The results of the determination of the sifting values, uneven grain size number, and curvature number for the individual samples are presented in Table 1.

According to the uneven grain size number values Cu, it was found that all the samples of crushed PUR foam, except for Profing sample, can be defined as even-grained, since the uneven grain size number values were ranging below 5. Only Profing sample was defined as a material with medium uneven grain size due to the uneven grain size number of Cu = 7.14. According to the results of the determination of the curvature number values of the grain size curve Cc, which ranged between 1–1.72, the samples of crushed polyurethane foam can be characterized as having "good grain size".

Concept and preparation of experimental mixtures

Five experimental formulas (table 2) have been prepared within the scope of the experimental research, where PUR pulp with the fraction of 4/8 mm and a density of 35 kg.m^{-3} was used as the filler. The purpose of the preparation of these formulas was to find an optimal ratio among the amounts of the individual components and the physical and mechanical properties of the test specimens.

Testing of experimental formulas

Testing fresh concrete – Part 2: Slump-test (according to ČSN EN 12350-2).

Workability is a very important property of fresh concrete, which is the ability to be easily transported, stored and compacted in concrete forms. The results of this test are shown in Table 3 and they are graphically illustrated in Figure 2.

Testing fresh concrete – Part 6: Density (according to ČSN EN 12350-6).

The results of this test are presented in tabular form in Table 4 and graphically in Figure 3. The density of fresh concrete mixture varied from 1040 to 1100 kg.m^{-3}.

Testing hardened concrete – Part 3: Compressive strength of test specimens (according to ČSN EN 12390-3).

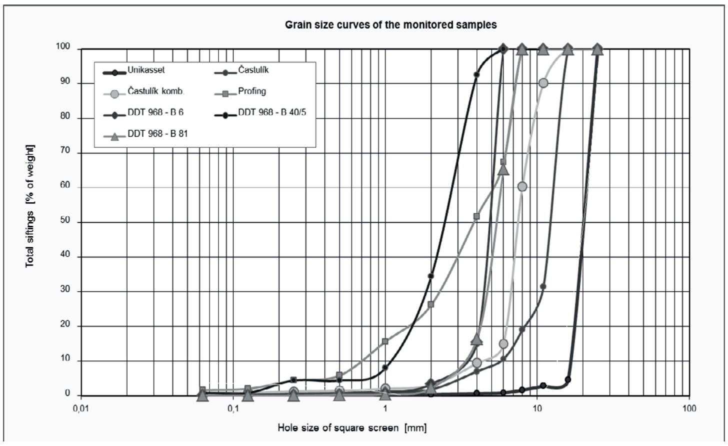

Fig. 1. Graphic expression of curves illustrating sample grain fineness

Rys. 1. Ilustracja graficzna stopnia rozdrobnienia próbek

Tab. 3. Slump test results

Tab. 3. Wyniki rozdrabniania

Marking	Slump test [mm]	Class	Mixture consistence
M1	210	S4	Semi-liquid
M2	130	S3	Very soft
M3	70	S2	Soft
M4	100	S3	Very soft
M5	120	S3	Very soft

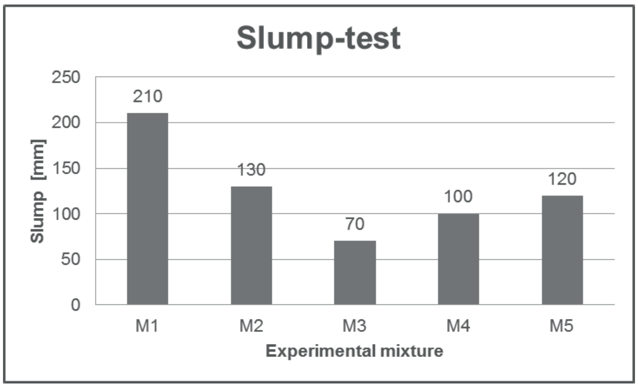

Fig. 2. Slump test values of experimental mixtures

Rys. 2. Wyniki rozdrabniania mieszanki doświadczalnej

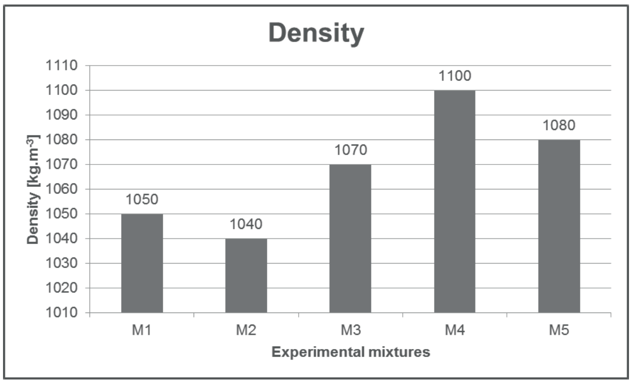

Fig. 3. The values of density of fresh concrete mixture of experimental mixtures

Rys. 3. Gęstość mieszaniny świeżego betonu z betonem

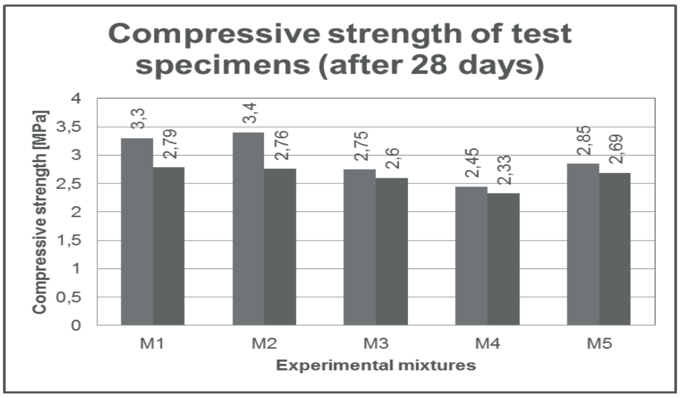

Fig. 4. Graph of the values compressive strength of test specimens

Rys. 4. Wyniki badania wytrzymałości na ściskanie

Tab. 4. The test results of density of fresh concrete mixture of experimental mixtures

Tab. 4. Wyniki badania gęstości mieszaniny świeżego betonu z mieszanką doświadczalną

Mixture	1st form			2nd form			3rd form			Density
	m_1	m_2	D_m	m_1	m_2	D_m	m_1	m_2	D_m	
	[kg]	[kg]	[$kg.m^{-3}$]	[kg]	[kg]	[$kg.m^{-3}$]	[kg]	[kg]	[$kg.m^{-3}$]	[$kg.m^{-3}$]
M1	0,974	4,503	1046	0,981	4,491	1040	0,992	4,540	1051	**1050**
M2	0,990	4,439	1022	0,988	4,435	1021	0,981	4,419	1019	**1040**
M3	1,000	4,596	1065	0,992	4,611	1072	0,991	4,612	1073	**1070**
M4	1,002	4,112	921	0,975	4,126	934	0,980	4,088	921	**1100**
M5	1,005	4,625	1073	0,993	4,633	1079	1,007	4,647	1079	**1080**

Tab. 5. Test results of compressive strength after 28 days

Tab. 5. Wyniki testów wytrzymałości po 28 dniach

Compressive strength of concrete after 28 days		
Mixture marking	**Cube**	**Prism**
	[MPa]	
M1	2,79	3,30
M2	2,76	3,40
M3	2,60	2,75
M4	2,33	2,45
M5	2,69	2,85

The test results are presented in tabular form (Table 5) and graphically (Figure 4). Cube compressive strength of the individual test specimens ranged from 2.33 to 2.79 MPa, and prism strength ranged from 2.45 to 3.40 MPa.

Conclusion

The individual physical and mechanical tests of the prepared experimental mixtures M1 – M5 have revealed that experimental mixture M3 showed the most optimal values in terms of its future use. Mixture M3 was defined as soft (class S2), i.e. with good workability and fresh concrete density of 1070 $kg.m^{-3}$ and the final compressive strength from 2.60 to 2.75 MPa. Lightweight concrete could be used in monolithic structures, or as filling material, e.g. in horizontal roof structures, in floors or ceiling structures. The experimental research has shown that crushed rigid polyurethane foam with a grain size of 4/8 mm and density of 30–35 $kg.m^{-3}$ can be used as filler in lightweight concretes. A new type of lightweight concretes can be produced and processed with different densities, assuming low final compressive strengths.

Since this type of polyurethane wastes is currently kept in landfills or incinerated, it is apparent that the use of these waste materials as new filler in the segment of lightweight concrete is one of the possible solutions

Acknowledgements

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Badania nad użyciem odpadów ze sztywnej pianki poliuretanowej przy produkcji betonu lekkiego

Zagadnienia obniżenia ilości produkowanych odpadów i metod bezpiecznego, niegroźnego dla środowiska oraz opłacalnego użycia, jak również pozbywania się odpadów, są omawiane na przykładzie rozwiązań światowych. Wg danych ze statystyk największych światowych firm oraz jedynej pozarządowej organizacji zajmującej się zarządzaniem materiałami wtórnymi, Międzynarodowego Biura Recyklingu (ang. The Bureau of International Recycling) z siedzibą w Brukseli, jasno wynika, że przemysł materiałów wtórnych zużywa 700–800 milionów ton tych materiałów rocznie, co stanowi ponad 40% wszystkich materiałów używanych w przemyśle. W artykule przedstawiono kierunki wykorzystania odpadów ze sztywnej pianki poliuretanowej, szczególną uwagę poświęcono odpadom pianki o gęstości od 30 to 40 kg/m3 i ich zastosowaniu jako wypełniacza w przemyśle betonów lekkich.
Na wstępie artykułu zawarte są informacje na temat obecnego stanu wykorzystania materiałów wtórnych oraz zamiaru wprowadzenia produktów z odpadów do przemysłu budowlanego. Pokazano wyniki badań oraz rozwój metod wykorzystania plastiku, gumy oraz odpadów metalurgicznych z przemysłu budowlanego oraz ogólne procesy, którym są poddawane odpady w celu dalszego wykorzystania. W artykule opisano wybrane materiały do przygotowania próbnych mieszanek betonowych i metod zastosowanych w trakcie badań. W części badawczej przeprowadzono analizę wielkości cząsteczek w użytej skruszonej poliuretanowej oraz dokonano wyboru najodpowiedniejszego typu do dalszej aplikacji do mieszanki betonowej. Jest to nowy rodzaj wypełniacza, który w 100% zastępuje wypełniacz naturalny. W artykule pokazano również opracowaną metodyke badań nad mieszankami betonowymi o podłożu poliuretanowym oraz wyniki testów właściwości fizycznych i mechanicznych. Testy przeprowadzone na badanej mieszance uwzględniły metodę opadania stożka, gęstość świeżej mieszanki betonowej oraz test siły kompresji. Wyniki testów pokazały, że skruszona pianka poliuretanowa może być użyta jako wypełniacz do betonów lekkich, oraz że może on być produkowany w różnych gęstościach, w zależności od proporcji użytych składników. We wnioskach potwierdzono możliwość wykorzystania sztywnej pianki poliuretanowej w przemyśle budowlanym jako materiału wtórnego, co jednocześnie jest metoda utylizacji tych odpadów.

Słowa kluczowe: pianka poliuretanowa, odpady, wykorzystanie ponowne , beton lekki