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THE POSSIBILITY OF USING WASTE MATERIALS IN BUILDING MATERIALS

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ABSTRACT: In recent years, great emphasis has been placed on the implementation of the principles of sustainable construction and environmental protection. Decreasing amount of natural resources and increasing amount of industrial waste have made it necessary to produce products with the use of recycled materials. A number of studies conducted allow us to state that artificial aggregates, industrial ashes and waste from the wood industry are widely used in the production of construction products. The aim of the article is to show that the use of waste materials will allow to reduce the weight and absorbability of concrete chips by using artificial aggregate type Certification and improve the thermal insulation of products through the use of sawdust and wood chips. A 2 factorial experience with a rotational experimental plan was planned. The article presents the results of physical and mechanical properties tests and statistical interpretation of the obtained results.

KEY WORDS: urban ecosystem waste raw materials, ash aggregate, concrete chipboard, lightweight concrete

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Introduction

The demands placed on today's construction products are increasingly stringent. In addition to their high strength properties, they must also have good thermal and acoustic insulation properties and be environmentally friendly. Integration with ecology is not only focused on the lack of negative impact on the environment, but also on the use of waste for their production, which causes slow degradation of the environment. In order to meet these requirements, numerous studies are carried out to modify the composition of light concrete by adding appropriate amounts of waste materials and thus not impairing its physical and mechanical properties.

A series of tests carried out on lightweight concrete with modified composition allowed us to conclude that they meet the requirements for modern concrete (Chandra, 2013). In addition to the testing of strength properties, the focus has also been on thermal insulation, which is becoming more and more important today and the requirements of the government are becoming more and more stringent. The results showed that waste concrete has good thermal insulation properties (Kim, 2003; Demirboğa, 2007; Benazzouk, 2008; Alengaram, 2013; Yong, 2014; Oktay, 2015; Zhu, 2015; Liu, 2014; Mo, 2017). The selection of an appropriate amount of waste aggregate as well as the type and quality of this aggregate had an impact on the good results of the research. Various waste aggregates were used, such as waste aggregate from coconut oil production (Alengaram, 2013), pumice stone, expanded perlite or waste rubber aggregates (Oktay, 2015). In addition to artificial aggregates, additives such as sawdust, wood shavings, straw or reed are also used to produce modern concrete modified with waste materials.

This paper presents the results of chipboard concrete tests, in the production of which artificial aggregate of the Certyd type was used. The aim of the research was to reduce the weight and absorbability of chip-concrete by using artificial aggregate of the Certyd type.

Chipboard concrete production process based on secondary raw materials

The development of construction and, consequently, concrete consumption, has made it necessary to improve their formulas in order to be able to use substitute raw materials. Therefore, the properties of alternative aggregates are increasingly being investigated.

A number of studies focus not only on the properties of the aggregate itself, but also on the product produced with it. Recently, recycling aggregates have become more and more recognizable as a type of aggregate of the Certification type. It is an artificial raw material, an ash-ash produced in accordance with the new technology consisting in sintering the ashes produced during the combustion of hard coal. This process allows to obtain light, porous ceramic aggregate with high thermal insulation and high resistance to atmospheric and chemical factors, fungi, insects and rodents. It is an odourless, highly resistant and relatively low absorbability material (Bardan, 2016). Due to its properties, it is used in construction, road construction, geotechnics and gardening. For a long time it has been used in the production of concrete, allowing to obtain a product with reduced weight and much better strength parameters. Artificial aggregate type Certification of fractions 0-4 mm, 4-8 mm and 8-16 mm was used for testing.

Sawdust with 0-2 mm fraction and wood chips with 2-10 mm and 10-20 mm fractions obtained from a sawmill were also used in the production of concrete chipboard. Before adding organic filler to concrete mix, it must be properly prepared by mineralization, which increases the adhesion of the given chips to the cement slurry and enables proper bonding of the mix and hardening of concrete. The mineralization process also prevents the rotting of chips in the finished concrete chipboard product, ensures its proper durability and reduces shrinkage. Aluminum sulphate $Al_2(SO_4)_3$ and calcium hydroxide $Ca(OH)_2$ were used in this study. The amount of the mineralizer was dictated by the experimental plan adopted at the beginning, in which its amount was included as a variable value, maintaining the ratio between $Al_2(SO_4)_3$ and $Ca(OH)_2$, which was 2:1.

The composition of the chip-concrete mixture was determined on the basis of a two-factor plan for rotationalgom, which was considered optimal due to the following criteria:

- the feasibility criterion – the possibility of implementing the plan,
- information technology criterion – possibility of obtaining data necessary to achieve the objective research,
- efficiency criterion – possibility to perform an experiment at minimum cost for implementation,
- X – fine aggregate fraction content 0-2 mm,
- Y – the aggregate content of the coarse fraction 4-8 mm and 8-16 mm.
  Constant values:
- cement content – const.
- water content – const.

Table 1 presents the experimental plan for the production of a particle concrete product with the use of an artificial aggregate of the Certyd type. Quantity of organic aggregate and artificial aggregates were adjusted proportionally to the amount of cement and water in the crop. It was assumed that organic aggregate will completely replace natural aggregate in the concrete mix. Then, according to the experimental plan, a percentage of organic aggregate was replaced with artificial aggregate of the type Certyd.

Table 1. Experimental plan

Series No.	Coded values		Actual values	
	X	Y	X – fine aggregate	Y – bulky aggregate
1	-1	-1	29.28	29.28
2	+1	+1	70.72	70.72
3	-1.414	0	0	50
4	+1.414	0	100	50
5	0	-1.414	50	0
6	0	+1.414	50	100
7	0	0	50	50
8	-1	+1	29.28	70.72
9	+1	-1	70.72	29.28
10	Control sample			

Source: author's own work.

The quantity of components per 1 m^3 was calculated based on the quantity of components per series. It was assumed that 10 samples were made for each series. Earnings water was divided into three parts. Two of them were used for mineralization and the third one for addition in the last phase of mixing. The preparation of the chip-concrete mixture consisted in weighing the organic aggregate according to the recipe and placing it in a mixer, where it was stirred dry for one minute and then subjected to the mineralization process, which was carried out in two stages. After initial mixing of dry components consisting of sawdust and chips of two fractions, an aqueous solution of aluminium sulphate at a concentration consistent with the experimental plan was added. The mixing of the filler with the mineralizing agent lasted about three minutes, followed by a 15-minute break. After that time, a calcium hydroxide solution was added to the mineralized organic aggregate in the amount of twice the mass of aluminium sulphate and all the components in the mixer were mixed for three minutes. The order of dosing the components resulted from the need to saturate the organic aggregate with the mineralizing agent and then neutralize the acidic reaction formed by the action of aluminium sulphate. After a 15-minute break, following the second stage of mineralization, cement and Certyd type aggregate were added to the mixer. All the ingredients were mixed thoroughly for the next three minutes, obtaining a ready-made mixture of chip-concrete with the addition of Certyd type aggregate, ready to be formed.

Steel moulds of dimensions 10x10x10x10 cm complying with the PN-EN 12390-1 standard were used for moulding. The walls of the moulds had previously been covered with a release agent in order to protect them against the adhesion of the chip-concrete mixture. Due to the type of materials used, it was decided to manually compact the moulds in two layers using a 1.8 kg compactor. For each layer 16 impacts of the compactor from a height of about 10 cm were accepted. The samples were stripped after 24 hours and placed on special wooden grids in air-dry conditions for 28 days. After this period they were subjected to the following tests: compressive strength, absorbability and bulk density.

Testing of chip-concrete samples using waste materials and their statistical analysis

Analysis of compression strength

The compression strength test was carried out on 46 specimens. For each series the mean compression strength was determined and the standard deviation was calculated, variance

and coefficient of variation. The results of the analysis are presented in table 2.

The average compression strength ranged from 3.47 MPa to 11.04 MPa. The standard deviation for each series was from 0.21 to 0.81. Among all the samples, the lowest level of differentiation was observed for the samples from series 4 containing the aggregate Certification of fractions 0-2 mm in the amount of 84.62 kg/m^3, fractions 4-8 mm in the amount of 22.02 kg/m^3, fractions 8-16 mm in the amount of 22.68 kg/m^3, fractions 8-16 mm in the amount of 22.68 kg/m^3, fractions 2-10 mm in the amount of 22.02 kg/m^3 and fractions 10-20 mm in the amount of 22.68 kg/m^3. This means that the 4-series samples are the best with the least different compression strength results. In the 5 series, the results are the most varied.

Table 2. Results of statistical analysis of compressive strength of cement composites based on artificial aggregate type Certification and organic aggregate

Series No.	Average compression strength [MPa]	Standard deviation S_x	Variation S_x^2	Coefficient of variation V_x [%]
I	5.82	0.26	0.02	4.41
II	7.65	0.33	9.08	4.27
III	6.02	0.21	0.06	3.50
IV	7.73	0.16	16.60	2.01
V	3.47	0.72	29.87	20.86
VI	8.60	0.41	36.07	8.16
VII	5.04	0.81	3.77	15.97
VIII	11.04	0.46	-	4.19
IX	3.90	0.65	20.12	16.58
X	5.97	0.60	0.02	10.11

Source: author's own work.

Using linear regression to estimate the effect of X and Y variables on the compression strength of particle concrete specimens after 28 days of maturation, the regression model proved significant (F = 27.587) and explained about 78% of the dependent variable (R^2 = 0.7751). The results of linear regression analysis are presented in table 3.

Table 3 Linear regression analysis of compressive strength testing of cement composites based on organic and artificial aggregate

N=46	Regression analysis of the dependent variable: Compressive strength R= 0.88045373 R^2= 0.77519878 Amendment R2= 0.74709863 F(5,40)=27.587 p					
	b*	Stand. error z b*	b	Stand. error z b	t(40)	p
Free word			5.50683	0.37001	14.8826	0.00000
X	-0.10239	0.07543	-0.26638	0.19624	-1.3573	0.18226
Y	0.81581	0.07543	2.12239	0.19624	10.8148	0.00000
XX	0.27823	0.08355	0.82349	0.24728	3.33020	0.00187
YY	0.13578	0.08355	0.40186	0.24728	1.62514	0.11198
XY	-0.11725	0.07520	-0.46257	0.29667	-1.55921	0.12682

Source: author's own work.

The form of the regression equation and the graphical interpretation of the changes in compression strength, depending on the adopted variables X and Y are shown in figure 1.

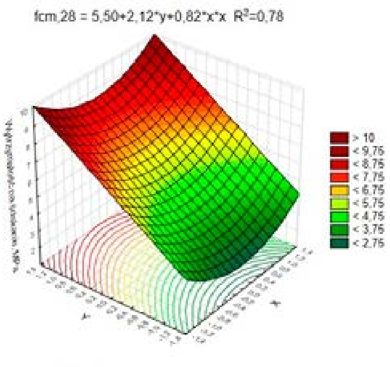

Figure 1. Graphical interpretation of changes in compression strength, depending on the adopted X and Y variables

Two of the predictive factors taken into account in the model had a significant influence on the results of compression strength after 28 days of cement composite maturation: the content of the fraction certificate 0-4 mm (X), 4-8 mm and 8-16 mm (Y). As can be seen from the regression equation, predictor X affects the result by being in a square. Analyzing the above graph one can see a dependence that the increase in the number of fractions 4-8 mm and 8-16 mm Certification causes also an increase in compression strength. When using the maximum content of X and Y factors, the strength increases by more than 60% compared to the strength of cement composite with organic filler only. A 60% increase in strength is also observed when organic filler is replaced by only Y factor in 100%, while X factor is omitted.

Absorbability analysis

The weight gain of samples in the absorption test depends on two variables: X – content of the fine fraction certificate 0-4mm and Y – content of the thick fraction certificate 4-8 and 8-16mm. The combination of variables and average absorbability results was tested on 34 samples and the results of the analysis are presented in table 4.

The average absorbability of the samples ranged from 24.74% to 38.27%. The standard deviation for particular series ranged from 0.33 to 2.87. Among all the samples the lowest level of differentiation was observed for the samples from series 8 containing aggregate Certification of fraction 0-2 mm in the amount of 24.78 kg/m^3, fraction 4-8 mm in the amount of 31.14 kg/m^3, fraction 8-16 mm in the amount of 32.08 kg/m^3 and fraction sawdust 0-2 mm in the amount of 59.84 kg/m^3, fraction chips 2-10 mm in the amount of 12.89 kg/m^3 and fraction chips 10-20 mm in the amount of 13.28 kg/m^3. This means that the 8-series samples are the best with the least variation in absorbability. In series 1, the results are the most varied.

Table 4. Results of statistical analysis of water absorption tests of cement composites based on artificial aggregate type Certification and organic aggregate

Series No.	Absorbency average [%]	Standard deviation S_x	Variation S_x^2	Coefficient of variation V_x [%]
I	24.74	2.87	79.62	11.62
II	25.09	0.70	69.07	2.80
III	27.43	1.28	24.20	4.67
IV	28.40	1.86	8.84	6.54
V	38.27	1.83	81.22	4.78
VI	27.46	1.34	17.67	4.88
VII	35.26	1.99	86.71	5.63
VIII	24.93	0.33	73.75	1.33
IX	33.70	2.22	58.16	6.57
X	29.23	1.30	1.32	4.45

Source: author's own work.

Table 5. Analysis of linear regression in the study of absorbability of cement composites based on organic and artificial aggregate

N=46	Regression analysis of the dependent variable: Absorbability R = 0.80763105 R^2 = 0.65226791 Amendment R2 = 0.59017290 F(5,28) = 10.504 p					
	b*	Stand. error z b*	b	Stand. error z b	t(40)	p
Free word			32.2461	1.28849	25.0262	0.00000
X	0.21319	0.11164	1.1218	0.58749	1.9096	0.06647
Y	-0.55859	0.11201	-3.0545	0.61254	-4.9866	0.00002
XX	-0.45910	0.12902	-2.8892	0.81198	-3.5582	0.00135
YY	-0.06839	0.12934	-0.4380	0.82850	-0.5287	0.60114
XY	-0.26431	0.11173	-2.0785	0.87864	-2.3656	0.02515

Source: author's own work.

Using linear regression to estimate the effect of the X and Y variables on the water absorption test results of particle concrete samples after 28 days of maturation, the regression model proved to be significant (F = 10.504) and explained about 80% of the dependent variable (R^2 = 0.6523). The results of linear regression analysis are presented in table 5.

The form of the regression equation and the graphic interpretation of the changes in absorbability, depending on the adopted variables X and Y are shown in figure 2.

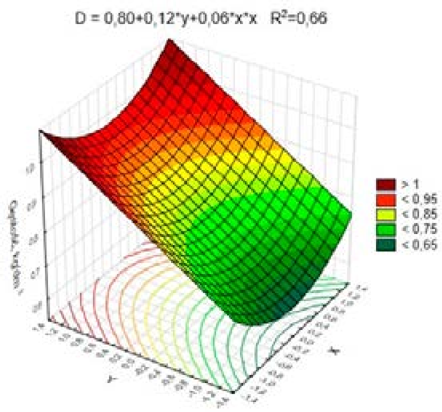

Figure 2. Graphical interpretation of water absorption changes, depending on the adopted variables X and Y

Analyzing the above graph it can be stated that two of the predictive factors influence the water absorption capacity of cement composite. As in previous cases, these predicators are the content of the fraction certificate 0-4 mm (X), 4-8 mm and 8-16 mm (Y). The absorbability decreases with the increase of the Certificate content, which is caused by a much lower absorbability of lightweight aggregate in comparison with organic filler. The highest decrease in absorbability of about 50% was recorded with the use of X and Y factors as a substitute for organic filler in the amount of 100% of its mass.

Volumetric density analysis

The volumetric density test was performed on 34 samples. For each of the series the mean volumetric density was determined and standard deviation, variance and coefficient of variation were calculated. The results of the analysis are presented in table 6.

Table 6. Results of statistical analysis of volumetric density of cement composites based on artificial aggregate type Certification and organic aggregate

Series No.	Average volumetric density result [kg/dm³]	Standard deviation S_x	Variation S_x^2	Coefficient of variation V_x [kg/dm³]
I	0.778	0.14	0.03	18.07
II	1.043	0.04	0.08	3.43
III	0.855	0.10	0.00	11.28
IV	0.971	0.15	0.03	15.14
V	0.727	0.03	0.10	3.74
VI	1.025	0.05	0.06	5.06
VII	0.766	0.03	0.04	3.44
VIII	1.053	0.01	0.09	0.90
IX	0.759	0.02	0.06	2.94
X	0.834	0.01	0.01	0.61

Source: author's own work.

The mean volumetric density of samples ranged from 0.727 kg/dm^3 to 1.053 kg/dm^3. The standard deviation for each series ranged from 0.01 to 0.15. Among all the samples the lowest level of differentiation was observed for the samples from the series 10 containing aggregate Certification of fraction 0-2 mm in the amount of 42.31 kg/m^3, fraction 4-8 mm in the amount of 22.02 kg/m^3, fraction 8-16 mm in the amount of 22.68 kg/m^3 and fraction sawdust 0-2 mm in the amount of 42.31 kg/m^3, fraction chips 2-10 mm in the amount of 22.02 kg/m^3 and fraction chips 10-20 mm in the amount of 22.68 kg/m3. This means that the 10-series samples are the best with the least variation in bulk density. In Series 1, the results are the most varied.

Using linear regression to estimate the effect of the X and Y variables on the bulk density of particle concrete samples after 28 days of maturation, the regression model proved to be significant (F = 11.025) and explained about 81% of the dependent variable (R^2 = 0.6632). The results of linear regression analysis are presented in table 7.

The form of the regression equation and the graphical interpretation of changes in bulk density, depending on the adopted variables X and Y are shown in figure 3.

Table 7. Linear regression analysis of volume density testing of cement composites based on organic and artificial aggregate

N=46	Regression analysis of the dependent variable: Volumetric density R= 0.81434985 R^2 = 0.66316568 Amendment R2 = 0.60301669 F(5,28) = 11.025 p					
	b*	Stand. error z b*	b	Stand. error z b	t(40)	p
Free word			0.79999	0.03742	21.3763	0.00000
X	0.12270	0.10987	0.01905	0.01706	1.1167	0.27359
Y	0.76174	0.11024	0.12292	0.01779	6.9093	0.00000
XX	0.31491	0.12699	0.05848	0.02358	2.4798	0.01942
YY	0.22160	0.12729	0.04189	0.02406	1.7408	0.09269
XY	0.02104	0.10996	0.00488	0.02552	0.1914	0.84958

Source: author's own work.

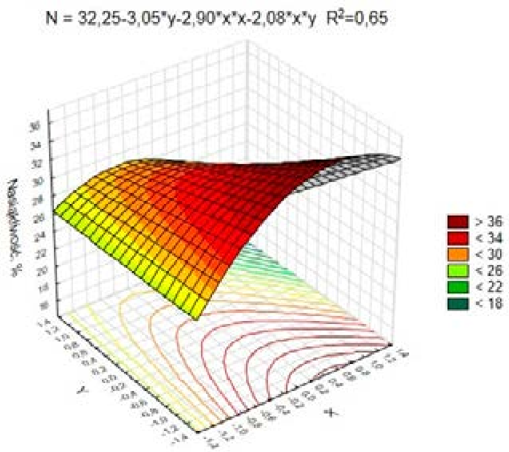

Figure 3. Graphical interpretation of changes in bulk density depending on the adopted variables X and Y

The density results after 28 days of composite maturation were affected by two predictive factors: the content of fraction certificate 0-4 mm (X) and 4-8 mm and 8-16 mm (Y). The highest density of the composite was observed at the maximum content of both 0-4 mm, 4-8 mm and 8-16 mm fractions. This is related to the higher density of the Certificate in comparison with organic aggregates. When organic filler is replaced with 100% fine fraction certificate 0-4 mm and thick fraction 4-16 mm, the density increases by about 20%. The same increase was achieved using only the 4-16mm fraction certificate.

Conclusions

A number of studies conducted allowed us to determine the recipe for obtaining lightweight concrete using waste materials with very good physical and mechanical parameters. The results of basic tests, such as compressive strength, absorbability and density, prove that the products obtained have good physical and mechanical parameters, and in some series – better results than standard lightweight concretes made on the basis of natural aggregates. The use of artificial aggregate made it possible to obtain ecological products with good strength parameters, which proves that the requirements for modern concrete have been met.

Acknowledgements

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Literature

Aamr-Daya E. et al. (2008), *Feasibility study of lightweight cement composite containing flax by-product particles: Physico-mechanical properties*, "Cement and Concrete Composites" Vol. 30, Issue 10, p. 957-963, DOI: 10.1016/j.cemconcomp.2008.06.002

Alengaram U.J. (2013), *Utilization of oil palm kernel shell as lightweight aggregate in concrete – A review*, "Construction and Building Materials" Vol. 38, p. 161-172, DOI: 10.1016/j.conbuildmat.2012.08.026

Bardan (2016), *Właściwości i zastosowanie CERTYDU – lekkiego kruszywa sztucznego*, "Kruszywa: produkcja – transport – zastosowanie" No. 1, p. 58-62

Bedi R., Chandra R., Singh S.P. (2013), *Mechanical properties of polymer concrete*, "Journal of Composites", ID 948745, 12 pages, DOI: 10.1155/2013/948745

Demirboğa R. (2007), *Thermal conductivity and compressive strength of concrete incorporation with mineral admixtures*, "Building and Environment" Vol. 42, Issue 7, p. 2467-2471, DOI: 10.1016/j.buildenv.2006.06.010

Du H., Du S., Liu X. (2014), *Durability performances of concrete with nano-silica*, "Construction and Building Materials" Vol. 73, p. 705-712, DOI: 10.1016/j.conbuildmat.2014.10.014

Guo Y. et al. (2014), *Compressive behaviour of concrete structures incorporating recycled concrete aggregates, rubber crumb and reinforced with steel fibre, subjected to elevated temperatures*, "Journal of Cleaner Production" Vol. 72, p. 193-203, DOI: 10.1016/j.jclepro.2014.02.036

Kabay N. (2015), *Properties of concrete with pumice powder and fly ash as cement replacement materials*, "Construction and Building Materials" Vol. 85, p. 1-8, DOI: 10.1016/j.conbuildmat.2015.03.026

Kim K.H. et al. (2003), *An experimental study on thermal conductivity of concrete*, “Cement and Concrete Research” Vol. 33, Issue 3, p. 363-371, DOI: 10.1016/S0008-8846(02)00965-1

Liu M.Y.J. et al. (2013), *Evaluation of thermal conductivity, mechanical and transport properties of lightweight aggregate foamed geopolymer concrete*, “Energy and Buildings” Vol. 72, p. 238-245, DOI: 10.1016/j.enbuild.2013.12.029

Łuczaj K., Urbańska P. (2015), *Certyd – nowe, lekkie, wysokowytrzymałe kruszywo spiekane*, “Materiały budowlane” No. 520, p. 42-45

Oktay H., Yumrutaş R., Akpolat A. (2015), *Mechanical and thermophysical properties of lightweight aggregate concretes*, “Construction and Building Materials” Vol. 96, p. 217-225, DOI: 10.1016/j.conbuildmat.2015.08.015

Olszak P. (2016), *Lekkie kruszywa CERTYD – unikatowym wyrobem budowlanym*, “Kruszywa: produkcja – transport – zastosowanie” No. 4, p. 38-42

Zeyad A.M. et al. (2017), *Pozzolanic reactivity of ultrafine palm oil fuel ash waste on strength and durability performances of high strength concrete*, “Journal of Cleaner Production” Vol. 144, p. 511-522, DOI: 10.1016/j.jclepro.2016.12.121

Zhu Q., Barney C.W., Erk K.A. (2015), *Effect of ionic crosslinking on the swelling and mechanical response of model superabsorbent polymer hydrogels for internally cured concrete*, “Materials and Structures” Vol. 48, Issue 7, p. 2261-2276, DOI: 10.1617/s11527-014-0308-5