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Procedia Engineering 150 (2016) 1468 – 1473
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2016

Effective Concrete Modified by Complex Additive Based on Waste Products of Construction Acrylic Paints

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Abstract

Improvement in quality of concrete compositions can be achieved both by using chemical additives, and using local components to create a new generation of concrete, which is a highly relevant objective for concrete technology. The industrial wastes produced by the enterprises of Volgograd region are complex mineral and organic compounds having various chemical and physical properties. Among additives of the organic nature the construction acrylic paints production waste is of scientific and practical interest.
It has been checked that it is possible to use an organic additive, a water-dispersible acrylic monomer (WDAM) – construction acrylic paints production waste as a modification, in the fine grain concrete, improving the basic properties of the construction composition. Studies have shown particular pattern of the modified concrete formation process, consisting of the water-repellent plasticizing effect of WDAM additives. The regularities of changes in the quality parameters of the concrete composition and the number of introduced additives are established. The relations of changing performance properties of effective concrete with modification WDAM have been confirmed by the results of experimental studies and developed regression model.
The study shows that the creation and use of new modifiers is one of the actual ways to further enhance the performance of building materials, as well as evidentiates the tendency to expand the list of chemical additives with complex effect with organic waste. It is evident that the utilization of waste products and more efficient use of material resources have a proven economic effect.

Peer-review under responsibility of the organizing committee of ICIE 2016

Keywords: effective fine grain concrete; a modifying polymer additive; a technogenic organic raw material; mathematical model; material saving.

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Peer-review under responsibility of the organizing committee of ICIE 2016
doi:10.1016/j.proeng.2016.07.083

1. Introduction

The basis of modern concrete technology is the creation of high-quality artificial stone, characterized by high dispersion, a small imperfection and structure stability. Improvement in quality of concrete compositions can be achieved both by use of chemical additives, and when using local components to create a new generation of concrete, which is a highly relevant objective of concrete technology. A new generation of concrete are high-tech, high-quality, multi-concrete mixtures and compositions with additives that preserve the required properties at a service in all operating conditions. Growing multicomponent concretes are due to significant systemic effects, what enables to manage the structure formation at all stages of the technology, ensuring receipt of composites of "directed" quality, composition, structure and properties [1-7].

A wide range of domestic and imported chemical additives makes it difficult to make a choice. Concrete manufacturers seek to improve its properties by modification, while reducing the consumption of cement, reduce energy costs in the production of reinforced concrete, and minimize the cost of additives under stable terms of their quality. It is quite a challenging task that can be solved using a variety of waste and coproducts of many industries as mineral and chemical modifiers of concrete [8-12].

2. Research objective

The industrial wastes produced by the enterprises of the Volgograd region are complex mineral and organic compounds having various chemical and physical properties. Most of them are experimentally tested at the department of building materials and special technologies of Volgograd State University of Architecture and Civil Engineering to reveal the possibility of using for construction of composite materials, as well as additives or components that improve the basic properties of building compositions [13-15].

Among additives of the organic nature the paint material (PM) production waste, water-dispersible PM in particular, is of scientific and practical interest. Feature of acrylic composition is that acrylic polymer emulsion as a binder is independently used in the manufacture polymer-cement solutions. Acrylic composition in general terms is a pigment, water, and an acrylic resin serving as a binder component.

Organic additive of water-dispersion of acrylic monomer (WDAM) is a paint material production waste that is physically in the first stage of skinning, in which the particles are drawn together to reversible contact. Thus, this fact enables authors to investigate the dispersed aqueous phase solution as the modifying additives of concretes [16,17].

3. Description of investigations

For experimental studies a series of samples were prepared in the laboratory of the department 'Building Materials and Special Technologies'. Tests were conducted in accordance with GOST 18105-2010 'Concretes. Rules for monitoring and evaluation of safety', GOST 10180-2012 'Concretes. Methods for the strength evaluation of control samples'. Water absorption was determined in accordance with GOST 12730.3-78 'Concretes. Methods for determination of water absorption'. When conducting research and tests modern physical and physicochemical analysis methods, mathematical methods of experimental design and computer processing were used.

The applicability of WDAM in concrete was determined by comparing the index of the modified concrete mixes quality and fine grain concrete of control composition. Fine grain concrete is chosen in view of its particular structure, due to a high degree of uniformity and fineness; a large percentage of the content of a cement stone; lack of hard stone skeleton; high values of porosity and surface area of the solid phase. WDAM efficiency as a water-repellent additive was determined by the reduction degree of water absorption of the concrete, as well as testing tools and auxiliary devices were used according to GOST 10180, GOST 10181.1 and GOST 12730.3.

Indicator of the additive efficacy was evaluated according to GOST 24211 - 2008. There were 5 series of samples prepared, the amount of additive injected varied from 0.3% to 3%, 0 series are control samples.

Primary analysis showed that the maximum increase in the density and compression (bending) strength of fine concrete samples modified WDAM, was about 10% and 25% - 30%, respectively. Reduced porosity and water absorption index was about 60% and 65%, respectively with dosing additives WDAM from 0.3 to 3% (table 1).

Table 1. Changes in the values of physical and mechanical properties of modified concrete on the amount of additives WDAM.

Indicator name	The amount of additive WDAM (% of cement weight)					
	0	0,3	0,5	1	2	3
Compressive strength, MPa	32,3	35,6	37,8	41,5	41,8	41,9
Bending strength, MPa	5,6	6,5	7,2	7,7	7,6	7,7
Density, kg/m^3	2267	2342	2417	2448	2445	2448
Porosity, %	16,2	12,7	11,3	10,7	10,5	10,4
Water absorption, %	8,3	5,5	4	3,8	3	3,7

When dosing WDAM from 1% to 3% there are slowing down changes in physical and mechanical properties, what indicates the irrational use of modifier dosage of more than 1% (table. 1). Preliminary studies have shown the possibility and feasibility of using modifying organic additives of paint production based on water dispersion of acrylic monomer (WDAM) in cement concrete technology.

The ability of chemical additives to cause several effects simultaneously is an advantage of their combined effect, along with the ability to enhance any effect on the principle of additivity. Combining types and quantitative proportions of the various additives enables to adjust the structure and thus the physical and mechanical properties of the cement stone and concrete or to replace the combination of various types of additives with one modifier complex action, such as, for example, WDAM.

WDAM influence on important physico-mechanical properties of the concrete in comparison with commonly used additives in the construction is shown in table 2.

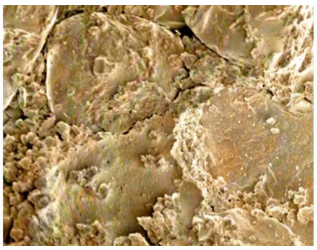
Table 2. Effect of type and quantity of a modifying additive on the physical and mechanical properties of fine grain concrete.

Indicator name	The type and amount of additive (% of cement weight)								
	WDAM			NGL			C-3		
	1	1,5	2	1	1,5	2	1	1,5	2
Compressive strength, MPa	33,3	40,8	41,7	33,5	40,5	41,5	33,4	40,4	41
Density, kg/m^3	2258	2444	2440	2255	2430	2430	2250	2405	2410
Porosity, %	12,7	10,7	10,4	12,8	10,8	10,4	12,5	11,3	12,7
Water absorption, %	5,7	3,8	3,2	5,76	3,8	3,3	5,67	4,1	3,6

A significant decrease in water absorption of modified concrete, porosity decrease and density and the compressive strength increase in comparison with the effects of the plasticizer-3 and waterproofing additive NGL-94, confirms the possibility of using WDAM as an additive with the plasticizing and water-repellent effect.

In the analysis of three-dimensional image of fine grain concrete test samples, which was obtained by using a universal double-beam system Versa 3D ™ DualBeam ™, many interfaces in the concrete structure (28 days), affecting the physical and mechanical characteristics of the original fine composition, are clearly visible (Fig. 1 (a)).

a



b

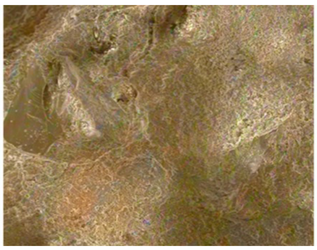


Fig. 1. The microscopic three-dimensional image of fine grain concrete samples (a) control samples; (b) samples modified by WDAM.

A prerequisite for the improvement of concrete structure formation was a factor related to the boundaries of the section "Cement joist - filler", where there are dimensional structural defects and their matching with characteristic dimensions for a variety of physical phenomena in interfacial contact area, and it became one of the main indicators for a significant change in the properties of concrete by modifications WDAM. Modifier targets the processes of forming the cement composition grained structures in Fig. 1 (b), which are characterized by structural changes in the modified cement system caused by receipt of a denser composition structure, the pore space reduction in the viewing area, increasing the capacity of cement binder, together with the development of plasticizing effect in cement matrix modified by WDAM. It provides a greater degree of use of building crystalline strength potential, improves the quality of co-operation of all the components of the concrete composition.

The complex modifying effect of WDAM additives manifested as a result of various physical processes occurring in the hardening system, and also due to chemical processes at the interface between the phases "cement stone - grain aggregate", "cement stone - pore structure" [16,18,19]

WDAM plasticizing effect depends on the presence of hydrocarbon radical and a double bond in the molecule of the acrylic monomer, which are capable of reacting with the binder minerals or products of hydration, which has a favorable effect on the improvement of the technological and operational properties. Hydrophobic properties of WDAM additives exhibited in the formation of a dense and homogeneous structure of the modified concrete composition. There is a decrease in amount and sizes of macrospore in Fig. 1 (a) and Fig. 1 (b), which have the correct circumferential shape with smooth oval edges and sizes from 0.5 to 0.05 mm with a predominant pore size of 0.1 mm. The system of uniformly distributed pores with a water-repellent surface in the hardened modified concrete decreases capillary leak, and reduces the permeability of concrete. Repellent effect of WDAM gives hydrophobic (water-repellent) properties to the walls of the pores and capillaries in the concrete.

Thus, a water dispersion of acrylic monomer provides meaningful impact on the formation of a fine grain structure of the composition. Management of structural changes in the modified cement system enables to produce concrete compositions with improved properties due to the hydrophobic plasticizing effect of WDAM.

Maximum increases of the capability to take into account the technological factors, and design requirements for the concrete are due to the methodology of the design of its composition. The relationship "property - structure – concrete structure" is the basis for an approach to the design of concrete formulations based on a quantitative analysis results and the joint solution of mathematical equations relating the performance properties of concrete with parameters of its structure [20].

Selection of the optimization factors of concrete modified by hydrophobic plasticizer WDAM, is on the basis of technological and economic feasibility and obtaining of a material with improved performance characteristics.

After statistical processing of the experimental data the regression equation, quantitatively characterizing the dependence of the strength, density, porosity, water absorption by the modified concrete on studied factors, was obtained.

The mathematical model of the process is a function that links the parameters of optimization: compressive strength (R_{com}), bending strength (R_{ben}), density (p), water absorption (W) with variable factors - content additives WDAM (x_1,% of cement weight) and water-cement ratio W / C (x_2) (table 3).

Table 3. Levels and intervals of factors variation.

Factors	Code value	Interval of variation	Levels of factors		
			Upper +1	Main 0	Lower -1
WDAM	X_1	0,5	2	1,5	1
W / C	X_2	0,1	0,45	0,4	0,35

After statistical processing of the experimental data the regression equations (1), (2), (3), (4) quantitatively characterizing the dependence of the compressive strength and bending strength, density, water absorption by the modified concrete on the investigated factors, are obtained:

$$Y1(R_{com}) = 40.2 + 2.3 \cdot X_1 + 2.65 \cdot X_2 + 0.125 \cdot X_1 \cdot X_2 + 0.1 \cdot X_1^2 - 0.85 \cdot X_2^2 - 1.95 \cdot X_1^2 \cdot X_2 + 0.1 \cdot X_1 \cdot X_2^2 \quad (1)$$

$$Y2(R_{ben}) = 7.87 + 0.35 \cdot X_1 + 0.55 \cdot X_2 - 0.05 \cdot X_1 \cdot X_2 - 0.15 \cdot X_1^2 - 0.25 \cdot X_2^2 - 0.25 \cdot X_1^2 \cdot X_2 - 0.05 \cdot X_1 \cdot X_2^2 \tag{2}$$

$$Y3(\rho) = 2446.56 + 18.5 \cdot X_1 + 12.5 \cdot X_2 - 1.25 \cdot X_1 \cdot X_2 - 6.33 \cdot X_1^2 - 7.33 \cdot X_2^2 - 8.75 \cdot X_1^2 \cdot X_2 - 0.25 \cdot X_1 \cdot X_2^2 \tag{3}$$

$$Y4(W) = 3.78 - 0.05 \cdot X_1 + 0.25 \cdot X_2 + 0.325 \cdot X_1 \cdot X_2 + 0.033 \cdot X_1^2 + 0.23 \cdot X_2^2 - 0.175 \cdot X_1^2 \cdot X_2 - 0.125 \cdot X_1 \cdot X_2^2 \tag{4}$$

Graphical interpretation of the density, porosity, compressive strength, and water absorption response function is shown in Fig. 2.

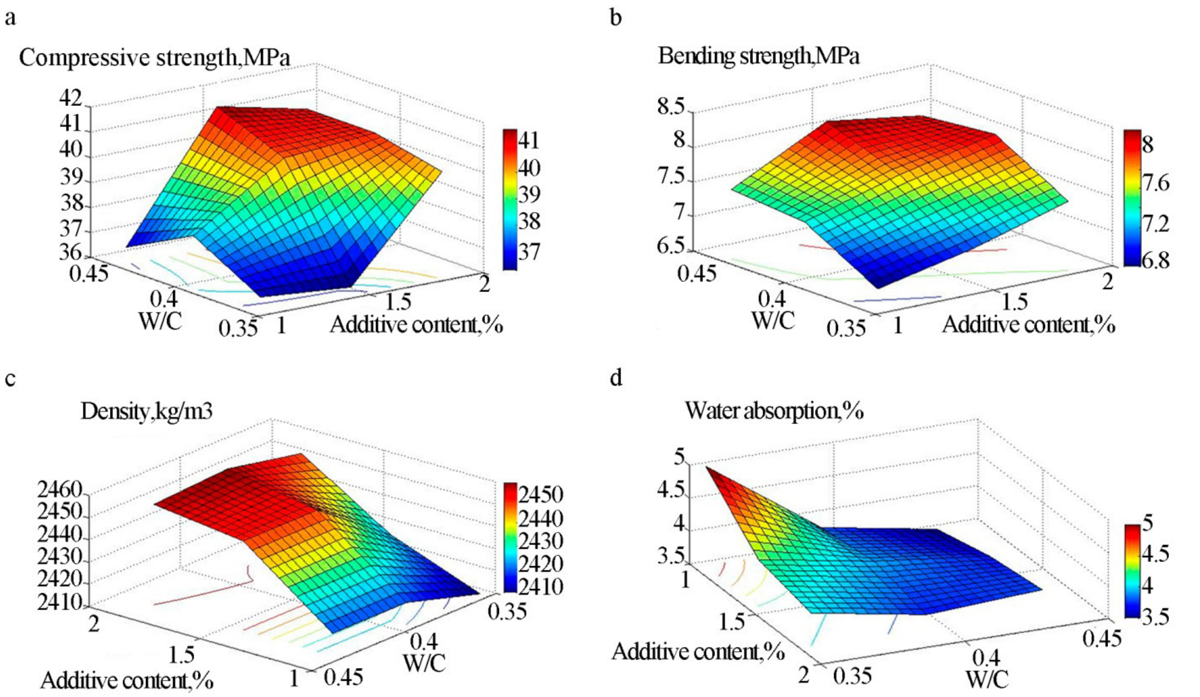


Fig. 2. The function of the concrete response with WDAM additive
(a) compressive strength; (b) bending strength; (c) density; (d) water absorption.

The compressive strength reaches a maximum value (40 - 41 MPa) within the range of WDAM dosing of 1.5 to 2.0% and the value of W/C from 0.4 to 0.45 (Fig. 2, (a)), which estimates 25% of the growth rate with regard to the plain composition. Addition of WDAM in an amount of 1 to 1.5% also promotes the growth of the compressive strength indicator, and at lower W/C (0.35 - 0.4), an indicator increase of W/C is about 15% of the plain composition. Thus, the recommended dosage of WDAM ranging from 1 to 2% is considered optimal in terms of dry residue. Addition of WDAM reduces the W/C with an increase in the compressive strength of the modified concrete.

Maximum bending strength is achieved within WDAM metering from 1.5 to 2% (Fig. 2, (b)). The value of bending strength is 8 MPa, which exceeds the control sample by 30%. Such increase in strength is due to W/C value change in the range of 0,4 - 0,45, much as growth pattern in compression strength. Additive WDAM, showing a plasticizing effect, contributes to a more ordered structure of the modified compositions, promoting the growth of the strength properties.

The nature of the changes of cement brick density confirms once again the effect of WDAM plasticizing as part of concrete. The maximum indicator value (2450 kg/m3) occurs in the range of WDAM metering from 1.5 to 2%

when the W/C is within 0,4 - 0,45, which exceeds the control composition by 8% (Fig. 2, (c)).

The modified concrete structure consolidation affected the water absorption indicator (Fig. 2, (d)). Its reduction was 40% in comparison with a control sample. The optimum range of WDAM dosing for this indicator is from 1.5 to 2% with change in W/C in the range of 0,4 - 0,45. A significant reduction in the indicator of modified concrete water absorption shows water-repellent effect of WDAM additives.

4. Conclusion

The suggested concrete modifier based on waste of paint production of WDAM can compete with domestic hydrophobic plasticizer, improving construction product performance. The study shows that the creation and use of new modifiers is one of the real ways to further enhance of performance of building materials, the tendency to expand the list of chemical additives with complex effect, due to organic waste, contributes to import substitution in the construction industry market. The economic effect due to utilization of technogenic waste and more efficient use of material resources is evident.

References

[1] V.I. Kalashnikov, How to transform the old generation concrete in high-performance concretes of new generation, Concrete and reinforced concrete, Equipment, Materials, Technologies. 1 (2012) 82–89.
[2] S. Marceau, F. Lespinasse, J. Bellanger, C. Mallet, Microstructure and mechanical properties of polymer-modified mortars, European Journal of Environmental and Civil Engineering. 16 (2012) 571–581.
[3] C. Qingyu, S. Wei, G. Liping, Z. Guorong, Polymer-modified concrete with improved flexural toughness and mechanism analysis, Journal of Wuhan University of Technology-Materials Science Edition. 27 (2012) 597–601.
[4] N.Z. Muhammad, A. Keyvanfar, M.Z. Abd. Majid, A. Shafaghat, J. Mirza, Waterproof performance of concrete: A critical review on implemented approaches, Construction and Building Materials. 101 (2015) 80–90.
[5] J. Plank, E. Sakai, C.W. Miao, C. Yu, J.X. Hong, Chemical admixtures, Chemistry, applications and their impact on concrete microstructure and durability, Cement and Concrete Research. 78 (2015) 81–99.
[6] Y. Tian, S. Shuaifeng, H. Shuguang, Mechanical and dynamic properties of high strength concrete modified with lightweight aggregates presaturated polymer emulsion, Construction and Building Materials. 93 (2015) 1151–1156.
[7] Yu.D. Chistov, A.S. Tarasov, Development of multi-mineral binders, Russian Chemical Journal. 4 (2003) 12–17.
[8] S.A. Strulev, V.P. Yartsev, Polymer concrete based on epoxy and polyester resins using asbestos-frictional materials waste, Academy. Architecture and Construction. 3 (2011) 109–111.
[9] F. Jingjing, L. Shuhua, W. Zhigang, Effects of ultrafine fly ash on the properties of high-strength concrete, Journal of Thermal Analysis and Calorimetry. 121 (2015) 1213–1223.
[10] I. Havlikova, V. Bilek, L. Topolar, H. Simonova, P. Schmid, Z. Kersner, Modified Cement-Based Mortars: Crack Initiation and Volume Changes, Materials in Technology. 49 (2015) 557–561.
[11] M. Ksiazek, The influence of penetrating special polymer sulfur binder, Polymerized sulfur applied as the industrial waste material on concrete watertightness, Composites Part B, Engineering. 62 (2014) 137–142.
[12] M.C.S. Ribeiro, A. Fiuza, A.C.M. Castro, F.G. Silva, M.L. Dinis, J.P. Meixedo, M.R. Alvim, Mix design process of polyester polymer mortars modified with recycled GFRP waste materials, Composite Structures. 105 (2013) 300–310.
[13] L.A. Alimov, T.K. Akchurin, O.Yu. Pushkarskaya, Analysis of the mechanism of silica containing additives effect on the basis of metallurgy waste as a part of the concrete compositions, Herald of Volgograd State University of Architecture and Civil Engineering, Series: Construction and architecture. 59 (2015) 127–134.
[14] V.D. Tuhareli, T.K. Akchurin, T.F. Cherednichenko, Effective modified concrete using refinery waste for monolithic construction, Herald of Volgograd State University of Architecture and Civil Engineering, Series: Construction and architecture. 56 (2014) 112–120.
[15] N.S. Hiris, T.K. Akchurin, Formation of the internal structure of fine gran concrete of a high density and strength with filling metallurgical slag and two frequency vibration compaction, Herald Volgograd State University of Architecture and Civil Engineering, Series: Construction and architecture. 54 (2014) 121–125.
[16] A.V. Tuhareli, T.K. Akchurin, Technology of effective modified cement concrete with the paint waste products, Civil Engineering Gazette Caspian: Scientific and Technical Journal. 8 (2014) 48–52.
[17] A.V. Tuhareli, T.K. Akchurin, Prospects and possibilities of the use of paint waste products for modification of cement concrete, Resource and energy efficient technologies in the construction industry in the region: a collection of scientific papers based on the materials of the International scientific-practical conference proceeding. Saratov: Saratov State Technical University. (2014) 92–97.
[18] C. Zhitao, Y. En-Hua, Y. Yingzi, Y. Yan, Latex-modified Engineered Cementitious Composites (L-ECC), Journal of Advanced Concrete Technology. 12 (2014) 510–519.
[19] J. Hot, H. Bessaies-Bey, C. Brumaud, M. Duc, C. Castella, N. Roussel, Adsorbing polymers and viscosity of cement pastes, Cement and Concrete Research. 63 (2014) 12–19.
[20] L.I. Dvorkin, V.I. Gots, O.L. Dvorkin, Tests of concrete and mortars, Designing their compositions, Infra-Engineering, Moscow, 2014.