The impact of the formation conditions and properties of the water treatment plants sludge on its usage in the ceramic bricks production

A A Orlov, M Yu Belkanova, R K Lymar

Architecture and Construction Institute, South Ural State University, 76, Lenin ave., 454080 Chelyabinsk, Russia.

E-mail: orlovaa@susu.ru

Abstract. Water treatment plants (WTP) sludge can be used in the construction industry. However, the composition and properties of WTP sludge are determined by the quality of water in the water source and the water treatment technology. At the same time, the technology for the manufacture of construction products requires a consistent quality of raw materials and reproducible characteristics of the finished products. In this paper, we studied the impact of a modifying add from WTP sludge on the properties of the clay composition and ceramic bricks. We used the WTP sludge formed in the fall and winter periods in the city of Chelyabinsk. The air-dry WTP sludge was introduced into the clay composition in an amount of 5-10% by mass. It is shown that the characteristics of the ceramic fragment are independent of the sludge collection season. It was found that the modifying add allows us to reduce the ceramics baking temperature by 50 °C without worsening the material baking index. The introduction of a 10% WTP sludge add helps to reduce the tendency of the air-dried brick to crack formation and accelerates the drying mode.

1. Introduction

Water treatment plants (WTP) sludge is a by-product of the drinking water production technology. The average volume of sludge is 1 - 5% of the station’s performance [1]. On a global scale, according to some estimates [2], about 10,000 tons of WTP sludge are formed daily. The toughening of the environmental requirements to the placement of such sludge leads to the need to search for new and develop the existing WTP sludge disposal methods.

Many works deal with the use of sludge in the construction industry [3, 4]. So, in the production of cement, it is recommended to use an add of 4-10 to 50% by the dry matter of sludge [5-7]. Ceramic bricks, floor tiles can include from 5 - 10 to 20, and even 40% of sludge by mass [7-11]. There is information on the obtaining of a heat-insulating material – granulated foam-glass - through the use of waterworks sludge and glass fragments [7]. The authors of [12] report the inclusion of WTP sludge both in concretes and mortars in the amount of 1–5% of the mass of the introduced sand.

In the production of building ceramics, WTP sludge can partially replace clay, since it contains a significant amount of aluminum and silicon oxides [13-15]. The additional advantages of using WTP sludge include a decrease in the baking temperature and an increase in the raw material grinding degree, as well as a decrease in the shrink of ceramics and an increase in its strength [16-17]. At the same time, we need a profound study of the influence of the amount of sludge on the quality of the
obtained products. Thus, the authors of [7] note that an increase in the sludge content by over 7% by volume increased water absorption and stratification, increased the number of beds in bricks, and reduced the brick grade. The authors of [10, 18] note that the amount of sludge and the baking temperature are the two key factors affecting the quality of bricks.

However, before using sludge as a component of raw materials in the construction industry, we need its preliminary preparation: dehydration and drying. It is recommended to dry and grind sludge for the production of concretes and mortars. So, upon receipt of a clay composition, sludge was added in an amount of 5–13% by volume at a moisture content of 78.8% [7]. In some cases, the pre-treatment costs make the process expensive: for example, when added into cement, sludge should be dried to 50% of the moisture content, which made the process unprofitable [7].

A distinctive feature of all kinds of WTP sludge is their high moisture content - up to 99% [2,14,19] and a significant content of aluminum hydroxides (less commonly, iron hydroxides) - coagulant hydrolysis products used in water treatment [1,20,21]. As a result, WTP sludge is classified as non-filtered but compressible sludge with a high specific filtration resistance. The dewaterability of the WTP sludge is determined, firstly, by the quality of water in the water source, which is subject to seasonal changes [11], and secondly, by the technological water treatment scheme and the configuration of structures [22].

The purpose of this paper is to develop a technology for using the WTP sludge as a modifying add in the clay composition, which would allow us to obtain high-quality ceramic bricks with reproducible characteristics. We should establish how the WTP sludge formation conditions and the variation of the sludge properties affect the characteristics of ceramic bricks.

2. Materials and method

2.1. Preparation of the WTP sludge as a modifying add

WTP sludge was used as an add into the clay composition to obtain ceramic bricks. The sludge was collected from Chelyabinsk horizontal sinkers of water treatment plants twice during the year: sludge formed in the fall period (WTPS 1) and in the winter period (WTPS 2). The technological water treatment scheme at the facilities is two-stage and includes sinkers and high-rate filters. Aluminum sulfate reagents and AN-905 polyacrylamide-based flocculant are used at the facilities. The average water quality in the water source and the reagent dosage during the sludge formation are shown in Table 1.

The specific filtration resistance of the sludge in the fall and winter periods is $8,400 \times 10^{10}$ and $9,900 \times 10^{10} \text{ m/kg}$, accordingly; the moisture content is 98 %. To dehydrate the sludge, we used freezing - thawing at $-16 \pm 2 \, ^\circ \text{C}$ in the freezing chamber, and then vacuuming at $66.7 \times 10^{3} \, \text{Pa}$ and drying at $105 \pm 2 \, ^\circ \text{C}$ in the dryer.

| Table 1. Sludge formation conditions. |
|--------------------------------------|
| Water in the water source | Reagent dosage |
| Turbidity, mg/L | Water colour index, degrees | T, °C | Coagulant aluminum sulfate, mg/L | Flocculant, mg/L |
| fall period (WTPS 1) | 3.85 | 14 | 10.8 | 5.2 | 0 |
| winter period (WTPS 2) | 2.85 | 12 | 0.8 | 8.1 | 0.05 |
2.2. Planning of the experiment

To evaluate the impact of the formation conditions and properties of the WTP sludge on the properties of modified ceramics, we planned a two-factor experiment according to Hartley’s method. The WTP sludge was introduced into the clay composition as a modifying add. The experiment was carried out with the WTP sludge adds of two types (WTPS 1, WTPS 2). Two factors were varied: the amount of the add in the clay composition (WTPS 1, % and WTPS 2, % of the clay composition mass) and the raw material baking temperature (T_b °C). The responses were: plasticity, air and igneous shrink. The impact of the add type on the properties of ceramics was evaluated by the igneous shrink as one of the key parameters affecting the durability and strength of ceramic materials. We calculated that a sufficient number of experiment repeats for each response should be two to ensure an experimental error of less than 5%.

We calculated the confidence interval to evaluate the impact of the formation conditions and properties of the WTP sludge on the igneous shrink of ceramic samples.

The properties of the clay composition and the ceramic fragment were determined according to the requirements of the regulatory documents specified in Table 2.

Table 2. Test methods.

| Property                    | Regulatory document                                      |
|-----------------------------|----------------------------------------------------------|
| Plasticity of the clay mass | GOST 21216-2014 Clay raw materials. Test methods, paragraph 5.3. |
| Air shrink of the clay sample | GOST 21216-2014 Clay raw materials. Test methods, paragraph 5.26 |
| Igneous shrink               | GOST 21216-2014 Clay raw materials. Test methods, paragraph 5.27.4.3 |

The heating rate during drying was kept constant and equal to 3 °C/min. At the final temperature, the samples were kept for 30 min according to the requirements of GOST 21216-2014. The clay composition for the manufacture of the samples was prepared at KEMMA LLC factory of ceramic products, Chelyabinsk.

The properties of the clay composition without the WTP sludge adds are presented in Table 3.

Table 3. A comparison of the clay composition properties.

| Property       | Add-free clay composition |
|----------------|---------------------------|
| Plasticity, %  | 15.0                      |
| Air shrink, %  | 9.7                       |
| Igneous shrink, % | 1.4                     |

3. Results and discussion

To evaluate the impact of the WTPS 1 and WTPS 2 sludge add on the properties of modified ceramics, we carried out two two-factor experiments according to Hartley’s method. The plan matrix and the results are presented in Table 4.

Based on the experiment results, we can conclude that the impact of the WTPS 1 and WTPS 2 adds is similar. Both adds reduce the air shrink from 9.7% (add-free clay composition) to 7.2 - 8.0%. This effect occurs due to the presence of a significant amount of natural organic substances and polyacrylamide in the sludge [23]. Thus, the introduction of the adds will allow us to reduce the tendency of the raw materials to the crack formation and accelerate the drying mode.

The introduction of the WTPS 1 and WTPS 2 adds leads to an increase in the plasticity, and therefore expands the range of the operating moisture content. Therefore, the sludge adds reduce the moisture sensitivity of the clay composition.
Table 4. The plan-matrix and responses of the two-factor experiment

| Factor one, X | Factor two, Y | Plasticity, % | Air shrink, % | Igneous shrink, % |
|---------------|---------------|---------------|---------------|------------------|
| Code          | D (%)         | Code          | T_b (°C)      | WTPS 1 | WTPS 2 | WTPS 1 | WTPS 2 | WTPS 1 | WTPS 2 |
| -1            | 5.0           | -1            | 950           | 15.5   | 15.8   | 8.0    | 7.7    | 1.60   | 1.45   |
| 0             | 7.5           | -1            | 950           | 16.8   | 16.9   | 7.6    | 7.5    | 1.65   | 1.50   |
| 1             | 10.0          | -1            | 950           | 16.9   | 17.2   | 7.5    | 7.2    | 1.80   | 1.70   |
| -1            | 5.0           | 0             | 1000          | 15.5   | 15.8   | 8.0    | 7.7    | 1.86   | 1.85   |
| 0             | 7.5           | 0             | 1000          | 16.8   | 16.9   | 7.6    | 7.5    | 2.02   | 2.05   |
| 1             | 10.0          | 0             | 1000          | 16.9   | 17.2   | 7.5    | 7.2    | 2.15   | 2.15   |
| -1            | 5.0           | 1             | 1050          | 15.5   | 15.8   | 8.0    | 7.7    | 2.43   | 2.45   |
| 0             | 7.5           | 1             | 1050          | 16.8   | 16.9   | 7.6    | 7.5    | 2.46   | 2.50   |
| 1             | 10            | 1             | 1050          | 16.9   | 17.2   | 7.5    | 7.2    | 2.69   | 2.70   |

Based on the data from Table 4, we built graphs of the dependence of the igneous shrink on the baking temperature and the add amount (Figures 1 and 2). The nature of the dependence in Figures 1 and 2 suggests that an increase in the add amount leads to an increase in the igneous shrink, i.e. more flux is formed at a constant temperature. The impact of the add is particularly noticeable at low temperatures. Thus, the introduction of the adds in the clay composition allows us to reduce the ceramics baking temperature by 50 °C without worsening the material baking index.

To evaluate the impact of the seasonal variation of the sludge properties, we compared the confidence intervals of the igneous shrink with the WTPS 1 and WTPS 2 adds. The results are presented in Table 5.

According to the data in Table 5, the confidence intervals for each experiment intersect, and in most cases, almost coincide. So, the minimum values of the interval with one add are more than the minimum values with the other add. Therefore, the values of the igneous shrink obtained with the WTPS 1 add are equal to the values obtained with the WTPS 2 add. Thus, the formation conditions and properties of the WTP sludge do not significantly affect the properties of the modified ceramics.
Table 5. A comparison of confidence intervalsa.

| WTPS 1 | Igneous shrink, % | WTPS 2 | confidence interval | WTPS 1 | WTPS 2 |
|--------|------------------|--------|---------------------|--------|--------|
|        | 1 meas.a 2 meas. | av. value | 1 meas. 2 meas. av. | min max | min max |
| 1.62   | 1.58             | 1.60   | 1.47 1.43 1.45      | 1.51 1.69 | 1.36 1.54 |
| 1.68   | 1.62             | 1.65   | 1.52 1.48 1.50      | 1.52 1.78 | 1.41 1.59 |
| 1.83   | 1.78             | 1.80   | 1.72 1.68 1.70      | 1.69 1.91 | 1.61 1.79 |
| 1.88   | 1.84             | 1.86   | 1.86 1.84 1.85      | 1.77 1.95 | 1.79 1.91 |
| 2.03   | 2.01             | 2.02   | 2.07 2.03 2.05      | 1.98 2.06 | 1.96 2.14 |
| 2.17   | 2.13             | 2.15   | 2.18 2.12 2.15      | 2.06 2.24 | 2.03 2.27 |
| 2.47   | 2.40             | 2.43   | 2.47 2.43 2.45      | 2.28 2.58 | 2.36 2.54 |
| 2.48   | 2.44             | 2.46   | 2.54 2.47 2.50      | 2.38 2.54 | 2.35 2.65 |
| 2.71   | 2.67             | 2.69   | 2.73 2.67 2.70      | 2.60 2.78 | 2.58 2.82 |

a 1 meas. and 2 meas. are the first and second measurements of the igneous shrink in each line of the experiment
b av. value. is the average value of the igneous shrink in the line.

4. Conclusion

We introduced WTP sludge as a modifying add to manufacture ceramic bricks. The experiment was performed using the water treatment plants sludge in the city of Chelyabinsk, Russia. The sludge was collected from the settlers in the fall and winter periods. Both the quality of water in the water source and the dosage of the aluminum sulfate coagulant and the flocculant differ in these periods.

We studied the properties of the clay composition with the addition of the WTP sludge obtained in the fall and winter periods. The adds were dosed in amounts of 5, 7.5 and 10% by mass. The introduction of the WTP sludge adds helps to reduce the tendency of the raw materials to the crack formation and accelerates the drying mode. We showed that the modifying add can reduce the ceramics baking temperature by 50 °C without worsening the material baking index.

We showed that an increase in the amount of the add from 5 to 10% reduces the sensitivity of the clay composition to the changes in the moisture content. At the same time, the plasticity increases from 15.0 to 16.9...17.2%, and the air shrink decreases from 9.7 to 7.2...7.5%; the igneous shrink increases from 1.40 to 2.69...2.70%. Thus, an increase in the amount of the WTP sludge from 5 to 10% increases the processability of the clay composition and improves the characteristics of ceramic bricks.

We established that the seasonal changes in the quality of water in the water source and the variations in the reagent dosage needed to treat water during the WTP sludge formation do not significantly affect the properties of the ceramics modified with the WTP sludge.

References

[1] Lyubarsky V 1980 Waterworks Sludge and its Treatment Methods (Moscow: Stroyizdat) p 129
[2] Babatunde A and Zhao Y 2007 Crit. Rev. Environ. Sci. Technol. 37 129–164
[3] De Carvalho Gomes S, Zhou J, Li W and Long G 2019 Progress in manufacture and properties of construction materials incorporating water treatment sludge: A review. Resources, Conservation and Recycling 145 148–59. DOI:10.1016/j.resconrec.2019.02.032
[4] Ahmad T, Ahmad K and Alam M. 2016 Characterization of water treatment plant’s sludge and its safe disposal options. Procedia Environmental Sciences 35 950–5
[5] Chen H, Mab X and Dai H 2010 Reuse of water purification sludge as raw material in cement production. Cem. Concr. Compos. 32 436–9
[6] Yen C, Tseng D, Lin T 2011. Characterization of eco-cement paste produced from waste sludges. *Chemosphere* **84** 220–6

[7] Schegolkova N 2015 Waste of water treatment plants and of water purification plants: problem or business project? *Water Magazine* **97** 28–33

[8] Rodrigues L and de Holanda J 2018 Valorization of municipal waterworks sludge to produce ceramic floor tiles *Recycling* **3**, DOI:10.3390/recycling3010010

[9] Huang C, Pan J, Sun K and Liaw C 2001 Reuse of water treatment plant sludge and dam sediment in brick-making *Water Science and Technology* **44** 273–7

[10] Kizinievic O, Zurauskiene R, Kizinievic V and Zurauskas R 2013 Utilisation of sludge waste from water treatment for ceramic products *Constr. Build. Mater.* **41** 464–73

[11] Teixeira S, Santos G, Souza A, Alessio P, Souza S and Souza N 2011 The effect of incorporation of a Brazilian WTPs sludge on the properties of ceramic materials *Appl. Clay Sci.* **53** 561–5

[12] Sales A and de Souza F 2009 Concretes and mortars recycled with water treatment sludge and construction and demolition rubble *Construction and Building Materials* **23** 2362–70. DOI:10.1016/j.conbuildmat.2008.11.001

[13] Ling Y, Thram R, Lim S, Fahim M, Ooi C, Krishman P, Matsumoto A and Yeoh F 2017 Evaluation and reutilization of water sludge from fresh water processing plant as a green clay substituent *Applied Clay Science* **143** 300–6

[14] Nikolaenko E and Belkanova M 2016 Influence of the treatment method on the water yielding capacity of natural water sediments *Procedia Engineering* **150** 2315–20. DOI:10.1016/j.proeng.2016.07.311

[15] Cruz D, Oliveira J, Alvarenga M, Lavall R and de Oliveira C 2016 Quality improvement of ceramic bricks by incorporation of sludge from water treatment units *The Journal of Engineering and Exact Sciences* **2** 42–56

[16] Rodrigues L and de Holanda J 2018 Valorization of municipal waterworks sludge to produce ceramic floor tiles. *Recycling* **3**, DOI:10.3390/recycling3010010

[17] Nora M, Hameda A, Alia F and Khimb O 2015 Properties and performance of water treatment sludge (wts)-clay bricks *Jurnal Teknologi (Sciences & Engineering)* **32** 83–93

[18] Benlalla A, Elmoussaouiti M, Dahhou M and Assafi M 2015 Utilization of water treatment plant sludge in structural ceramics bricks *Applied Clay Science* **118** 171–7

[19] Yanin E 2010 Osadok vodoprovodnykh stantsii (sostav, obrabotka, utilizatsiya) [Sludge of Water Treatment Plants (Composition, Treatment, Utilization)] *Zhurn. Ekologicheskaya ekspertiza* **5** 2–45

[20] Verrelli D, Dixon D and Scales P 2009 Effect of coagulation conditions on the dewatering properties of sludges produced in drinking water treatment *Colloids and Surfaces A: Physicochemical and Engineering Aspects* **348** 14–23. DOI:10.1016/j.colsurfa.2009.06.013

[21] Verrelli D, Dixon D and Scales P 2010 Assessing dewatering performance of drinking water treatment sludges *Water Research* **44** 1542–52. DOI:10.1016/j.watres.2009.10.036

[22] Belkanova M, Nikolaenko E and Gevel D 2017 Technological aspects of waterworks sludge treatment *IOP Conference Series: Materials Science and Engineering* **262**, DOI:10.1088/1757-899X/262/1/012221

[23] Chen S, Chen S, Wu J, He N, Shi Y, Li C and Wang Y 2020 Rheological Properties of Photocurable Coal-Series Kaolin Slurry *Cailiao Gongcheng/Journal of Materials Engineering* **48** 142–7