The Effect of Mineral Powders Derived from Industrial Wastes on Selected Mechanical Properties of Concrete

Anna Galińska 1, Sławomir Czarnecki 2

1,2 Faculty of Civil Engineering, Wrocław University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

slawomir.czarnecki@pwr.edu.pl

Abstract. In recent years, concrete has been the most popular construction material. The main component of the concrete is cement. However, its production and transport causes significant emissions of CO₂. Reports in the literature show that many laboratories are attempting to modify the composition of the concrete using various additives. These attempts are primarily designed to eliminate parts of cement. The greater part of the cement will be replaced with the selected additive, the more significant is the economic and ecological effect. Most attempts are related to the replacement of the selected additive in an amount of from 10 to 30% by weight of cement. Mineral powders, which are waste material producing crushed aggregate, are increasingly used for this purpose. Management of the waste carries significant cost related to their storage and disposal.

With this in mind, the aim of this study was to evaluate the effect of mineral powders derived from industrial wastes on selected mechanical properties of concrete. In particular, the aim was to determine the effect of quartz and quartz-feldspar powders. For this purpose, 40, 50, 60% by weight of the cement was replaced by the selected powders. The results obtained were analysed and compared with previous attempts to replace the selected additive in an amount of from 10 to 30% by weight of cement.

1. Introduction

Currently, concrete is still one of the most commonly used construction material. The cement is the main component of ordinary concrete [1]. This is one of the reasons why the researchers are looking for new additives, which not only improve the mechanical properties of concrete, but also have an impact at decreasing the use of cement during manufacturing process.

During cement manufacturing a huge amount of CO₂ is produced. The reduction of cement usage would provide economic as well as ecological benefits. The greater part of cement would be replaced with proper additive the less are the costs of the concrete manufacturing.

With reports in the literature it can be seen that there are attempts to modify the composition of the concrete using various additives. These attempts are primarily designed to eliminate parts of cement mostly in 10-30% of its mass with selected additives. As it is shown in the paper [2], the investigation was carried out replacing from 10% to 40% of the cement mass with quartz powder and it has been proved that it affects as an increasing value of the compressive strength after 7 and 28 days and it also affects the hydration process. The most of the authors are investigating mainly the rheology and the compressive strength of concrete. During these tests, they are replacing cement with basalt, limestone and quartz powders [3-7]. According to [8-10], attempts were undertaken to replace the 10-30% of
cement mass with quartz, feldspar-quartz and basalt mineral powders. Based on these results it is shown that applying these additives has an influence on the mechanical properties of concrete. However, the negative or positive influence is dependent on the type and mass of the used powders.

Considering the above, the main purpose of the following paper is the evaluation of the influence of application mineral additives at mechanical properties of concrete. The influence of application of the quartz powder and feldspar-quartz powder was investigated. For this purpose, 40%, 50% and 60% of cement mass was replaced with selected powders. Those powders are waste material produced in the mineral mines as the effect of crushing the aggregates. The results of this investigation are analysed, compared and presented in the following paper.

2. Materials Properties
In order to prepare concrete mixes, Portland cement CEM I 42.5R was used [11]. The chemical and physical properties of cement are presented below in table 1.

| Chemical parameters | Result [%] | Physical parameters | Result |
|---------------------|-----------|---------------------|--------|
| SO₃                 | 3.30      | Initial setting time [min] | 180    |
| Cl⁻                 | 0.08      | Compressive strength [MPa] 2 days | 30.1   |
| Na₂Oₑq              | 0.778     | 28 days             | 54.4   |
| Loss of ignition     | 3.52      | Surface area [mm²]   | 4200   |
| Insoluble residue    | 1.00      |                     |        |

The selected additives were quartz powder and feldspar-quartz powder. Those powders are waste materials from the production process of crushing the aggregates at the mineral mine (SKSM sp z o.o. Sobótka, at Lower Silesia, Poland). Table 2 presents the chemical properties of these powders.

|                     | Quartz          | Quartz-feldspar |
|---------------------|-----------------|-----------------|
| SiO₂                | min. 99.00      | SiO₂ 74.00-78.00|
| Al₂O₃               | max. 1.00       | Al₂O₃ 12.50-14.00|
| Fe₂O₃               | max. 0.05       | Fe₂O₃ 0.20-0.40|
| TiO₂                | max. 0.05       | TiO₂ max. 0.05  |
| K₂O+Na₂O            | 7.50-8.50       |                 |
| MgO                 | max. 0.50       |                 |
| CaO                 | max. 0.50       |                 |

In order to prepare concrete mixes, the mineral aggregate, which meets the requirements in accordance with norm [15], was used. The fine quartz aggregate with maximum size of grain of 2 mm [16] and coarse aggregate with maximum size of grain of 8 mm [17] were used. The density of grains was 2.62 mg/m³. The cement paste was prepared using water which meets the requirements in accordance with [18]. The plasticizer Qblock Plus was used with content of chloride lest than 0.1% and
content of alkalis less than 1%, which meets the requirements in accordance with [19]. The properties of additives are presented in [20].

3. Preparation of Concrete Mixes

The research was provided at concrete mixes, in which 40%, 50% and 60% of cement mass was replaced with quartz powder and quartz-feldspar powder. The recipes of concrete mixes were prepared using three equations method. In table 3, the recipe of each mix is presented with comparison to the base mix without any additives.

|                        | X0   | Q-40 | Q-50 | Q-60 | F-40 | F-50 | F-60 |
|------------------------|------|------|------|------|------|------|------|
| Quartz powder          | -    | 140.8| 176  | 211.2| -    | -    | -    |
| Quartz-feldspar powder | -    | -    | -    | -    | 140.8| 176  | 211.2|
| Cement                 | 352  | 211.2| 176  | 140.8| 211.2| 176  | 140.8|
| Water                  | 176  | 176  | -    | -    | -    | -    | -    |
| < 2mm aggregate        | 676  | 676  | -    | -    | -    | -    | -    |
| 2-8mm aggregate        | 1205 | 1205 | -    | -    | -    | -    | -    |
| Plasticizer            | 2    | 2    | -    | -    | -    | -    | -    |

Table 3. The composition of the concrete mixes (kg/m³ of concrete).

Figure 1. Exemplary view of weight the components of concrete mix: a) fine aggregate, b) coarse aggregate, c) cement, d) powder

The concrete mixes were prepared with proper temperature and humidity at the Laboratory at the Wroclaw University of Science and Technology. The mixtures were prepared as follows: at the beginning the cement, powder and aggregate were mixed together and afterwards the water with plasticizer was added to the mixture. The components were mixed together and placed in forms compacting at the end. The forms were previously cleaned and wetted with mineral oil.
After compacting, the samples were cleaned and next left under the foil with water tank. After 48 hours, the samples were unformed and left in the cabin with and air humidity of 60% (±5%) and an air temperature of 20 °C (±2 °C).

Respectively after 7 days and 28 days of preparing the samples, the bending tests were performed in the strength test machine in order to obtain the critical force. Depending on the value of this force the tensile strength was identified. The samples were tested in strength test machine ZD-40 (figure 3).

The samples were placed in the machine and were tested in perpendicular angle to the free surface of the sample during forming as it is shown in the figure 4.
Each of the sample was tested by using increasing loading force with speed 10% and power 4 in accordance to the cracking moment, and then the values of the critical force were obtained, as well as the scheme of destruction, which is presented in the figure 5.

![Figure 4](image1.png)

*Figure 4. The scheme of the bending test and the view based on [21]*

1 – loading shaft, 2- specimen, 3- stanchion

The halves of the samples obtained from the bending test were used to identify the compressive strength. The tests were performed also in the strength test machine ZD-40. The samples were placed between the plates of size 40x40 mm each. In order to identify compressive critical strength force the samples were put under the unvarying loading. At the critical moment, the compressive force was noted (figure 6) in accordance with [21].

![Figure 5](image2.png)

*Figure 5. The view of the sample before and after the test.*

4. Results and discussions
Based on the performed tests, the results of the compressive strength and tensile strength of concrete are presented in table 4.
Figure 6. The view of the sample before and after compressive strength test

Table 4. Compressive and tensile strength of concrete samples

| Sample | Tensile strength [MPa] | Compressive strength [MPa] |
|--------|------------------------|---------------------------|
|        | after 7 days | after 28 days | after 7 days | after 28 days |
| X0     | 4.31        | 5.63         | 30.97       | 37.50        |
| Q-40   | 1.72        | 2.34         | 8.96        | 9.13         |
| Q-50   | 2.34        | 4.69         | 11.29       | 12.17        |
| Q-60   | 2.34        | 3.13         | 2.17        | 5.90         |
| F-40   | 4.69        | 4.84         | 17.79       | 19.42        |
| F-50   | 4.06        | 5.00         | 11.86       | 13.33        |
| F-60   | 4.69        | 5.00         | 17.83       | 18.46        |

The addition of quartz powder instead of part of cement reduced the compressive strength of tested concretes significantly from 6% to 93% 7 days after concreting and from 10% to 85% 28 days after concreting, respectively to the amount of powder used. The addition of quartz-feldspar powder in order to replace the 40-60% of cement mass decreases the compressive strength of concrete at about 50% in comparison with comparative concrete sample. Replacing cement with 40-60% of its mass with quartz powder reduced the tensile strength after 7 days by about 40-65% and after 28 days by about 17-58%. However, the use of the quartz-feldspar powder did not significantly affect the tensile strength after 7 days and after 28 days as well.

5. Conclusions
According to the results presented in this paper, the application of quartz powder and quartz-feldspar powder has an impact on compressive strength of concrete and on its tensile strength. Interesting fact is that replacing cement with quartz-feldspar powder at about 40-60% did not affect the tensile concrete strength much in comparison with comparative concrete. It makes it reasonable to use this type of powder at concrete elements, in which the most important criterion of application is the tensile strength of concrete.

Replacing the cement with selected additives in amount higher than 30% of its mass with quartz powder significantly decreases the compressive and tensile strength of concrete. However, the amount of this additive lower than 30% of cement mass allows to obtain values of strength comparable to the
comparative samples [8-10]. According to this, application of this addition might be an alternative for replacing cement during concrete manufacturing.

Acknowledgment(s)
Special acknowledgements to Mr. Wiesław Cieśla Wroclaw University of Science and Technology for valuable help during the preparation of specimens and testing their mechanical properties.

References
[1] Ł. Sadowski and T. G. Mathia, “Multi-scale metrology of concrete surface morphology: fundamentals and specificity.”, Construction and Building Materials, vol. 113, pp. 613-621, 2016.
[2] J. Tikkanen, “Effects of mineral powders on hydration process and hydration products in normal strength concrete”, Construction and Building Materials, vol. 72, pp. 7-14, 2014.
[3] S. Ucick and V. Kmeceva, “The Effect of Basalt Powder on the Properties of Cement Composites”, Procedia Engineering. vol. 65, pp. 51-56, 2013.
[4] T. Reddy and J.K. Elumalai, “Study of macro mechanical properties of ultra high strength concrete using quartz sand and silica fume”, International Journal of Research in Engineering and Technology, vol. 03/09, 391-396, 2014.
[5] J. Tikkanen, V. Penttala and A. Cwirzen, “Mineral powder concrete - Effects of powder content on concrete properties”, Magazine of Concrete Research, vol. 63(12), pp. 893-903, 2011.
[6] C. Dhanalaxmi and K. Nirmalkumar, “Study on the Properties of Concrete Incorporated With Various Mineral Admixtures – Limestone Powder and Marble Powder”, International Journal of Innovative Research in Science, Engineering and Technology, vol. 4(1), pp. 18511-18515, 2015.
[7] S. Kumar, G. Acharya and S. Mhamai, “Reactive Powder Concrete with mineral admixtures”, Journal of Emerging Technologies and Innovative Research, vol. 2(6), pp. 1749-1757, 2015.
[8] M. Popek and Ł. Sadowski,”Selected Physical Properties of Concrete Modified using Mineral Powders.”, Procedia Engineering, vol. 172, pp. 891-896, 2017.
[9] M. Popek, Ł. Sadowski, and J. Szymanowski, „Abrasion Resistance of Concrete Containing Selected Mineral Powders.”, Procedia Engineering, vol. 153, pp. 617-622, 2016.
[10] M. Popek and Ł. Sadowski, „Effect of Selected Mineral Admixtures on Mechanical Properties of Concrete.”, Key Engineering Materials, vol. 728, pp. 367-372, 2017.
[11] EN 197-1:2011. Cement. Composition, specifications and conformity criteria for common cements.
[12] http://ozarow.com.pl/cement-portlandzki-42-5-r/ (2017, Feburar 15)
[13] http://www.sksm.pl/images/oferta/karty_katalogowe/Karta_katalogowa_MK30.01wyp_w_1.pdf (2017, Februay 15)
[14] http://www.sksm.pl/images/oferta/karty_katalogowe/karta_katalogowa_MS_063D_01_w_1_5.pdf (2017, Februay 15)
[15] PN-EN 12620+A1:2010 Aggregates for concrete
[16] http://eurovia.pl/checkupickruszywa/pdf/certificate-35.pdf (2017, Februay 15)
[17] http://eurovia.pl/checkupickruszywa/pdf/certificate-32.pdf (2017, Februay 15)
[18] PN EN 1008:2004 Mixing Water For Concrete - Specification for sampling, Testing and assessing the suitability of water, including water recovered from Production processes of concrete
[19] EN 934-3:2009. Admixtures for concrete, mortar and grout. Admixtures for masonry mortar. Definitions, requirements, conformity, marking and labelling.
[20] http://www.farkom.pl/src/Pliki/Qmix%20DH/Qmix%20DH%20KCH.pdf (2017, March 11)
[21] PN-EN 196-1. Methods of testing cement. Determination of strength.