Modified Pavement Quality Concrete as Material Alternative to Concrete Applied Regularly on Airfield Pavements

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Abstract. The work presents test results of two series of hardened cement concrete intended for airfield pavements. Concrete types designed on the basis of regularly used materials were included in the first series. Granite, quartzite, basalt aggregate, gravel and amphibolite aggregate were used in concrete mixes. Cement CEM I 42,5, fine aggregate (washed sand), water, admixtures (air entraining agent and plasticizer) were also included in the mix composition. Basic parameters for the designed mixes (consistency class and air contents) were specified. The influence of aggregate type on parameters of hardened concretes was assessed. Concrete compressive strength, fracturing strength were analysed. The analysis was conducted during diversified research periods in order to assess the joint influence of aggregate type and the length of curing on the change of concrete parameters. In case of the second series, the material alternative based on the modification of concrete composition of the first series using ceramic modifier was discussed. The applied additive was described and the influence thereof on the change of parameters of mixes and hardened concretes was assessed. According to the obtained parameters of mixes and hardened concrete it was proved that the used modifier in the form of dust has significant impact on the analysed parameters. Increased mechanical (compressive strength, fracture strength) and physical parameters of concrete were proved. Curing concretes were also analysed during diversified research periods. Favourable influence of the suggested modifier on the changes of internal structure of cement concrete was proved. Changes in cement matrix structure, contact layers between cement matrix and grains of aggregate and modifier and porosity characteristics were observed. The analysis of different microstructure of modified concrete and the obtained parameters of hardened modified concrete proved the purposefulness of using the ceramic modifier in the composition of concrete mixes intended for airfield pavements.

1. Introduction
Durability of airfield pavements is identified with the reliable operation of airfield pavement structure within the assumed service life. The development of the world-wide aviation industry determines designing of cement concrete which complies with high durability criteria. Providing suitable functional properties of concrete intended for airfield pavements should guarantee the provision of relatively high durability and frost resistance. It is necessary to consider the resistance of this type of concretes to the influence of de-icing agents, as well as the resistance to high temperatures from nozzles of contemporary operated aircrafts.

The purpose of the research was the assessment of the influence of the applied additive on the change of mechanical and physical parameters of the hardened cement concrete. Standard composition
of pavement quality concrete intended for airfield pavements and concrete types with ceramic additive were analysed. Selected parameters of concrete mixes and hardened concrete within the diversified research periods were analysed in order to assess the influence of the applied additive on the quantity thereof.

Laboratory research included two groups of concrete with diversified concrete mix composition. Basic parameters of the designed concrete mixes were defined (consistency class (V) according with [15], air contents (p) according with [16]).

The purpose of the research was the evaluation of influence of the ceramic modifier on the change of hardened concrete parameters over time. Prepared concrete mix of series I and II after concrete pouring (in accordance with the standard [17]) was subject to standard curing [18] for the assumed research periods (7, 28 days). Hardened concretes were used in destructive testing, their average compressive strength was specified according to [19 and 20] in during diversified research periods. Parameters of hardened concretes were specified (average compressive strength (fck), fracturing resistance (fcu) according [21]).

Selected concrete samples (series II) were intended for microscopic observation on scanning electron microscope. Samples preparation and interpretation of obtained results were in compliance with those described in subject literature [4, 5]. Recent fracture was prepared from CC-I and CC-2 concrete which were covered with carbon layer approx. 10nm thick. Preparation surface subject to observations by means of scanning electron microscope was not less than 1.0cm², and the scope of magnifying power was assumed between 200x to 100000x [3, 8, 9].

2. Testing methods

In case of the first group (I), the standard composition of cement concrete was analysed. Concretes of C30/37 class were designed. Concretes of this type were intended for airfield pavements. Composition of mixes included in group I complied with the requirements of [10, 11]. Diversification of mix composition referred to the applied coarse aggregates. The mix, determined as I-G, was prepared on the basis of granite grit fraction 2/8, 8/16, 16/32mm. Mix I-K refers to the applied quartzite aggregate, I-B refers to the applied basalt aggregate, I-Z – gravel aggregate, while I-A refers to amphibolite aggregate. In case of all mixes of series I, water and cement CEM I 42,5 HSR was used, which complies with the requirements of [14 and 12-13]. The applied cement was distinguished by the reduced alkalis contents, and its specific surface was 3431cm²/g. Cement was applied to concrete mixes of series I in the following quantity: 368-398 kg/m³ (table 1). Maximum value of w/c ratio according to standard requirements [10] is 0,4; w/c ratio of the designed mixtures was assumed for 0,37. Additional advantage of low w/c ratio is the decrease of porosity in transition zone around aggregate [2]. In case of reduced w/c ratio, water content in capillary pores, particularly dangerous for concrete freezing in low temperatures, is reduced as well.

In case of series I, fine, washed aggregates, of grain-size distribution of 0/2mm and air entraining admixture were used, which is necessary condition to obtain frost-resistance concrete [6]. Considering, at the design stage, air entraining admixtures ensured also concrete scale-tight resistance caused by de-icing salts [1] used for airfield pavement maintenance. Due to this fact I and II concrete mixtures were assumed to contain air entraining admixture in the amount of from 1.69kg/m³ to 1.83kg/m³. Proper preparation and consolidation of mixture allowed for using the plasticizer in the amount of from 0.70kg/m³ to 0.76kg/m³.

Composition of concrete mixes which belong to group II (II) were coincident, concerning the quantity of coarse aggregate, cement and admixtures, with the components discussed in case of group I. Diversification of group (II) with respect to group (I) was based on taking into consideration the presence of the suggested additive. The additive in the form of ceramic dust was dozed as the substitute of fine aggregate, in the amount of 10.5%, which was equal to 38.6-41.8kg/m³. The mineralogical composition of ceramic powdered included following: quartz, mullite, tridymite, corundum and trace amounts of silty minerals - figure1.
Table 1. Compositions of the designed mixes of the following series I-A, I-B, I-G, I-K and I-Z

| Components | Cement [kg/m³] | Water [kg/m³] | Aggregate 0/2 mm [kg/m³] | Aggregate 2-31.5 mm [kg/m³] | Plasticizer [kg/m³] | Aerating agent [kg/m³] |
|------------|----------------|---------------|--------------------------|----------------------------|---------------------|-----------------------|
| I - A      | 398.00         | 148.00        | 498.00                   | 1279.00                    | 1.83                | 0.76                  |
| I - B      | 380.00         | 141.00        | 587.00                   | 1370.00                    | 1.75                | 0.72                  |
| I - G      | 370.00         | 137.00        | 478.00                   | 1360.00                    | 1.70                | 0.70                  |
| I - K      | 385.00         | 143.00        | 630.00                   | 1265.00                    | 1.77                | 0.73                  |
| I - Z      | 368.00         | 136.00        | 690.00                   | 1240.00                    | 1.69                | 0.70                  |

Figure 1. Phase composition of modifier applied in case of series II concretes [4]
Mechanical parameters analysis of the suggested additive, especially high strength and resistance to variable temperature conditions, indicated that it is possible to increase concrete durability, made of the suggested additive.

3. Results and Discussions

3.1. Mixes applied conventionally onto airfield pavements

Grain size distribution curves of the designed concrete mixes of group I were presented in Figure 2. All designed curves are within the recommended range of grain size distribution, defined according to the standard limit curves [10].

![Figure 2. Designed aggregate mixtures curve, together with limit curves (lower and upper)](image)

Mixes of series I proved diversification with regard to the selected parameters. In case of concretes of series I-A, I-G and I-K, the consistency was classified as dense plastic. Concrete of series I-Z was distinguished by dense plastic consistency, whereas concrete I-B was distinguished by semi-liquid consistency. All analysed mixes complied with requirements of [12] with regard to optimum air contents within 4.5-5.5%. (table 2).

| Mix parameters | I - A | I - B | I - G | I - K | I - Z |
|----------------|------|------|------|------|------|
| V [mm]         | 20.0 | 77.0 | 20.0 | 20.0 | 38.0 |
| p [%]          | 5.3  | 4.5  | 4.9  | 5.5  | 5.4  |

The choice of the aggregate used in the mix influenced the obtained parameters of hardened concrete. Samples performed in accordance with the requirements [17], cured in humidity >95% and
temperature 20°C (according to [18]) for 7 and 28 days. The type of applied aggregate influences ultimate compressive strength of hardened concrete in case of both periods. It was proved that the concrete of series I-B achieved the highest average strength after 7 days 47.8MPa with the deviation of 0.9. Concrete of series I-Z (average value 34.4MPa with S_d of 2.09) - table 3 had the lowest resistance after 7 days of curing. In case of extending the curing time up to the standard 28 days, concrete of series I-K (ultimate compressive strength of 62.3MPa with S_d of 0.65) obtained the most favourable resistance parameters - figure 3.

**Table 3. Results of the basic cement concrete**

| parametres                  | I - A | I - B | I - G | I - K | I - Z |
|-----------------------------|-------|-------|-------|-------|-------|
| Time of care: 7 days        |       |       |       |       |       |
| Average compressive strength [MPa] | 41.9 | 47.8 | 43.1 | 46.7 | 34.4 |
| standard deviation, S_d     | 0.70  | 0.90  | 0.81  | 0.80  | 2.09  |
| Time of care: 28 days       |       |       |       |       |       |
| Average compressive strength [MPa] | 53.0 | 58.3 | 57.4 | 62.3 | 40.5 |
| standard deviation, S_d     | 0.82  | 0.70  | 0.45  | 0.65  | 3.27  |

One of the highest parameters of concrete intended for airfield pavements is the flexural strength during bending [7]. In case of the analysed concrete types it was proved that concrete of series I-K obtained the highest value. Average value of the analysed characteristic was 7.2MPa (S_d = 0.25), in case of concrete of I-K series, in case of concrete of series I-B 6.9MPa (S_d = 0.15), concrete of series of I-A 6.6MPa (S_d = 0.40), and in case of I-G 6.1MPa (S_d = 0.05). Concrete of series I-Z achieved the lowest tensile strength during bending (4.3MPa - S_d = 0.20).

![Figure 3. Increase in compressive strength of cement concretes series I.](image-url)

Pursuant to the analysis of the achieved test results (Figure 4) it was proved that concretes of series I-G and I-K were distinguished by the most favourable mechanical parameters (ultimate compressive strength and bending strength). Moreover, absorbability of these concretes achieved the lowest values and complied with standard requirements. High concrete resistance combined with its low absorbability contributes to the increased resistance of concrete to external destructive factors (e.g. water penetration, fluctuation of temperature oscillating around 0°C, influence of aggressive media). Obtained test results allow to believe that the durability of these concretes will be sufficiently high.
Figure 4. Results of the series I concretes parameters: a) compressive strength, b) flexural strength, c) mass absorbability.

3.2. Mixtures of modified Grains
Grain size distribution curves of the designed concrete mixes of group II were presented in Figure 5. All designed curves are within the recommended range of grain size distribution, defined according to the standard limit curves [10].

Figure 5. Designed aggregate mixtures curve, together with limit curves (lower and upper)

Mixes of series I proved diversification with regard to the selected parameters. In case of concretes of series I-A, I-G and I-K, the consistency was classified as dense plastic. Concrete of series I-Z was distinguished by dense plastic consistency, whereas concrete I-B was distinguished by semi-liquid consistency. All analysed mixes complied with requirements of [12] with regard to optimum air contents within 4.5-5.5%. (table 4)

Table 4. Results of the modified concrete mix parameters

| Mix parameters | II - A | II - B | II - G | II - K | II - Z |
|----------------|--------|--------|--------|--------|--------|
| V [mm]         | 20.0   | 65.0   | 18.0   | 17.0   | 30.0   |
| p [%]          | 5.0    | 4.9    | 5.1    | 5.0    | 5.4    |
According to the assessment of influence of the characteristic "average compressive strength" defined for concretes of series II cured for 28 days it was proved that the concrete of series II-K achieved the highest value. In case of concrete of series II-K the average value of the analysed characteristic was 66.4MPa, in case of concrete of series II-B 62.9MPa, in case of concrete of series II-G 60.8MPa, and series I-A 55.8MPa. Concrete of series II-Z achieved the lowest ultimate compressive strength - 43.6MPa. Similar correlation was proved in case of tensile strength during bending – table 5. Concrete II-G based on granite aggregate proved the lowest absorbability in series II. It needs to be emphasised that the average absorbability of all concretes of series II was lower than the allowable value (5% according to \[10\]).

Figure 6. Results of the series II concretes parameters: a) compressive strength, b) tensile strength, c) mass absorbability.

According to the obtained test results it was proved that concrete of series II-G achieved the most favourable characteristics. Classification criterion was the cumulative assessment of ultimate compressive strength, tensile strength during bending and concrete absorbability.

| Table 5. Results of the modified cement concrete |
|-----------------------------------------------|
| parametres                                    | Cement concrete |
|                                               | I - A | I - B | I - G | I - K | I - Z |
| Compressive strength                          |       |       |       |       |       |
| Average compressive strength [MPa]            | 55.8  | 62.9  | 60.8  | 66.4  | 43.6  |
| standard deviation, Sd                         | 2.18  | 1.75  | 0.83  | 1.18  | 2.73  |
| Flexural strength                              |       |       |       |       |       |
| Average flexural strength [MPa]               | 6.7   | 7.3   | 6.8   | 7.6   | 4.8   |
| standard deviation, Sd                         | 0.20  | 0.20  | 0.06  | 0.25  | 0.20  |
| Mass absorbability                             |       |       |       |       |       |
| Average mass absorbability [%]                | 3.48  | 4.36  | 3.19  | 3.62  | 3.94  |
| standard deviation, Sd                         | 0.11  | 0.14  | 0.09  | 0.18  | 0.20  |

3.3. The assessment of the influence of the applied modifier on parameters of hardened concrete

Applied ceramic dust did not significantly affect the change of parameters of fresh concrete mixes. Air content in mixes II-B and II-G increased accordingly by 0.4% and 0.2% compared to the mixes of series I. In case of mixes II-A and II-K, the reduction of air content to 5.0% was proved (accordingly by 0.3% and 0.5%). In case of mixes II-Z and I-Z, the air content is 5.4%. In both series I, and II, the air content in fresh mix comply with the requirements of \[12\]. Air content in all mixes is between 4.5% and 5.5%. Ceramic dust additive affects insignificantly the reduction of mix workability, however it does not affect the change of consistency class of concrete mixes.

Significant influence of the suggested dust on the changes of mechanical parameters of hardened concrete was proved. In case of application of alternative aggregate types (amphibolite, basalt, granite,
quartzite and gravel) this influence is diversified (Figure 7), however the tendencies are comparable. Additive in the form of dust used in the composition of concrete mix contributes to the increased ultimate compressive strength (from 2.8MPa to 4.5MPa) and flexural strength during bending (from 0.1MPa to 0.74MPa). This additive also significantly reduces the absorbability of the hardened concrete (from 0.62% from 1.33%).

Figure 7. Results of the parameters: a) compressive strength, b) flexural strength, c) mass absorbability.

Taking into consideration the average compressive strength, the highest growth was proved in case of concrete of series II-B (7.8%), and the lowest growth in case of II-A (5.3%). The highest growth of the characteristic tensile strength during bending was proved in case of concrete of series II-G (12.6%), and the lowest growth in case of concrete of series II-A (1.5%). Application of dust also influenced the reduction of absorbability of concrete of series II-Z (about 25%) and concrete of series II-G (about 20%).
Physical and mechanical parameters (among others, average compressive strength and flexural strength) are internal concrete structure derivatives. The following factors influenced, among others, the concrete structure of series I and II: air voids characteristics, occurrence of aggregate grains (fine, coarse and ceramic dust) of various mineral composition and diversified shapes and dimensions, structure of cement matrix and contact area between matrix and grains. Correction of concrete mix composition of series II, using ceramic dust, contributed to the provision of concretes of better developed internal structure. This was displayed in case of all analysed concrete types. Favourable influence of dust on porosity characteristics was proved. Air voids developed in concretes of series II were distinguished by much smaller diameters and average distances between pores. In case of concrete of series II-G, the most favourable impact of dust on parameters of hardened concrete and its internal structure was proved. Comparing the porosity characteristics of concrete of series, I-G and II-G the significant difference in case of the registered diameters and distance between air voids were proved. Ceramic dust used in mixes of series II contributed also to the change of size and the content of individual hydration products in cement matrix. In case of concrete of series, I-G, crystallization of portlandite was proved (plates of up to 10µm), numerous concentration of ettringite crystals (the length of a single crystal up to 8 µm). In concrete matrix of series, I-G, fine-grained hydrated calcium silicates type C-S-H occurred. In case of concrete of series II-G reduced amount of portlandite and ettringite crystals were proved. The occurred crystals were smaller (up to 5µm). Crystallization of fine-fibrous hydrated calcium silicates of type C-S-H was more developed in case of concrete of series II. The length of a single C-S-H crystal did not exceed 100µm. Significant differences were found in the structure of contact area between aggregate grains (fine and coarse) and cement matrix in concrete of series I and II. Contact area of matrix-aggregate in case of concrete I-G was composed of portlandite and ettringite crystals. Quite often, micro cracks occurred, which resulted in the reduction of mechanical parameters. Contact area between aggregate grains and matrix in case of concrete of series II was composed of fine-fibrous C-S-H. Significantly fewer ettringite crystals occurred within this area. Contact areas of cement matrix and grains of ceramic modifier in case of concrete of series II were continuous, no micro cracks occurred.

4. Conclusions
Based on the obtained results, the following conclusions were drawn:
- dozing the dust to the mix results in the change of internal construction of hardened concrete;
- ceramic dust used in the composition of concretes of series II does not significantly influence the change of parameters of fresh mix. This is significant in the process of incorporation of mix into the structure;
- concretes of series II are distinguished by the increased durability in comparison with concretes of series I. In case of average compressive strength this increase is about 8% for concrete of series II-B. Analysis of flexural strength proved the most significant growth in case of concrete II-G the range of 13%;
- ceramic additive used in concrete mix contribute to the loss of concrete mass absorbability.
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