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Assessment of Granite, Quartz and Syenite Aggregate Suitability Intended for the Application in Case of Transport Pavement Concrete

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Abstract. Based on the analysis of the obtained laboratory test results, the article presents the suggestion concerning the use of quartz and syenite aggregate as granite aggregate alternative, in the composition of cement concrete intended for airfield pavements. The scope of laboratory tests with regard to rock materials included the assessment of basic properties of the applied aggregates and their influence on the change of parameters of internal structure of hardened cement concrete. The analyses included evaluation of the selected aggregate parameters, i.e. bulk density, absorbability, sand equivalent, abrasion, crushing and polishing resistance. The influence of the applied materials on the change of the basic physical properties (bulk density and absorbability) was specified and mechanical parameters (compressive, splitting tensile strength and bending strength) of the curing concrete within diversified periods. According to the observed changes in the internal structure of concretes, the influence of the aggregate type on the obtained parameters of hardened concretes and their airfield pavement application were determined.

1. Introduction
The earlier recognition of concrete parameters with granite aggregate intended for airport pavements makes it possible to infer the superiority of this type of aggregate. Currently, however, alternatives to technological solutions are sought for obtaining concretes with comparable parameters [1-5]. According to the analysis of the obtained laboratory test results, the article suggests using quartz and syenite aggregate in the composition of cement concrete intended for airfield pavements. The article is aimed at the assessment of the suitability of the suggested aggregates in the composition of cement concrete intended for airfield pavements. The purpose of the research was the evaluation of basic physical properties of the applied aggregate in the form of quartz and syenite with reference to granite aggregates properties.

2. Purpose and scope of testing
Analyses focused on three series of various types of aggregate. Series labelled Q was quartz aggregate fraction of 2/8mm and 8/16mm, series S was syenite aggregate of grain-size distribution of 2/8mm and 8/16mm, while series G was the reference aggregate – granite aggregate of grain-size distribution of 2/8mm and 8/16mm. In case of the selected types of aggregate the following were determined: volume density (ρv) according to [6], absorbability (W) according to [7], abrasion resistance (MDE) according to [8], crushing resistance (LA) according to [9] and frost resistance of aggregates (F) according to [10].
The influence of the type of the applied aggregate on the change of concrete mix parameters was determined. The experiment assumed to perform three series of concrete mix. The first series was reference concrete mix (MG). Two consecutive series included concrete mix with granite aggregate substitute in the form of quartz aggregate (series MQ) and quartz with syenite (series MS). The tests included: mix density \((\rho_m)\) according to [11], consistency \((S)\) using concrete slump method according to [12], air contents \((p)\) using manometer method according to [13]. The prepared concrete mix series MG, MQ and MS after being arranged into (cubic moulds 150x150x150 mm and 150x300 mm according to [14]) were subject to standard curing [15] for the assumed research periods (7 and 28 days).

The experiment assumed to perform three series of concrete. The first series was reference concrete (CG), in accordance with the requirements of [16]. Two consecutive series included concrete with aggregate substitute in the form of quartz aggregate (series CQ) and quartz with syenite aggregate (series CS). The influence of the applied materials on the change of basic mechanical properties was also assessed, i.e. compressive strength \((f_{cm})\) according to [17], splitting tensile \((f_{ct})\) according to [18] of the modified cement concrete with reference to airfield pavement application. The determined concrete physical parameters included the following: volume density \((\rho_v)\) according to [19] and absorbability \((N)\) according to [16] after diversified curing periods.

It was assessed whether the applied aggregate influences the change of parameters of internal structure of hardened cement concrete. In order to assess the impact of the used types of aggregates on the changes of internal structure, concretes were subject to observations in scanning electron microscope (SEM). Preparation of samples and interpretation of the obtained results were in compliance with those described in literature work [20]. Fresh fractures were prepared using concrete CG, CQ and CS. The preparation surface was observed by means of scanning electron microscope SEM and each time it was more than 1 cm². The magnification ranged from 200x to 100000x.

3. Research materials

According to the obtained results it was proved that grain-size distribution of the analysed granite aggregate ranged from 0.5 mm to 11.2 mm (fraction 2/8 mm) and from 5.6 mm to 16.0 mm (fraction 8/16 mm), grain size distribution of porphyry aggregate ranged from 2.0 mm to 11.2 mm (fraction 2/8 mm) and from 8.0 mm to 16.0 mm (fraction 8/16 mm) and grain size distribution of amphibolite’s aggregate ranged from 2.0 mm to 11.2 mm (fraction 2/8 mm) and from 8.0 mm to 16.0 mm (fraction 8/16 mm) - figure 1.

![Figure 1. The aggregate grains curve: a) 2/8 mm, b) 8/16 mm](image_url)

Based on the observations conducted by means of Scanning Electron Microscope Quanta Feg 250 it was proved that the granite grains are of irregular, angular and sharp shape - figure 2.
Based on the chemical microanalysis of the analysed granite grit, the occurrence of the following elements, i.e. silicon, oxygen, carbon was proved (figure 3a) - table 1. Based on the chemical microanalysis of the analysed quartz grit, the occurrence of the following elements, i.e. silicon, oxygen, aluminium was proved (figure 3b). Based on the chemical microanalysis of the analysed syenite grit, the occurrence of the following elements, i.e. oxygen, calcium, silica, iron, potassium, magnesium was proved (figure 3c).

The composite included the following basic materials: natural sand fraction 0/2 mm, aggregates fraction 2/8 mm and 8/16 mm, admixture reducing the amount of water based on calcium lignosulfonate, aerating admixture based on synthetic tensides, pipeline water which complies with requirements of [21] maintaining water-cement ratio at 0.4 – in accordance with the requirements of [16]. Aggregate grading composition of mix series MG, MQ and MS was selected according to the guidelines of [16] taking into consideration limit curves of good grain size distribution (Figure 4).
Quantity selection of the remaining components (table 2) was based on experimental methods maintaining the consistency of reference mix at S1 level and taking into consideration the exposure class XF4, with the air amount between 4.5 - 5.5%.

**Table 2. Compositions of the designed mixes of the following series MG, MQ and MS**

| Components       | MG [kg/m³] | MQ [kg/m³] | MS [kg/m³] |
|------------------|------------|------------|------------|
| Cement           | 375        | 375        | 375        |
| Aggregate 0/2mm  | 518        | 516        | 511        |
| Aggregate 2/8mm  | 845        | 841        | 600        |
| Aggregate 8/16mm | 556        | 555        | 367        |
| Water            | 150        | 150        | 150        |
| Plasticizer      | 1.69       | 1.69       | 1.69       |
| Aerating agent   | 0.94       | 0.94       | 0.94       |

4. Assessment of parameters of the analysed aggregates, concrete mixes and physical and mechanical parameters of hardened concrete

According to the conducted tests (table 3) in case of the analysed aggregate types it was proved that syenite aggregate is distinguished by the greatest volume density. The quartz and granite aggregate are distinguished by the lowest volume density. In case of absorbability, comparable parameters were obtained in case of quartz and syenite aggregates, while in case of granite aggregate this value is lower and not does exceed 0.6%.

**Table 3. Parameters of the aggregates used in the research**

| parameter | unit | G 2/8 mm | 8/16 mm | Q 2/8 mm | 8/16 mm | S 2/8 mm | 8/16 mm |
|-----------|------|----------|---------|----------|---------|----------|---------|
| ρa        | Mg/m³| 2.65     | 2.65    | 2.63     | 2.65    | 2.79     | 2.79    |
| W         | %    | WA24 0.6 | WA24 0.5 | WA24 0.9 | WA24 0.8 | WA24 0.8 | WA24 0.9 |
| MDE       | -    | 8.46 - M10 | 5.04 - M10 | 12.04 - M15 |
| LA        | -    | 34.80 - L35 | 13.01 - L15 | 24.19 - L25 |
| F         | %    | 0.20 - F1 | 0.60 - F1 | 0.20 - F1 |

In case of the examined aggregate type, it was proved that quartz and granite are distinguished by the highest abrasion resistance, the amount of which does not exceed 10. According to the obtained
experimental test results it was proved that aggregates of Q series were distinguished by the highest crushing resistance, while aggregate of G series of the lowest crushing resistance. All analyzed aggregates meet the requirements for structural concrete, for which the LA value does not exceed 35. In case of all analysed aggregates, the frost resistance in experimental test corresponded to F1 class.

According to the obtained laboratory test results (table 4) it was proved that the air content in all mixes complies with standard requirements [16]. In case of MQ mix, the air content was the highest and it was 4.8%. Significant diversification was proved in case of volume density. Mix of MQ series was distinguished by the highest parameter, while the mix of MS series was distinguished by the lowest parameter. Based on the obtained results, no significant influence of the aggregate type on the concrete mix consistency was proved. In case of all analysed mixes, the consistency defined in experimental test corresponded to S1 class.

Table 4. Parameters of mixtures series MG, MQ and MS.

| Mix  | $\rho_m$ [kg/m³] | Consistency [mm] - S | p [%] |
|------|-----------------|----------------------|------|
| MG   | 2392            | 11 - S1              | 4.5  |
| MQ   | 2637            | 10 - S1              | 4.8  |
| MS   | 2365            | 5 - S1               | 4.5  |

During scientific research, the amount of the required samples was determined using student’s T-distribution assuming the significance level of 0.05. The minimum essential number of samples ranged between 4 and 5, depending on the type of the conducted test. In case of such assumptions, 6 samples were selected, which, each time, were intended for the laboratory tests.

According to the obtained experimental test results (figure 5a) it was proved that the type of coarse aggregate significantly influences volume density of hardened concrete. Concretes of CG series were distinguished by the highest volume density, while concretes of CQ series of the lowest volume density.

Type of aggregate also influences the amount of water absorbed by concrete. In case of the examined aggregate type, it was proved that concrete series CQ and CS are distinguished by the lowest absorbability, the amount of which does not exceed 3.8%. Concrete of CG series is distinguished by the absorbability of 4%. It should be emphasized that all of the analysed concrete types complied with the requirements of [10] standard with regard to absorbability.

Figure 5. Average hardened concrete density (a) and absorbability (b) of series CG, CQ and CS during diversified curing periods

The type of the coarse aggregate applied to the mix significantly influences the obtained mechanical parameters of hardened concrete. The growth of compressive strength in case of CG and CQ series concretes, analyzed after 7 and 28 days, independent of the aggregate type retained on the comparable level of 7MPa. The increase in the compressive strength of the CS concrete was higher and amounted to 8MPa. Concrete of CG series was distinguished by the highest tensile splitting strength, while
concretes of CS and CQ series the lowest one. In case of the analysed concrete type of CS and CQ series the diversification was approx. 0.5 MPa, both after 7 and 28 days of curing - figure 6b.

Figure 6. Average hardened concrete compressive strength (a) and tensile splitting strength (b) of series CG, CQ and CS during diversified curing periods

According to the conducted SEM observations it was proved that the type of aggregate contributes to the change of internal structure of cement matrix. Template micro pictures obtained during the observations were presented in figure 7-9. The internal structure of the CG series of concrete characterized air pores with the smallest diameters. The maximum diameter of air voids in CG concrete is 75 µm, in CQ concrete it is 140 µm and in CS concrete is 100 µm. Crystallization of ettringite (length up to 10 µm) and cracked walls of air void interior were proved (figure 7a). Crystallization of ettringite (length up to 2 µm) and cracked walls of air void interior were proved (figure 7b). Crystallization of ettringite (length up to 3 µm) and cracked walls of air void interior were proved (figure 7c).

Figure 7. Internal microstructure air pores of concrete types: (a) series CG, (b) series CQ and (c) series CS

Contact areas between aggregate grains and cement matrix, in case of concrete of CG series, undergo cracking of the width up to 3 µm (figure 8a). Contact areas between aggregate grains and cement matrix, in case of concrete of CQ series, undergo cracking of the width up to 5 µm (figure 8b). Crystallization of ettringite (length up to 1 µm) were proved. Contact areas between aggregate grains and cement matrix, in case of concrete of CS series, undergo cracking of the width up to 7 µm (figure 8c). Crystallization of ettringite (length up to 2 µm) were proved.
Cement matrix, in case of concrete of CG series, is consistent and crystallization of hydrated calcium silicate occurs in fine-fibrous form (figure 9a). Cement matrix, in case of concrete of CQ series, undergo cracking of the width up to 3-4 µm (figure 9b). Cement matrix, in case of concrete of CS series, is consistent (figure 9c) and crystallization occurs in fine-grained form.

5. Conclusions

According to the conducted laboratory tests, the following conclusions have been reached:

- granite aggregate composition contains silicon, oxygen, carbon, quartz aggregate composition contains silicon, oxygen, aluminium and syenite contains oxygen, calcium, silicon, iron, potassium, magnesium, carbon and aluminium;
- aggregates used in the tests are diversified in terms of their parameters (volume density, absorbability, abrasion resistance, crushing resistance and frost resistance);
- applied aggregates affect the changes of internal structure of concrete composite (contact areas between aggregate grains and cement matrix, crystallization of cement matrix, air void);
- significant influence of the used aggregates on the change of parameters of cement concrete intended for the airfield pavements was proved;
- quartz and syenite aggregates used in concrete mix cause decrease of volumetric density of hardened concrete;
- aggregates quartz used in concrete mix contribute to the decrease of concrete ultimate compressive strength after standard curing period by 20%, concrete tensile splitting strength after standard curing period by 11% and decrease of concrete absorbability by 0.3%;
- aggregates syenite used in concrete mix contribute to decrease of concrete ultimate compressive strength after standard curing period by 4%, tensile splitting strength after standard curing period by 14% and decrease of concrete absorbability by 0.2%.
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