Influence of type and composition of aggregate on mechanical parameters of concrete

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Abstract. The paper deals with a thorough analysis of the influence of the type of aggregate and its resulting grain size curve on the basic strength parameters of concrete. From the point of view of the type, natural crushed aggregate of amphibolitic type, natural crushed aggregate of granodioritic type and natural mined sedimentary aggregate of the psammitic type were monitored. The same concrete strength class was proposed for the analysis of the impact of individual types of aggregates. In one case it was a concrete mixture with a maximum aggregate grain size $D_{\text{max}}$ of 16 mm with a continuous grain size curve and in the second case a concrete mixture with a maximum grain size $D_{\text{max}}$ of 22 mm with a discontinuous grain size curve, in the absence of a 4-8 mm fraction. In both cases, the mixture of individual aggregate fractions was determined so that the resulting grain size curve of the mixture was the same for all aggregate types. Thanks to this approach it was possible to directly monitor the influence of the type of aggregate and the grain size curves on the resulting concrete parameters. The results of the experiment show that a significant impact while maintaining the same grain size curves of the resulting aggregate mixture can be seen mainly in the type of aggregate. The absence of a 4-8 mm fraction when designing a concrete mixture with a $D_{\text{max}}$ of 22 mm proves to be completely problem-free from the point of view of concrete parameters in both fresh and hardened condition. A part of the research was also verification of the possibility of using natural crushed sand of fraction 0-4 mm for production of high-strength situ ready-mixed concretes.

1. Introduction

New trends in the production of high performance concretes provide a prerequisite for mixture designs based on precisely described and defined parameters entering the production process. In terms of concrete technology, it is mainly the creation of optimal grain size curves of aggregate, but also the optimal combination of individual binder components. Special requirements for high performance concretes are laid both in terms of strengths and, for example, high resistance against mechanical wear or wear by water flow. For the production of high performance concretes, it is often necessary to use different input components, such as quality dense natural aggregates, as opposed to conventional concrete.

This paper deals with the assessment of the possibility of producing concretes at the boundary of high-strength concretes with a discontinuous grain size curve. The aim of the experiment is to define the suitability of the resulting grain size curve of the aggregate mixture in terms of the maximum grain used and the absence of the 4-8 mm fraction. A large part of authors tends to the theory that with
increasing volume of aggregate and increasing maximum aggregate grain, undesirable volume changes of the composite decrease. This fact often results in improvements in the mechanical and durability parameters of the concrete. [1, 2, 3] Generally, however, no consensus can be found across scientific publications and published results within the impact of the absence of any of the aggregate fractions on the resulting composite parameters. However, most authors tend to the theory that a discontinuous grain size curve has a positive impact on high-strength concrete (HSC) parameters. [4, 5].

The formation of a discontinuous grain size curve of the aggregate also brings savings from the concrete manufacturer's perspective, because the 4-8 mm fraction is generally the most omitted from the composition of the mixture, which is the most economically demanding in terms of crushed aggregates used for production of HSC. Further economic saving, but also the achievement of more suitable mechanical parameters, may mean the use of a 0-4 mm fraction of crushed aggregate. In general, however, this type of aggregate is mainly used in prefabricated production, mainly due to the negative impact on the consistency of the mixture. However, the impact of the use of this crushed aggregate fraction in connection with conventional sand for HSC production was monitored in the experiment.

A good precondition for using this aggregate for the production of HSC can be seen in higher doses of binder components which can provide enough cement slurry for the desired degree of consistency for ready-mixed concrete.

2. Experiment
Concrete mixtures of strength class C 50/60, i.e. concretes at the boundary of HSC, were designed within the experiment. All mixture designs matched the S4 degree of consistency by slump test according to EN 12350-2. [6] CEM I 42.5 R Portland cement was used for the production in consistent dosage and aggregates of various types in terms of both extraction technology and petrography. In two cases, the aggregates were crushed and in one case the aggregate was mined. Crushed aggregates were from the perspective of petrography classified as granodiorite and as amphibolite. In the case of mined aggregate, it was a psammitic sedimentary rock. Before the design of concrete mixtures, basic tests were carried out on the aggregates to determine grain size and density. The specific results, including a description of the aggregates used, are given in the following Table 1.

2.1. Aggregate properties
Grain size was determined in accordance with EN 933-1 [7], grain density in accordance with EN 1097-6 [8] and shape index in accordance with EN 933-4 [9].

| Aggregate origin/locality | Rock                  | Fraction [mm] | Density [kg·m⁻³] | Shape index [-] |
|--------------------------|-----------------------|---------------|------------------|-----------------|
| Natural crushed / Zelesice | amphibolite          | 0 – 4         | 2930             | -               |
|                          |                       | 4 – 8         | 2960             | 18              |
|                          |                       | 8 – 16        | 2980             | 22              |
|                          |                       | 11 – 22       | 2940             | 13              |
| Natural crushed / Olbramovice | granodiorite      | 4 – 8         | 2620             | 23              |
|                          |                       | 8 – 16        | 2650             | 21              |
|                          |                       | 11 – 22       | 2680             | 22              |
| Natural mined / Zabcice    | psammitic sediment   | 0 – 4         | 2520             | -               |
|                          |                       | 4 – 8         | 2540             | 15              |
|                          |                       | 8 – 16        | 2530             | 18              |
|                          |                       | 16 – 22       | 2550             | 16              |

Table 1. Density and shape index of used aggregates.
2.2. Composition of concretes and results of mechanical parameters

Based on the results obtained on the aggregates used, a total of 6 concrete formulas were designed. The individual formulas differed only in the type of aggregate used. A total of 3 formulas were designed with a maximum aggregate grain of 16 mm with a composition of fractions 0-4, 4-8 and 8-16 mm and 3 recipes with a maximum aggregate grain of 22 mm with a composition 0-4, 8-16 and 11-22 mm. The grain size curves of each aggregate mixture were designed for each D$_{max}$ as constant. Thanks to this approach it was possible to monitor the impact of individual types of aggregate, eventually the use of crushed sand, on the resulting basic mechanical parameters of the concrete. The following Table 2 and Figure 1 and 2 show the composition of individual concretes and the resulting grain size curves of aggregate mixtures.

**Table 2.** Composition of individual concrete formulas.

| Material | Formula designation | 1   | 2   | 3   | 4   | 5   | 6   |
|----------|---------------------|-----|-----|-----|-----|-----|-----|
| CEM I 42.5 R [kg] |                     | 435 | 435 | 435 | 435 | 435 | 435 |
| 0-4 mm Zabcice |                     | 440 | 440 | 815 | 815 | 775 | 775 |
| 0-4 mm Zelesice |                     | 445 | 445 | -   | -   | -   | -   |
| 4-8 mm Zabcice |                     | -   | -   | -   | -   | 225 | -   |
| 4-8 mm Zelesice |                     | 230 | -   | -   | -   | -   | -   |
| 4-8 mm Olbramovice |                  | -   | -   | 200 | -   | -   | -   |
| 8-16 mm Zabcice |                     | -   | -   | -   | -   | 688 | 540 |
| 8-16 mm Zelesice |                     | 730 | 555 | -   | -   | -   | -   |
| 8-16 mm Olbramovice |                   | -   | -   | 713 | 535 | -   | -   |
| 11-22 mm Zabcice |                     | -   | -   | -   | -   | -   | 373 |
| 11-22 mm Zelesice |                     | -   | 405 | -   | -   | -   | -   |
| 11-22 mm Olbramovice |                 | -   | -   | -   | 378 | -   | -   |
| Superplasticizer [% m$_c$] |                  | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Water-cement ratio [-] |                     | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 |
On produced concretes was determined the consistency by cone setting at time 5 minutes and further after 7, 28 and 90 days, compressive strength on cubes with 150 mm edge according to EN 12390-3 [10] and flexural strength on prisms with size 100 × 100 × 400 in 4-point distribution according to EN 12390-5 were determined [11]. Following Table 3 summarizes the results of all tests performed.
Table 3. Results of realized tests.

| Parameter                  | Formula designation |
|----------------------------|---------------------|
| Slump-test [mm]            | 160 170 160 170 170 170 |
| Density [kg·m⁻³]           | 7-day 2500 2510 2350 2370 2320 2360 |
|                            | 28-day 2520 2530 2380 2360 2340 2390 |
|                            | 90-day 2520 2520 2360 2350 2340 2370 |
| Flexural strength [MPa]    | 7-day 6.6 7.4 6.6 6.0 5.3 5.6 |
|                            | 28-day 7.8 8.0 7.0 7.0 5.6 6.0 |
|                            | 90-day 8.0 7.9 7.0 7.2 5.8 6.5 |
| Compressive strength [MPa] | 7-day 59.7 69.9 57.3 60.4 52.0 56.4 |
|                            | 28-day 73.6 76.5 73.8 76.3 61.5 67.2 |
|                            | 90-day 73.3 74.5 76.2 79.3 63.2 68.1 |

From the results of consistency determination by cone setting method it is evident that crushed sand of fraction 0-4 mm can be easily used for the production of high-strength ready mixed concrete of the S4 degree of consistency with a suitable combination with 0-4 mm fraction of dredged sand. The use of this crushed sand can then be particularly suitable for structures with high abrasion resistance. According to the assumption it has been proven that if concretes with a higher content of binder components are produced, the crushed sand is also not an obstacle for their production in an appropriate ratio with the mined sand. It has also been proven that the maximum grain size of the aggregate has practically no effect on the consistency of the mixture.

The results of the compressive strength show significant differences, especially in terms of the type of aggregate used. The experiment clearly demonstrates the suitability of using quality crushed aggregates for the production of high strength concretes. It has also been demonstrated that the use of a discontinuous grain size curve and a larger maximum grain appears to be more appropriate for high strength concrete production. This trend is also evident in the determination of flexural strength of concrete. In this case, the quality of the aggregate is a decisive parameter and the use of quality magmatic rock appears to be the most suitable based on the results.

3. Conclusion
The realized experiment was focused on determining the influence of the maximum aggregate grain and the type of aggregate on the resulting mechanical parameters of high-strength concretes. Several concretes were produced using different types of aggregates (crushed × mined) and various petrographies (amphibolite × granodiorite × sedimentary psammite). All the concretes produced were designed with a constant dose of cement, superplasticizer and a water cement ratio. Mixtures were produced with a maximum aggregate grain size of 16 and 22 mm, while the individual grain size curves were also designed as constant. Thanks to this approach and the results obtained, the impact of different aggregates on the consistency of the concrete and on the basic strength parameters can be assessed.

The results of the experiment proved the suitability of using quality crushed aggregate for the production of concretes of higher strength classes. The type and mechanical parameters of the aggregate itself seem to be absolutely deciding in the production of HSC. This experiment also pointed to the suitability of using aggregates with a greater maximum grain size, wherein the composition is particularly suitable in terms of the achieved flexural strengths.
A part of the research was also an assessment of the possibility of using crushed sand of fraction 0-4 mm for ready-mixed concretes by consistency of slump test to S4. The results clearly prove that this aggregate can be used without difficulty in the production of concretes with a larger amount of binder component with a suitable combination with conventional mined or dredged sand with fraction 0-4 mm. This larger amount of binder component together in combination with conventional sand is necessary to achieve the desired plasticity of the mixture. The results of the strength of concretes with this aggregate show very good preconditions for its use especially in concretes exposed to increased abrasion, where the sand coming from crushed aggregate contains noticeably more resistant grains than the classic sand.

The results obtained will be used for further development of high-strength concretes with high strength, high resistance to mechanical wear and wear by water flow and minimal volume changes.

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