Influence of mineral aggregates on the rheological properties of concrete mixture

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Abstract. The aim of this research was to determine how the change of concrete mixture constituents: concentration of fine and coarse aggregate as well as the amount of fine particles, not exceeding 0.25 mm, influence concrete mixture’s rheological properties. Firstly, inner-concentration of fine aggregate (sand, fraction of 0/1 and 0/4) was changed. Secondly, coarse aggregate (gravel, fraction of 4/16) concentration was changed and finally, the amount of fine particles was changed. Results have shown that with the increase of sand (fraction of 0/1) quantity, the plastic viscosity also increased. On the other hand, yield stress, at the beginning decreased, but eventually increased. The increase of coarse aggregate quantity acted differently: plastic viscosity and yield stress decreased. Finally, the increase of fine particles quantity decreased the plastic viscosity as well as yield stress of concrete mixture.

1. Introduction
Aggregate characteristics: size, gradation, shape and surface texture have significant effects on concrete rheology. The different rheology behaviour is the result of the aggregate inter-particle forces and the particle movement in the liquid phases of fresh concrete [1-4]. The investigations indicate that the aspect ratio, angularity, and surface texture of aggregates affect the viscosity and yield stress of concrete mixture. Yield stress and viscosity of concrete mixture significantly increase with increased coarse aggregate volume fraction [5]. The test of concrete mixture rheological properties was conducted replacing the ordinary Portland cement with some mineral additives: finely ground blast furnace slag, fly ash and silica fume. Results revealed yield stress and plastic viscosity decreased with replacing ordinary Portland cement with blast furnace slag and fly ash [6]. The water requirement for concrete decreases with increased aggregate particle size. Finer the aggregate is more water for a given consistency it demands [7, 8]. Friction among aggregate has a big contribution to concrete rheology. Less the friction between the aggregate particles is more workable concrete it is possible to obtain. Particles with a nearly spherical shape and a smooth surface texture provide more workable concrete [9]. An optimal aggregate gradation provides a higher degree of packing and requires less paste to reach a given consistency since less cement paste is needed to fill the space among the aggregate [1].

It was determined that concrete mixtures with ultrafine fly ash represented the best rheological improvement while silica fume represented the worst. It was shown that the replacement of cement by silica fume results in an increase in the water demand and super-plasticizer dosage to maintain the rheological properties of the control. In contrast, the replacement of cement by ultrafine fly ash
resulted in a reduction of the water demand and super-plasticizer dosage to maintain the same rheological properties of the control [10].

It is known that yield stress and viscosity of concrete mixture typically increase with the sand content in the mortar [1].

The main aim of this research was to obtain the limits of rheological properties by changing aggregate proportions and fine particles quantity that the concrete mixture would possess the best workability and at the same time would be possible to avoid its segregation. The reference concrete mixture composition BA1-0 was recommended by native concrete mixture producers which they use for surface appealing concrete.

2. Materials and methodology
JSC “Akmenes cementas” (Lithuania) Portland cement CEM II/A-LL 42.5 R was used. Physical and mechanical properties of cement are given in table 1.

| Property, units                        | Value |
|----------------------------------------|-------|
| Specific surface area, m²/kg           | 410   |
| Normal consistency of cement paste, %  | 26.5  |
| Initial setting time, min.             | 195   |
| Compressive strength after 2 days / after 28 days, MPa | 27.1/54.0 |

Kvesu quarry sand with the fraction of 0/4, bulk density of 1550 kg/m³ and fineness module of 1.67 was used as fine aggregate for concrete mixtures. 0/1 sand fraction (density 1460 kg/m³, fineness module 2.37) was also used as fine aggregate. Gravel with the fraction of 4/16 and bulk density of 1327 kg/m³ was used as the coarse aggregate. Granulometric composition of aggregates was conducted according to LST EN 12620:2003+A1:2008 and presented in table 2.

| Sieve’s mesh, mm | 0/1 fr. sand | 0/4 fr. sand | 4/16 fr. gravel |
|------------------|--------------|--------------|-----------------|
| 32.0             | -            | -            | 100.0           |
| 16.0             | -            | -            | 95.6            |
| 8.0              | 100.0        | 100.0        | 34.9            |
| 4.0              | 100.0        | 97.8         | 2.9             |
| 2.0              | 99.9         | 86.3         | 0.7             |
| 1.0              | 94.8         | 68.5         | 0.7             |
| 0.500            | 39.1         | 37.9         | 0.7             |
| 0.250            | 3.0          | 4.9          | 0.7             |
| 0.125            | 0.3          | 1.2          | 0.7             |
| 0                | 0.2          | 0.1          | 0.1             |

Plasticizing admixture based on policarboxile polymers Glenium SKY 628 (BASF Construction Chemicals) was used with density of solution 1.06 g/ml. The total dosage of admixture was 1.2% of cement. During the research, dry aggregates were used for concrete mixtures. Cement and aggregates were dosed by weight while water and chemical admixture were dosed by volume. Chemical admixtures in the form of solutions were mixed with water and used in preparation of concrete mixtures. Concrete mixtures were mixed for 3 minutes in the laboratory in forced type concrete mixers.

The calculation of concrete mixture’s rheological properties was based according to formulas 1 and 2 [8, 11]. The yield stress of concrete mixture was calculated according to 1 formula.
Yield stress of concrete mixture calculated by its slump, kPa;

Density of concrete mixture, g/cm³;

Slump of concrete mixture, cm.

The plastic viscosity of concrete mixtures was calculated according to formula 2.

\[
\eta_b = \eta_v \cdot \exp \left( \frac{a_c \cdot \rho_v}{\rho_v + \frac{V}{C} \cdot \rho_c - b_c \cdot \rho_v} \cdot \left( 1 - \phi_{st} - \phi_{st} - \frac{V}{C} \cdot \rho_v - \rho_c \right) + \frac{a_{st} \cdot \phi_{st}}{1 - b_{st} \cdot \phi_{st}} \right)
\]

Here:

- \( \phi_o \): Air content in concrete mixture, %;
- \( V \): Water amount in concrete mixture per 1m³, l;
- \( C \): Cement content in concrete mixture per 1m³, kg;
- \( \rho_v, \rho_c \): Density of water and cement, kg/m³;
- \( \phi_{sm} \): Volume concentration of fine aggregate in mortar;
- \( \phi_{st} \): Volume concentration of coarse aggregate in concrete mixture;
- \( a_c, a_{sm}, a_{st} \): Coefficients concerning the surface texture of cement, fine and coarse aggregates. (\( a_c = 2.6; a_{sm} = 2.5; a_{st} = 2.6 \));
- \( b_c, b_{sm}, b_{st} \): Coefficients concerning the placement density of cement, fine and coarse aggregates particles in mortar and concrete mixture.

3. Results

3.1. The influence of fine aggregate quantity on the rheological properties of concrete mixture

Concrete mixture composition combined two fractions of fine aggregate: 0/1 and 0/4. In order to evaluate the influence of fine aggregate (sand, fraction 0/1) quantity to the rheological properties of concrete mixture (figure 1), the quantity of sand (fraction 0/1) was increased while the quantity of sand (fraction 0/4) was decreased. The quantity of sand (fraction 0/1) was increased from 11 to 36 % according to mass in respect to total fine aggregate’s quantity. The compositions of concrete mixtures (BA1) used in this research are presented in Table 3.
The amount of materials for 1m³ of concrete mixture, kg

| Materials                   | BA1-0 | BA1-1 | BA1-2 | BA1-3 | BA1-4 | BA1-5 |
|-----------------------------|-------|-------|-------|-------|-------|-------|
| Sand fraction 0/4           | 701   | 607   | 512   | 417   | 322   | 227   |
| Gravel fraction 4/16        | 986   | 986   | 986   | 986   | 986   | 986   |
| Glenium SKY 628             | 3.96  | 3.96  | 3.96  | 3.96  | 3.96  | 3.96  |
| CEM II/LL 42.5 R (MA)(A)    | 330   | 330   | 330   | 330   | 330   | 330   |
| Water                       | 178   | 178   | 178   | 178   | 178   | 178   |
| W/C                         | 0.54  | 0.54  | 0.54  | 0.54  | 0.54  | 0.54  |
| Sand fraction 0/1            | 492   | 429   | 366   | 303   | 240   | 177   |
| Sand fraction 0/4            | 986   | 860   | 733   | 607   | 480   | 354   |
| Gravel fraction 4/16         | 417   | 607   | 796   | 986   | 1175  | 1365  |
| Glenium SKY 628              | 3.96  | 3.96  | 3.96  | 3.96  | 3.96  | 3.96  |

**Figure 1.** The influence of inner ratio of fine aggregate on the rheological properties of concrete mixture

The optimal concrete mixture composition was chosen according to research results shown at figure 1. The inner concentration of fine aggregates was 16/32 (0.5) (BA1-1). The values of yield stress and plastic viscosity of concrete mixture were as follow: 362.0 Pa and 1.764 Pa*s.

3.2. The influence of coarse aggregate quantity on the rheological properties of concrete mixture

This part of the research was based on changing ratio between fine (sand with fractions 0/1 and 0/4) and coarse (gravel, fraction 4/16) aggregates. The concentration of coarse aggregate was increased from 22 % to 84 % in respect to total aggregate’s quantity, while at the same time fine aggregate’s concentration was decreased. It must be noted that the inner ratio between fine aggregate (fraction 0/1 and 0/4) was always at the level of 0.5. Concrete mixtures compositions (BA2) used in this research are presented in Table 4.

**Table 4.** Composition of concrete mixtures BA2

| Materials                   | BA2-0 | BA2-1 | BA2-2 | BA2-3 | BA2-4 | BA2-5 | BA2-6 |
|-----------------------------|-------|-------|-------|-------|-------|-------|-------|
| CEM II/LL 42.5 R (MA)(A)    | 330   | 330   | 330   | 330   | 330   | 330   | 330   |
| Water                       | 178   | 178   | 178   | 178   | 178   | 178   | 178   |
| W/C                         | 0.54  | 0.54  | 0.54  | 0.54  | 0.54  | 0.54  | 0.54  |
| Sand fraction 0/1            | 492   | 429   | 366   | 303   | 240   | 177   | 114   |
| Sand fraction 0/4            | 986   | 860   | 733   | 607   | 480   | 354   | 228   |
| Gravel fraction 4/16         | 417   | 607   | 796   | 986   | 1175  | 1365  | 1554  |
| Glenium SKY 628              | 3.96  | 3.96  | 3.96  | 3.96  | 3.96  | 3.96  | 3.96  |
The influence of ratio between coarse and fine aggregates on the rheological properties of concrete mixture is presented at figure 2.

![Figure 2. The influence of ratio between coarse aggregate and total aggregates on the rheological properties of concrete mixture](image)

BA2-0 concrete mixture composition was chosen as an optimal one which yield stress was 361.95 Pa and plastic viscosity was 1.764 Pa*s. Further decrease of yield stress (increase of coarse aggregate ratio) resulted in segregation therefore this point was chosen as optimal.

3.3. The influence of fine particles quantity on the rheological properties of concrete mixture

The total quantity of fine particles combined particles from sand and cement with the certain diameter. In order to investigate the influence of fine particles (not exceeding 0.25 mm) quantity on the rheological properties of concrete mixture, the amount of cement was increased (table 5). The quantity of fine aggregate (sand, fraction 0/1 and 0/4) was decreased respectively. It must be noted that the inner ratio between fine aggregate (fraction 0/1 and 0/4) was kept at the level of 0.5. The ratio of coarse aggregate in respect to total quantity of aggregates was kept at 0.52. Concrete mixture compositions (BA3) used in this research are presented in Table 5.

### Table 5. Composition of concrete mixtures BA3

| Materials                     | The amount of materials for 1m³ of concrete mixture, kg |
|-------------------------------|--------------------------------------------------------|
| CEM II/A-LL 42.5 R (MA)(A)    | BA3-0 230 BA3-1 280 BA3-2 330 BA3-3 380 BA3-4 430 BA3-5 480 |
| Water                         | BA3-0 178 BA3-1 178 BA3-2 178 BA3-3 178 BA3-4 178 BA3-5 178 |
| W/C                           | BA3-0 0.99 BA3-1 0.77 BA3-2 0.64 BA3-3 0.54 BA3-4 0.47 BA3-5 0.41 |
| Sand fraction 0/1             | BA3-0 353 BA3-1 336 BA3-2 320 BA3-3 303 BA3-4 286 BA3-5 270 |
| Sand fraction 0/4             | BA3-0 707 BA3-1 674 BA3-2 640 BA3-3 607 BA3-4 574 BA3-5 540 |
| Gravel fraction 4/16          | BA3-0 985 BA3-1 985 BA3-2 985 BA3-3 985 BA3-4 985 BA3-5 985 |
| Glenium SKY 628               | BA3-0 3.96 BA3-1 3.96 BA3-2 3.96 BA3-3 3.96 BA3-4 3.96 BA3-5 3.96 |

The influence of fine particles (not exceeding 0.25 mm) quantity on the rheological properties of concrete mixture is presented at figure 3. The base concrete mixture composition was chosen BA2-0 (figure 2) when conducting tests with BA3 mixtures.
4. Conclusions
The optimal inner ratio between fine aggregate (fraction of 0/1 and 0/4) was 0.5. The increase of ratio from 0.297 to 0.778 resulted in decrease of yield stress. Within the ratio of 0.297 and 0.5, plastic viscosity increased and further stayed at the steady value.

The optimal ratio between quantities of coarse aggregates and total aggregates was 0.52 (mixture without segregation). The increase of ratio resulted in the decrease of yield stress and plastic viscosity. Over the ratio limit of 0.72, plastic viscosity increased dramatically and mixture became very stiff.

The optimal quantity of fine particles was 559.96 kg/m$^3$. The increase (up to 559.96 kg/m$^3$) of fine particles resulted in decrease of yield stress and plastic viscosity. Further increase of the fine particles quantity resulted in increase of yield stress and concrete mixture became too stiff to work with.

5. References
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Figure 3. The influence of fine particles quantity on the rheological properties of concrete mixture

BA3-4 concrete mixture composition was chosen as an optimal one which yield stress was 286.0 Pa and plastic viscosity was 1.683 Pa*s.

![Graph showing the influence of fine particles quantity on the rheological properties of concrete mixture.](image-url)